Building Decarbonization Strategies for the Southwest

Analysis of the costs and emissions reduction potential of space and water heating decarbonization

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EXECUTIVE SUMMARY

Overview

Policymakers in Colorado, Nevada, and New Mexico have taken action to establish greenhouse gas emissions (GHG) reduction mandates or targets. Space and water heating are the biggest contributors to GHG emissions from buildings and those services are mostly provided by natural gas. Accordingly, gas utilities can play a critical role in reducing GHG emissions. In particular, gas utilities in the region can help decarbonize the buildings sector through support for electrification of major end uses such space and water heating and cooking. Gas utilities could also potentially replace some of fossil gas use with renewable natural gas (RNG) or hydrogen, provided that net emissions from these alternative fuels are zero or very small compared to the current fossil gas.

To inform gas utilities and policymakers in Colorado, Nevada, and New Mexico as they assess how to meet emissions reduction targets in a cost-effective manner, Synapse Energy Economics (Synapse) developed an in-house tool called the *Building Decarbonization Analysis* (BDA) tool. The BDA tool allows users to analyze the gas utility costs and emissions reductions associated with space and water heating carbon reduction strategies from the residential building sector.

Methodology and Assumptions

The BDA tool assesses the costs of GHG emission reduction strategies for the residential building sector from the perspective of gas utilities. The tool can analyze the costs and emissions reduction impacts for three main carbon reduction strategies: electrification, RNG, and green hydrogen. The BDA tool analyzes the potential and associated costs of annual avoided GHG emissions for each of the three GHG reduction strategies from 2023 through 2040, and it allows the user to develop portfolios composed of these three strategies.

Synapse modeled five natural gas utility jurisdictions across Colorado, Nevada, and New Mexico: Public Service Company of Colorado (Xcel Energy) and Black Hills Colorado Gas in Colorado, Southwest Gas and NV Energy in Nevada, and New Mexico Gas in New Mexico. For each gas utility, we identified an overlapping electric utility in order to assess the electric sector emissions associated with electrification.

Electrification: Synapse included two modeling options for electric heat pump adoption in the BDA tool: (a) a whole-home heat pump scenario, where the heat pump fully replaces the fossil-fuel-based heating system to meet 100 percent of the household space heating needs, and (b) a hybrid heat pump scenario, where a portion of households install whole-home heat pumps, and a portion install heat pumps supplemented by existing fossil-fuel-based heating systems to serve heating needs during the coldest days of the winter. To estimate the total net emissions savings from heat pumps, Synapse calculated the avoided natural gas emissions from heat pump adoption as well as the additional electric grid emissions based on emissions factors for the corresponding electric utilities in each geographic location.

Renewable natural gas: RNG can be produced from a variety of feedstocks, including organic waste (e.g., food waste, manure, energy crops, agricultural residues), energy crops (i.e., crops grown for the production of RNG), and non-biogenic waste (e.g., construction debris). The potential for RNG use in building decarbonization is limited by both the availability of feedstocks and demand from other sectors such as the transportation, electric generation, and industrial sectors. Synapse used estimates of RNG potential through 2040 developed by the consulting firm ICF International and allocated the potential across Western states.[1] We estimate that over the modeling period, the cost of RNG will be between $18–$27 per MMBtu higher than fossil natural gas; the RNG price forecast is based on the blend of feedstocks that will make up RNG production in each year, and their associated marginal prices. The BDA tool allows a user to specify "high" or "low" availability of RNG for natural gas users, based on the availability estimates developed by ICF International.

Green hydrogen: Hydrogen produced through electrolysis powered by renewable energy is called "green hydrogen" and is considered zero emission.[2] Hydrogen blending into natural gas is limited by the ability of the pipeline system and customer equipment to safely transport and use hydrogen fuel blends. The BDA tool allows a user to select either a high or low blending limit. The default high blending limit assumes that utilities in western states can blend up to a maximum of 10 percent hydrogen by volume (3.2 percent by energy content) into their natural gas networks. Alternatively, the user can specify a custom hydrogen blending limit. For example, the users may use a 20 percent blending limit based on recent proposals by several natural gas utilities[3] We assume that utilities can gradually increase the hydrogen blending each year (e.g, a 20-year ramp-up to 10 percent).[4] We developed two green hydrogen price forecasts to reflect the uncertainty of future production costs. The "high cost" trajectory reflects a future where fewer projects receive a $3/kg production tax credit established by the *Inflation Reduction Act* (IRA), or in which the capital cost of electrolyzers does not fall rapidly. The "low cost" trajectory assumes a much more abundant supply of green hydrogen that leads to lower prices.

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1 ICF International. 2019. Renewable Sources of Natural Gas: Supply and Emissions Reduction Assessment. Prepared for the American Gas Foundation. Available at https://gasfoundation.org/wp-content/uploads/2019/12/AGF-2019-RNG-Study-Full-Report-FINAL-12-18-19.pdf.

2 van Dorsten, B and De la Cruz, F.L. "Decoding the hydrogen rainbow." Wood Mackenzie. Available at: https://www.woodmac.com/news/opinion/decoding-the-hydrogen-rainbow/.

3 See for example: National Grid. April 2022. "Our clean energy vision," available at: https://www.nationalgrid.com/document/146251/download, Southwest Gas. April 2022. "Southwest Gas Announces Groundbreaking Hydrogen-Blending Pilot Program with University of Nevada, Las Vegas," available at: https://www.swgas.com/en/news/swgas-announces-groundbreaking-hydrogen-blending-pilot-program, and SoCalGas. September 2022. "H2 Blending Project," available at: https://www.socalgas.com/sustainability/hydrogen/h2-blending.

4 This approach has been proposed by local distribution companies in New York, such as National Fuel Gas in Appendix A of its Initial Long-Term Plan submitted to the New York State Public Service Commission under Case 22-G-0610 on December 22, 2022.

Scenario Analysis

To demonstrate the BDA tool, Synapse analyzed two scenarios for Xcel Energy Gas, Colorado's largest investor-owned gas utility. Synapse compared the costs of carbon emission abatement for different portfolios of resources to reach a hypothetical target of 60 percent reduction in 2020 emissions by 2040.

- **Scenario 1: High Electrification and Low Alternative Fuels** analyzes a scenario with high adoption of whole-home heat pumps and heat pump water heaters, where heat pump sales increase rapidly each year and reach 100 percent of space heating equipment sales in 2040. This scenario assumes a low RNG potential trajectory and low cost, and low green hydrogen potential trajectory and high cost.
- **Scenario 2: Moderate Electrification and High Alternative Fuels** analyzes a scenario with high potential for both RNG and green hydrogen (with a 20 percent blending by volume), and a smaller role for heat pumps. This scenario assumes some electrification of space and water heating, with only a 50-percent sales share of heat pumps in 2040. Of the customers adopting heat pumps, half of customers each year adopt a hybrid heat pump approach that retains the existing gas heating systems as supplemental/backup heating, and the other half adopt a whole-home heat pump. The scenario assumes high costs for RNG and low costs for green hydrogen.

Findings

Figure 1 shows the individual resource contributions to total avoided emissions through 2040. Both scenarios meet the target of over two million metric tons of avoided GHG emissions in 2040, or a 60 percent reduction in emissions from residential buildings, relative to 2020 levels. In Scenario 1, heat pumps contribute 80 percent of the avoided emissions in 2040, while in Scenario 2 alternative fuels provide the majority of the avoided emissions. Neither scenario includes avoided methane leaks resulting from electrification, which could occur in upstream natural gas production or gas distribution systems.

Figure 1. Annual avoided GHG emissions by resource and scenario

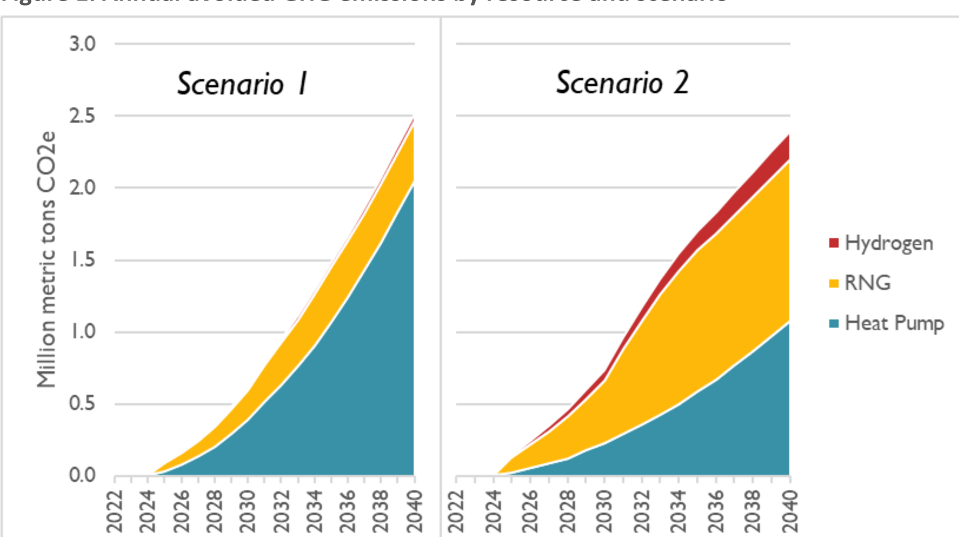
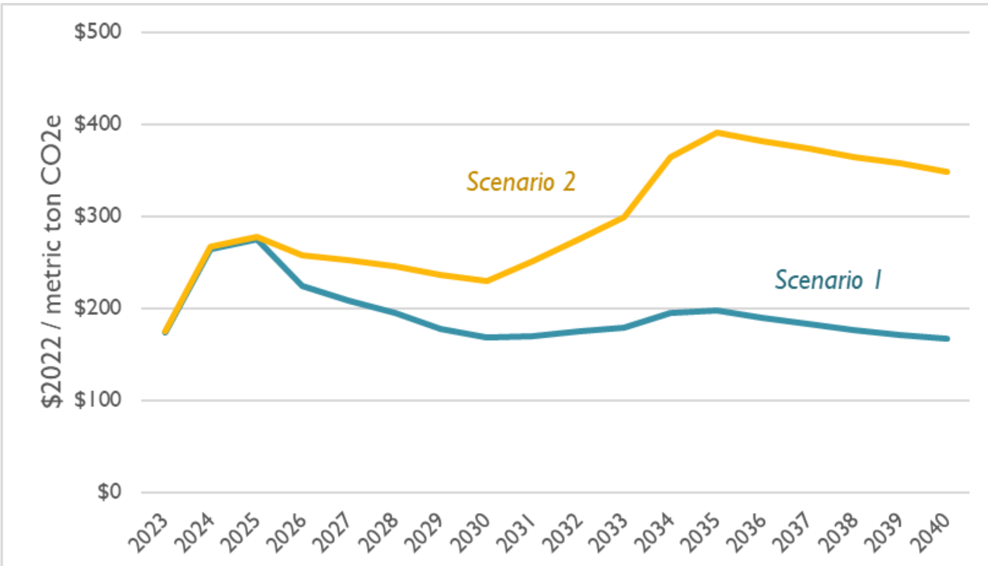


Figure 2 shows the annual weighted average cost to the gas utility per ton of avoided emissions for each scenario. Overall, RNG and green hydrogen are more expensive on a cost-per-ton basis for reduction emissions than heat pumps. Note that these cost estimates do not include costs of electricity, changes in electric system costs, participant costs to upgrade to heat pumps, or changes to gas utility system costs due to electrification.

Figure 2. Annual cost of avoided emissions by scenario



Commercial Buildings

The report concludes with a summary of a literature review of the costs and benefits of commercial building decarbonization measures. We focus on space and water heating end uses, with brief discussion of other end uses. This section summarizes the costs of the leading technologies and concludes with a discussion of the associated benefits.

1. INTRODUCTION

This report lays out potential building decarbonization strategies to help southwestern states meet their climate targets. Three southwestern states—Colorado, Nevada, and New Mexico—have passed or introduced legislation or taken executive action to establish greenhouse gas emissions (GHG) reduction mandates or targets. With the passage of House Bill 19-1261 in 2019, Colorado now requires the state to reduce GHG emissions by 26 percent by 2025, 50 percent by 2030, and 90 percent by 2050, relative to 2005 levels. Nevada also adopted aggressive GHG reduction targets by passing Senate Bill 254 in 2019, which set economy-wide emission reduction targets of 28 percent by 2025, 45 percent by 2030, and net-zero emissions by 2050, compared to 2005 levels. New Mexico Governor Lujan Grisham's Executive Order 2019-003 set statewide GHG emissions reduction targets of 45 percent by 2030 relative to 2005 levels. Further, in 2023, New Mexico legislators introduced S.B. 520 *Clean Future Act* which would have required the state to reduce the economy-wide GHG emissions to 50 percent by 2030 below 2005 levels, 75 percent by 2040, and 90 percent by 2050. Meeting these GHG emission reduction objectives will require these three states to substantially reduce or eliminate emissions from residential and commercial buildings.

Space and water heating are the biggest contributors to GHG emissions from residential buildings; 60 to 70 percent of the households in Colorado, New Mexico, and Nevada use natural gas for these end uses. Among commercial buildings, natural gas for space heating is the second largest source of energy and emissions. Utilities can play a critical role in reducing GHG emissions from both residential and commercial buildings. In particular, the gas and electric utilities in the region can help decarbonize the buildings sector through support for electrification of major end uses such space and water heating and cooking. The gas utilities could also potentially replace some of fossil gas use with renewable natural gas (RNG) or hydrogen, provided that net emissions from these alternative fuels are zero or very small compared to the current fossil gas. Under S.B. 21-264, gas utilities in Colorado are now required to create clean heat plans, with the goal of reducing their GHG emissions 4 percent by 2025 and 22 percent by 2030, below 2015 levels. Clean Heat Plans can include beneficial electrification measures or other measures such as RNG and green hydrogen to reduce GHG emissions from pipeline gas use. Given the relatively short timeframe for decarbonization compared with stock turnover times for the relevant equipment, a flexible and adaptable approach that evolves through implementation is likely to be necessary.[5] It is possible that Nevada and New Mexico will follow suit and pass legislation that would require gas utilities to pursue building decarbonization similar to Colorado's Clean Heat Plans.

To help guide the gas utilities and policymakers in Colorado, Nevada, and New Mexico as they assess how to meet emissions reduction targets in a cost-effective manner, Synapse Energy Economics

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[5] Hopkins, A., A. Napoleon, and K. Takahashi. *A Framework for Long-Term Gas Utility Planning in Colorado*. Prepared by Synapse Energy Economics for the Colorado Energy Office. October 2021. Available at https://www.synapse-energy.com/sites/default/files/Long-Term_Gas_Planning_in_Colorado_21-086.pdf.

(Synapse) developed an in-house tool for the Western Resource Advocates called *Building Decarbonization Analysis* (BDA) tool. The BDA tool allows users to analyze the gas utility costs and emissions reductions associated with space and water heating carbon reduction strategies from the residential building sector. Xcel Gas and Black Hills Gas in Colorado, Southwest Gas and NV Energy Gas in Nevada, and New Mexico Gas in New Mexico are the included gas utilities in this tool.

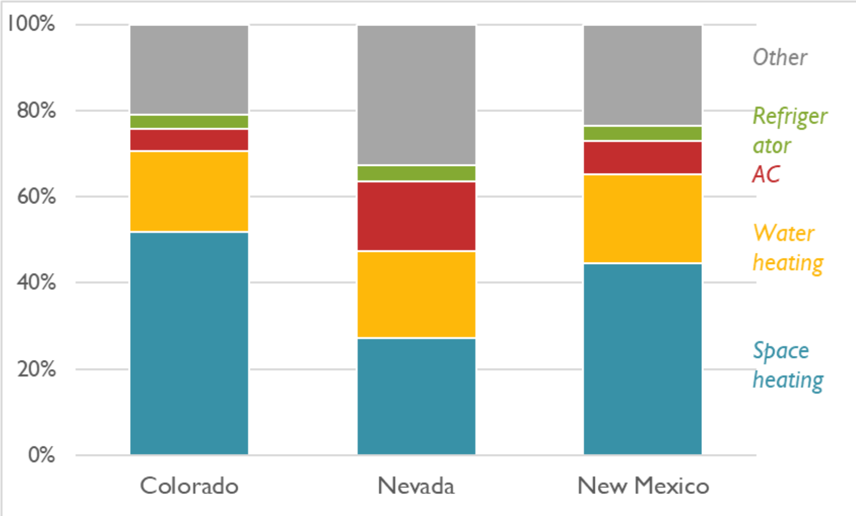
In this report, we first provide an overview of residential end-use characterization for space and water heating end uses. We then discuss key assumptions and methodologies regarding building electrification, RNG, and green hydrogen and present results of our analysis for a few BDA case studies. These case studies include scenario analysis of portfolios of carbon reduction strategies for Xcel Energy's gas utility in Colorado, where we analyzed the costs of a high electrification scenario and a high alternative fuel scenario. We also conducted sensitivity analyses on the carbon abatement costs of heat pumps using different utility incentive levels and by including the impact of avoided methane leaks resulting from electrification.

Lastly, our report includes a summary section on commercial building decarbonization. This section includes our literature review of the costs and benefits of commercial building decarbonization measures. We focus on space and water heating end uses, with brief discussion of other end uses. This section provides an overview of several decarbonization technologies and strategies that can contribute to decarbonization of thermal energy use in buildings, then summarizes the costs of the leading technologies, and concludes with a discussion of the associated benefits.

2. Residential End-Use Characterization for Space and Water Heating

Space and water heating are the two largest energy end uses in residential buildings. According to the U.S. Energy Information Administration (EIA) and as shown in Figure 3, these end-uses account for about 47 percent of all residential energy usage in Nevada (27 percent from space heating and 20 percent from water heating), 65 percent in New Mexico (45 percent from space heating and 21 percent from water heating), and 71 percent in Colorado (52 percent from space heating and 19 percent from water heating). This means that space and water heating are also the biggest contributors to GHG emissions from the residential building sector. Thus, decarbonizing space and water heating provides the greatest opportunity for building emission reductions.

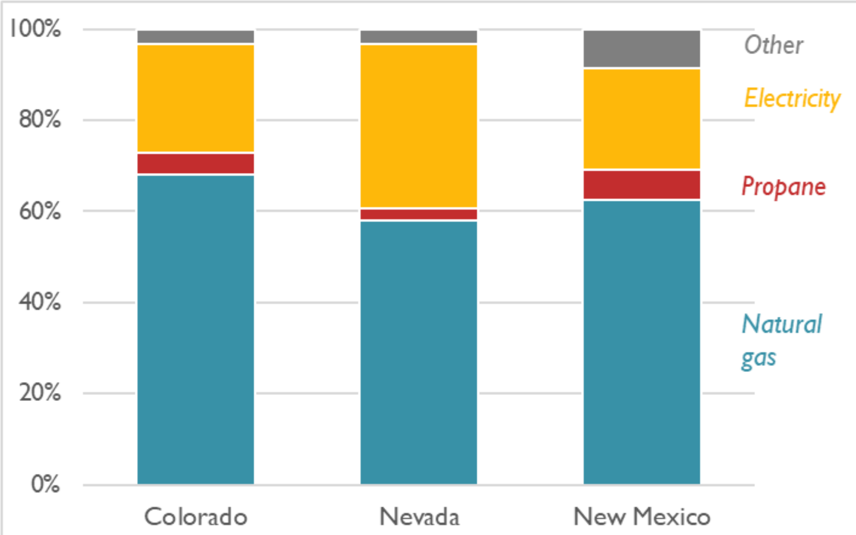
Figure 3. Primary household energy use by end use and state



Source: U.S. Energy Information Administration (EIA). 2023. 2020 Residential Energy Consumption Survey. Table CE3.1.ST. Available at: https://www.eia.gov/consumption /residential/data/2020/state/pdf/ce3.1.st.pdf.

Residential space heating is dominated by fossil fuels in the Southwest. Among all fuel sources, natural gas is the leading fuel for space heating. For example, as shown in Figure 4, 63 percent of households in Colorado, New Mexico, and Nevada on average use utility natural gas as their primary space heating fuel, followed by electricity (27 percent), and propane (5 percent).

Figure 4. Primary household space heating fuel by state



Source: U.S. Census Bureau. American Community Survey (ACS) 2021 5-year estimates: B25040 House Heating Fuel, occupied housing units. Available at: https://data.census.gov/table?g=B25040&g=040XX00US08,32,35&tid=ACSDT5Y2021.B25040

According to the U.S. Energy Information Administration, 56 percent of homes in the Mountain census region[6] use a gas central furnace as the main heating equipment, 11 percent use an electric central furnace, and 10 percent use an electric heat pump or ductless (mini-split) heat pump.[7] In the three states in this study—Colorado, New Mexico, and Nevada—the portion of households relying on a gas furnace is high: an average of about 73 percent of residential households use a forced air furnace as their primary space heating equipment.[8]

Similar to fuel usage for space heating, fossil fuels are the dominant fuels for residential water heating, as shown in Figure 5. On average, natural gas is the primary water heating fuel for 70 percent of residential households in Colorado, New Mexico, and Nevada, followed by electricity with 23 percent and propane with 6 percent.[9].

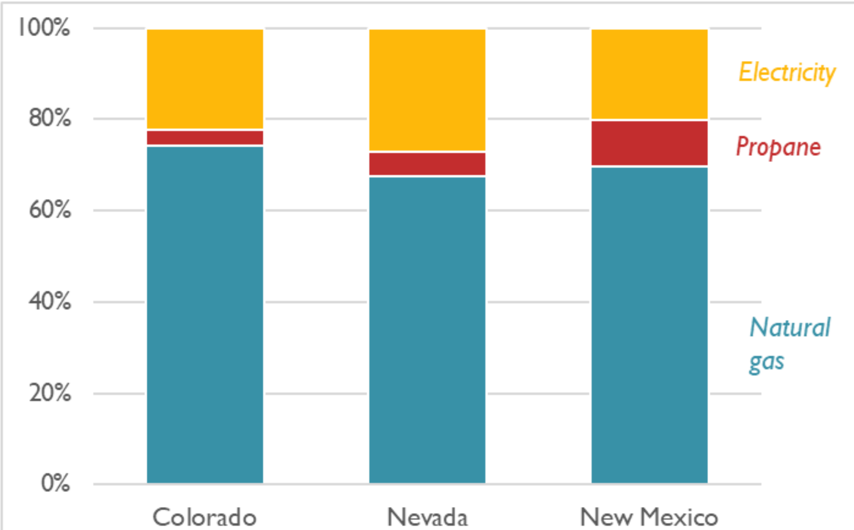
[6] The Mountain census region includes Arizona, Colorado, Idaho, New Mexico, Nevada, Montana, Utah, and Wyoming.

[7] U.S. EIA. *Residential Energy Consumption Survey: Table HC 6.8 Space heating in homes in the South and West regions, 2020.* Updated March 2023. Available at: https://www.eia.gov/consumption/residential/data/2020/.

[8] U.S. EIA. *Residential Energy Consumption Survey: Highlights for space heating in U.S. homes by state, 2020.* Updated March 2023. Available at: https://www.eia.gov/consumption/residential/data/2020/.

[9] U.S. EIA. *Residential Energy Consumption Survey: Highlights for water heating in U.S. homes by state, 2020.* Updated March 2023. Available at: https://www.eia.gov/consumption/residential/data/2020/.

Figure 5. Main water heating fuel by state



Source: U.S. Energy Information Administration. Residential Energy Consumption Survey: Highlights for water heating in U.S. homes by state, 2020. Updated March 2023. Available at: https://www.eia.gov/consumption/residential/data/2020/.

3. Analysis of Residential Building Decarbonization Strategies

3.1. Overview of the Building Decarbonization Analysis Tool

As we presented in the previous section, space and water heating end uses dominate residential building energy usage in Colorado, Nevada, and New Mexico; and the primary fuel for those end uses is natural gas. Thus, jurisdictions need to reduce fossil gas consumption from space and water heating end uses in order to reduce GHG emission from the building sector. Gas utilities can play a critical role in reducing GHG emissions through energy efficiency programs or innovative state policies such as Colorado's Clean Heat Standard.

The BDA tool we developed assesses the costs of carbon reduction strategies for the residential building sector from the perspective of gas companies in the three Southwestern states mentioned above. The tool can analyze the costs and emission reduction impacts for three main carbon reduction strategies: electrification, RNG, and green hydrogen.

- **Electrification** includes heat pumps for space heating and heat pump water heaters (HPWH) for water heating. The BDA also includes analysis of a hybrid heating option which uses electric heat pumps combined with buildings' existing gas heating systems as supplemental/backup heating.

- **RNG** includes a variety of feedstocks including landfill gas, animal manure, water resource recovery facilities, food waste, agricultural and forest residues, energy crops, and municipal solid waste.
- **Green hydrogen** is hydrogen gas produced though electrolysis powered by renewable energy.

The costs included in the BDA tool are the resource costs analyzed from the perspective of the utility company. For electrification, this is the cost of utility customer rebates for heat pumps and HPWH. For RNG and hydrogen, the costs are the incremental costs of each resource compared to fossil natural gas. Fossil natural gas prices are based on wholesale natural gas price forecasts developed by the U.S. Energy Information Administration.[10]

Synapse modeled five natural gas utility jurisdictions across Colorado, Nevada, and New Mexico. For each gas utility, we identified an overlapping electric utility. Table 1 lists the electric and gas utility pairs analyzed in this study, along with representative geographic areas they serve.[11]

Table 1. Utilities and representative geographies included in the BDA tool

State	Representative Location	Gas Utility	Electric Utility
Colorado	Denver County	Xcel Gas	Xcel Electric
Colorado	Weld County	Black Hills Gas	Tri-State Electric
Nevada	Clark County	Southwest Gas	NV Energy Electric
Nevada	Washoe County	NV Energy Gas	NV Energy Electric
New Mexico	Bernalillo County	NM Gas	PNM

The BDA tool analyzes the potential and associated costs of annual avoided GHG emissions for each of the three GHG reduction strategies from 2023 through 2040.

3.2. Space and Water Heating Consumption

To estimate the maximum gas emission reduction potential, Synapse developed total gas consumption estimates for space and water heating for each gas utility territory based on the product of (a) the average consumption per customer for space and water heating, and (b) the total number of utility gas customers who use gas for each end use.

We estimated average residential natural gas use for space and water heating using NREL's End-Use Load Profile (EULP) database. NREL developed this database using its residential building sector stock

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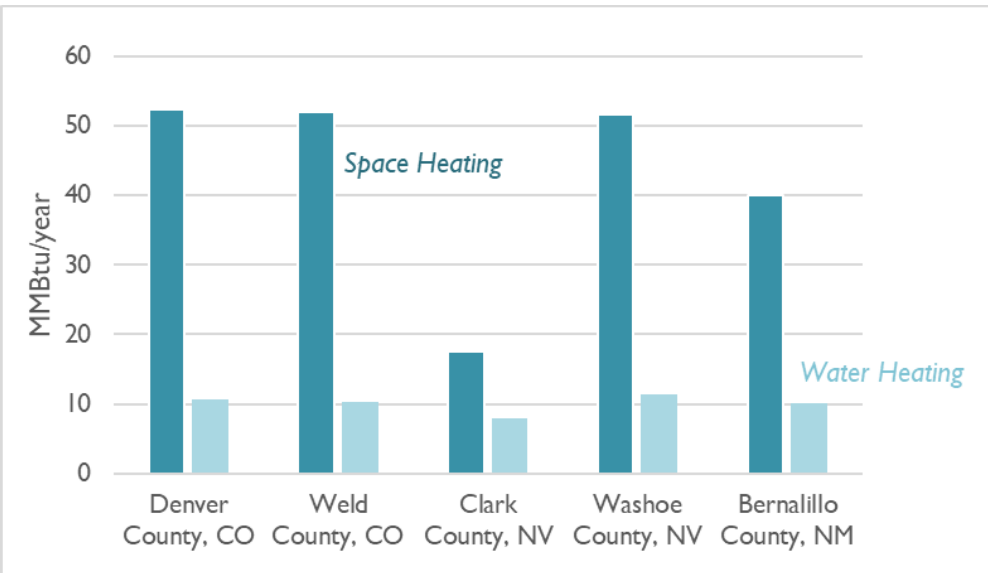
[10] U.S. Energy Information Administration. Annual Energy Outlook 2023. Table 13: Natural Gas Supply, Disposition and Prices, Henry Hub Spot Price. Available at: https://www.eia.gov/outlooks/aeo/data/browser/.

[11] Synapse used the geographic area to determine annual heating load per customer.

model or ResStock model.[12] NREL's ResStock is a granular, bottom-up model that uses multiple data sources, statistical sampling methods, and building energy simulations to estimate the annual sub-hourly energy consumption of the residential building stock across the United States.

For each of the five major gas utilities across the three states analyzed in this study, we identified the county that best represents each utility service territory and associated climate. We calculated the average natural gas heating energy consumption from the EULP database for each of the counties. We then estimated the average residential space and water heating service demand by adjusting the average residential natural gas consumption for the weighted average fuel efficiencies of existing gas heating equipment.[13] The service demand informed our estimate of the energy required to meet this same service demand using electric heat pumps. Figure 6 shows the average annual natural gas service demand by end use for a residential household in each of the gas utility territories analyzed in this study.

Figure 6. Average annual residential natural gas service demand per household by end use and location



Source: Developed based on NREL End-Use Load Profiles For the U.S. Building Stock.

To calculate the total emissions reduction potential from avoiding fossil gas use for space and water heating, we need to estimate the amount of gas used for each end use, for each utility. Not all customers of a natural gas utility use natural gas for space or water heating; some households may only use natural gas for other end uses such as cooking or clothes drying. To account for this, we tallied the total residential households using natural gas in the EULP database by end use for each utility territory and calculated the percent of households using natural gas for space and water heating, respectively.

[12] National Renewable Energy Laboratory. ResStock End Use Savings Shapes, 2022.1 Release. Available at: https://resstock.nrel.gov/datasets.

[13] AFUE for space heating equipment, EF for water heating equipment.

We then estimated the total number of residential customers using natural gas as their primary space or water heating fuel for each utility by multiplying the total number of utility customers[14] by the number of households that use natural gas as their primary heating fuel. Finally, we multiplied the total number of residential customers using gas as primary space or water heating fuel by the average household demand for each utility to get the total annual residential space and water heating potential for the entire utility territory. Table 2 presents the total estimated annual residential consumption by utility.

Table 2. Total annual residential natural gas consumption by end use and utility territory

Gas Utility	State	Space Heating *(BBtu/year)*	Water Heating *(BBtu/year)*
Xcel Gas	Colorado	65,146	12,633
Black Hills Gas	Colorado	8,857	1,660
Southwest Gas	Nevada	10,925	5,293
NV Energy Gas	Nevada	6,896	1,612
NM Gas	New Mexico	17,751	4,460

3.3. Electrification and Heat Pumps

An electric heat pump is an energy-efficient technology that uses compression cycles to move heat from one place to another. Heat pumps can provide space heating and cooling (by moving heat in or out of a building) as well as water heating (by moving heat into the storage tank). Because heat pumps move heat instead of generating it, the efficiencies of heat pumps can be greater than 100 percent. When used for space heating, the most common type of heat pump is referred to as an “air-source heat pump” or simply “heat pump.” (Other, more rare, heat pumps can use ground or water as the external heat sources.) An air-source heat pump used for water heating is often called a “heat pump water heater” or HPWH.

The efficiency of heat pumps is represented by the *coefficient of performance* (COP), defined as the ratio of useful heating or cooling to the total energy input. The temperature of the outdoor air affects the efficiency of air source heat pumps. Synapse accounted for the effects of temperature on the performance of heat pumps when estimating the annual average COP values.

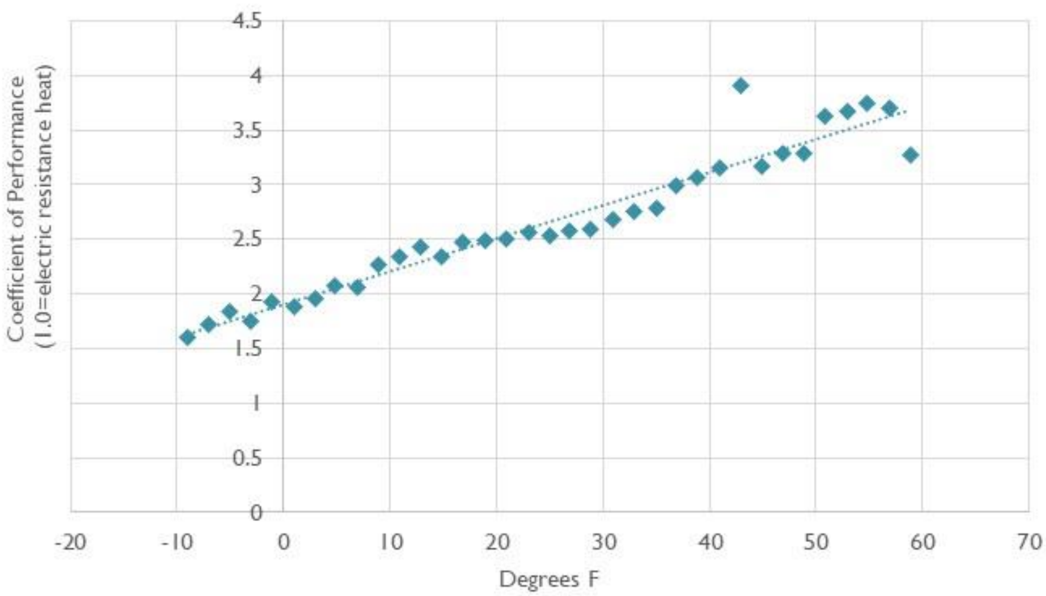
For the BDA tool, we developed a COP performance curve for air-source heat pumps from a 2016 in-field evaluation study of mini-split heat pumps by Cadmus Group.[15] Mini-split heat pumps are composed of an outdoor condenser and an indoor unit that directly provides heating or cooling. In contrast, ducted heat pumps provide heating and cooling through ducts similar to those of central air conditioners. Figure

[14] U.S. EIA. Form 176, Natural Gas Consumers by Company. Available at: https://www.eia.gov/naturalgas/data.php.

[15] Cadmus. 2016. Ductless Mini-Split Heat Pump Impact Evaluation. Figure 55. Available at: http://www.ripuc.ri.gov/eventsactions/docket/4755-TRM-DMSHP%20Evaluation%20Report%2012-30-2016.pdf.

7 presents a COP curve of cold climate heat pumps (a type of heat pump that has superior performance in cold climates) from the 2016 Cadmus study. The figure presents varying COP levels by temperature. We applied this performance curve to temperature data from NREL's ResStock model for each hour for the geographic locations in our study.[16] Because the overall performance of ducted heat pumps tends to be less efficient than mini-split heat pumps, we adjusted the calculated hourly COP to account for the difference in performance between mini-split heat pumps and ducted heat pumps, based on a 2022 in-field evaluation study by Cadmus Group.[17] For this calculation, we assumed an equal share for these two types of heat pumps.

Figure 7. Average space heating COP vs. outdoor temperature for cold-climate heat pumps based on field-measured performance



Synapse developed forecasts of average annual COP for each of the five gas utility territories analyzed in this study. We developed future projections of COP values through 2040 based on the National Renewable Energy Laboratory's (NREL) COP forecasts in its *Electrification Futures Study.*[18]

[16] NREL. October 2022. ResStock TMY3 State and County weather files. Available at: https://data.openei.org/s3_viewer?bucket=oedi-data-lake&prefix=nrel-pds-building-stock%2Fend-use-load-profiles-for-us-building-stock%2F2022%2Fresstock_tmy3_release_1%2Fweather%2F.

[17] Cadmus. 2022. Residential ccASHP Building Electrification Study. Available at: https://e4thefuture.org/wp-content/uploads/2022/06/Residential-ccASHP-Building-Electrification_060322.pdf.

[18] Jadun, P., et al. et al. 2017. Electrification Futures Study: End-Use Electric Technology Cost and Performance Projections through 2050. National Renewable Energy Laboratory. Available at: https://www.nrel.gov/analysis/electrificationfutures.html.

Table 3. Percent increase in heat pump COP by 2030 and 2040 for a slow, moderate, and rapid improvement scenario

Year	Slow Case	Moderate Case	Rapid Case
2030	112%	125%	133%
2040	115%	142%	167%

Source: NREL Electrification Futures Study.

For HPWH, we similarly developed average annual COP values for residential HPWHs based on several data sources. The primary source is a national study by Natural Resources Defense Council (NRDC) and Ecotope on HPWH performance, which estimated COP values for residential HPWHs with two tank sizes (50 gallon and 80 gallon) in 50 states for various locations in a residential house (e.g., basement, closet, garage).[19] We adjusted the HPWH COP values to reflect technology improvements since the study was conducted in 2016, based on current efficiency ratings for HPWHs.[20] Following the same procedure as for space heating heat pumps, we developed projections of HPWH COP improvement over time.[21]

Table 4. Percent increase in HPWH COP by 2030 and 2040 for a slow, moderate, and rapid improvement scenario

Year	Slow Case	Moderate Case	Rapid Case
2030	108%	117%	127%
2040	117%	125%	133%

Source: NREL Electrification Futures Study.

Synapse modeled residential heat pump adoption as a growing proportion of appliance replacements. We first estimated an average annual appliance stock turnover rate based on the life of gas space and water heating appliances, assuming current residential customers will replace their heating equipment at the end of its useful life.[22] To calculate the potential for heat pumps, we then estimated a heat pump equipment adoption rate, assuming a growing sales share of heat pump technologies over time. Users of the BDA tool can specify the annual adoption rate by changing the heat pump sales share in the first and last year. For the purpose of our scenario analysis for Xcel Colorado (detailed later in Section 3.6), we

[19] Natural Resources Defense Council. 2016. "NRDC/Ecotope Heat Pump Water Heater Performance Data." Available at: https://www.nrdc.org/experts/pierre-delforge/very-cool-heat-pump-water-heaters-save-energy-and-money.

[20] ENERGY STAR Certified Water Heaters. 2022. Available at: https://www.energystar.gov/productfinder/product/certified-water-heaters/.

[21] Jadun, P., et al. et al. 2017. Electrification Futures Study: End-Use Electric Technology Cost and Performance Projections through 2050. National Renewable Energy Laboratory. Available at: https://www.nrel.gov/analysis/electrificationfutures.html.

[22] We assumed a weighted average life of 18 years for gas space heating systems based on (a) 22-23 years for a boiler and 17-18 years for a furnace and (b) the share of furnaces and boilers in Colorado from NREL's EULP database. We assumed a weighted average measure life of 13.7 years for gas water heating based on (a) 15 years for condensing unit, 9 years for regular tank unit, 19 years for tankless unit, and (b) the share of these water heaters we obtained from NREL EULP database. Equipment lifetime data: MassSave. 2023. *Massachusetts Technical Reference Manual.* Available at: https://www.masssavedata.com/Public/TechnicalReferenceLibrary.

assume the heat pump and HPWH sales shares start at 5 percent per year in 2023 and linearly grow to 100 percent by 2040.[23]

New, readily available heat pump technologies such as cold-climate heat pumps are already capable of producing comfortable heat at below zero degrees. However, there are still concerns about the impact of heat pumps on electrical grid winter peak loads. Many utilities have promoted the use of hybrid heat pump systems, and states and regulators are considering the costs and benefits of implementing that approach. Hybrid heat pumps are used alongside fossil-fuel-based backup or supplemental heating systems. These hybrid systems can reduce up to 80 to 90 percent of natural gas used for space heating, and add lower electric peak demands than a whole-home heat pump without any backup heating would add.

We modeled two scenarios for heat pump resource potential: (a) a whole-home heat pump scenario, where the heat pump fully replaces the fossil-fuel-based heating system to meet 100 percent of the household space heating needs, and (b) a hybrid heat pump scenario, where half of households install heat pumps supplemented by existing fossil-fuel-based heating systems to serve heating needs during the coldest days of the winter. For the hybrid scenario, we determined the use of the gas backup system as a share of the total heating demand based on the *switchover temperature*, the threshold temperature at which the backup heating system is used instead of the heat pump. For our analysis, we assumed a switchover temperature of 10 degrees Fahrenheit based on an in-field heat pump evaluation study by the Center for Energy and Environment.[24]

To calculate avoided natural gas emissions from heat pump adoption, we used a carbon dioxide (CO_2) emissions factor of 0.053 metric tons (MT) per MMBtu for natural gas combustion, based on U.S. Environmental Protection Agency (EPA) estimates.[25] Electrification of space and water heating also avoids methane leaks from natural gas pipeline transportation. The BDA tool can include the impacts of methane leaks in the calculation of total CO_2 equivalent (CO_2e) emissions estimates and allows users to include or exclude the impact of such methane leaks.

The BDA tool allows the user to adjust the emission factor for natural gas to account for the potential methane leaks between wells and final use in buildings. We estimated the CO_2e impact of the methane leaks assuming (a) a methane leak rate of 2.3 percent based on a 2018 study by Alvarez et. al.[26] and (b) a global warming potential (GWP) factor of 83 corresponding to a 20-year timeframe based on a 2021

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[23] We assumed that the sales share in the first year is equal to our estimate of the current stock share of heat pumps in Colorado, based on our review of EIA RECS 2020. Given the lack of sales or stock share of HPWH for Colorado, we assumed that the first-year sales share for HPWH is equal to the heat pump sales share.

[24] Shoenbauer, B. et al. 2018. “Field Assessment of Ducted and Ductless Cold Climate Air Source Heat Pumps.” Available at: https://www.mncee.org/field-assessment-ducted-and-ductless-cold-climate-air-source-heat-pumps.

[25] U.S. Environmental Protection Agency. "Greenhouse Gases Equivalencies Calculator - Calculations and References" Accessed June 17, 2021: EPA (2020). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018. Annex 2 (Methodology for Estimating CO2 Emissions from Fossil Fuel Combustion), Table A-43.

[26] Alvarez et. al. 2018. “Assessment of methane emissions from the U.S. oil and gas supply chain.” Science. DOI: 10.1126/science.aar7204. Available at: https://science.sciencemag.org/content/361/6398/186.

report by the Intergovernmental Panel on Climate Change (IPCC).[27] The resulting combined CO_2e emissions rate of gas consumed in buildings and leaked methane is 0.089 metric tons per MMBtu. This represents about a 68 percent increase from the CO_2 emissions factor of gas combustion. Users of the BDA tool can also adjust the GWP factor from 83 to different factors such as 29.8, which corresponds to a 100-year timeframe based on the same IPCCC report mentioned above. Using this GWP factor increases the impact of the CO_2 emissions from burning natural gas by 25 percent (instead of 68 percent).[28]

To estimate the total net emissions savings through electrification, we calculated projected electric grid emissions factors for the corresponding electric utilities in each geographic location in our study.[29,30,31,32,33] As shown in Figure 8, the electric grid emissions rates steadily decline through 2040, reflecting the integration of cleaner energy resources. Thus, the net emissions savings potential of heat pumps for space and water heating increases over time.

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[27] Intergovernmental Panel on Climate Change. 2021. Climate Change 2021 – The Physical Science Basis. Table 7.15, pp.7-125. Available at: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf.

[28] On-site combustion of fossil gas produces 0.053 metric tons of CO_2 per MMBtu. Methane leaks would add 0.013 metric ton of CO2e per MMBtu over a 100-year timeframe and 0.036 metric ton of CO_2 per MMBtu over a 20-year timeframe.

[29] Tri-State Generation and Transmission – 2020 ERP. *Attachment A to Clean Energy Plan Verification.* CPUC Proceeding No. 20A-0528E. March 3, 2023. Available at: https://www.dora.state.co.us/pls/efi/EFI.Show_Docket?p_session_id=&p_docket_id=20A-0528E.

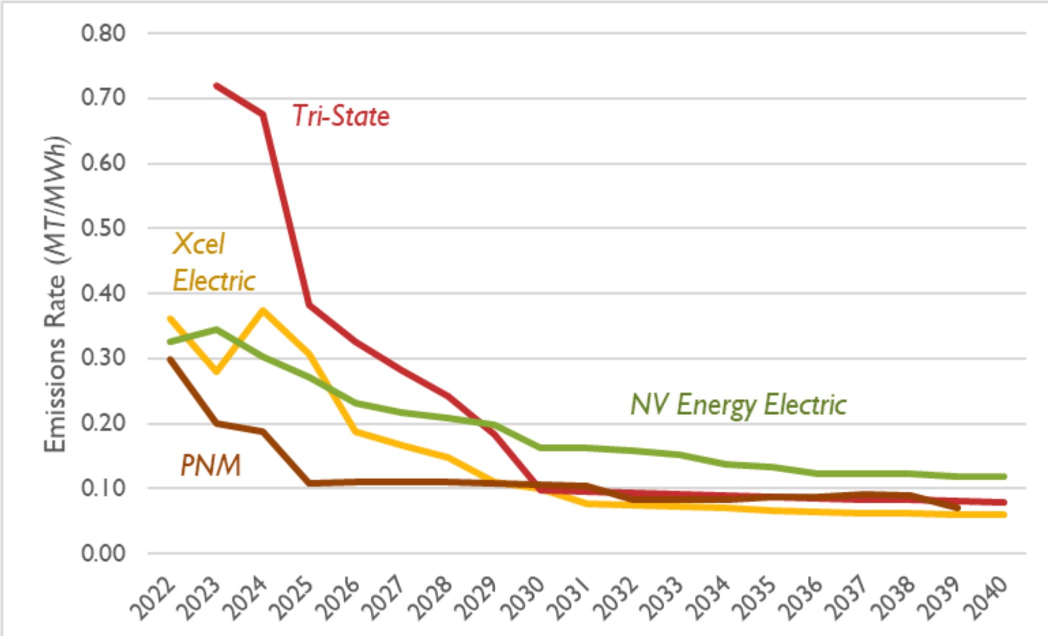
[30] PNM 2020-2040 Integrated Resource Plan Appendices. January 29, 2021. Available at: https://www.pnmforwardtogether.com/assets/uploads/PNM-2020-2040-IRP-APPENDICES.pdf.

[31] Public Utilities Commission of Nevada. *Joint Application of Nevada Power Company d/b/a/ NV Energy and Sierra Pacific Power Company d/b/a NV Energy for approval of the Fourth Amendment to the 2021 Joint IRP.* Docket No. 22-11032. December 1, 2022. Available at: https://pucweb1.state.nv.us/PDF/AxImages/DOCKETS_2020_THRU_PRESENT/2022-11/22582.pdf.

[32] Public Service Company of Colorado. *Attachment D – Modeling Summary Final.* CPUC Proceeding No. 21A-0141E. April 26, 2022. Available at: https://www.dora.state.co.us/pls/efi/EFI.Show_Docket?p_session_id=&p_docket_id=21A-0141E.

[33] Public Service Company of Colorado. *Updated Modeling Inputs & Assumptions: 2021 Electric Resource Plan and Clean Energy Plan Phase II.* CPUC Proceeding No. 21A-0141E. November 29, 2022. Available at: https://www.dora.state.co.us/pls/efi/EFI.Show_Docket?p_session_id=&p_docket_id=21A-0141E.

Figure 8. Projected electric utility grid emission rates for Tri-State Generation and Transmission Association, NV Energy's electric utility, Public Service Company of Colorado (Xcel Energy), and Public Service Company of New Mexico (PNM)



In this study we analyze electrification as a decarbonization resource, from the perspective of the gas utility and the costs it passes through to its ratepayers. Thus, the space and water heating electrification costs are the equipment incentive costs the gas utility pays to customers. This analysis does not include the costs of electricity, because that is an electric utility or electric utility customer cost; nor does it include the full upfront capital cost of the heat pump equipment. To compare the utility costs of upfront heat pump and HPWH rebates to the net present resource costs of hydrogen and RNG over time, Synapse calculated an annualized rebate cost. The utility pays for rebates in the first year of a heat pump's lifetime. The annualized rebate cost is upfront dollar value of the rebate (dollars per heat pump or HPWH) converted to an annual cost over the lifetime of the heat pump that represents that same net present cost as the upfront rebate. For example, a $1,000 rebate annualized over 18 years is $97.27 per unit each year.[34]

At the time of this report, gas-only utilities in the three states studied do not offer electrification rebates for heat pumps or HPWH. Thus, we used heat pump and HPWH rebate data from the corresponding paired electric utility. Where data was available, we included high, medium, and low rebate amounts in the BDA tool, listed in Table 5 and Table 6 below. The BDA tool also allows users to input a custom rebate amount.

[34] We annualized the rebate over 10 years using a real discount rate of 4.6 percent, based on Xcel Energy's current weighted average cost of capital of 6.7 percent from Colorado PUC Decision No C22-0642 and an inflation rate of 2 percent.

Table 5. Space heating: rebate amounts for heat pumps provided by electric utilities

Location	Gas Utility	Electric Utility	High Rebate *$/unit*	Medium Rebate *$/unit*	Low Rebate *$/unit*
Denver County, Colorado	Xcel Gas	Xcel Electric	$2,200	$1,650	$500
Weld County, Colorado	Black Hills Gas	Tri-State Electric	$2,400	$1,800	-
Clark County, Nevada	Southwest Gas	NV Energy Electric	$4,000	$2,250	$600
Washoe County, Nevada	NV Energy Gas	NV Energy Electric	$4,000	$2,250	$600
Bernalillo County, New Mexico	NM Gas	PNM	$575	$465	$355

Table 6. Water heating: rebate amounts for heat pump water heaters provided by electric utilities

Location	Gas Utility	Electric Utility	High Rebate *$/unit*	Medium Rebate *$/unit*	Low Rebate *$/unit*
Denver County, Colorado	Xcel Gas	Xcel Electric	$800	$600	-
Weld County, Colorado	Black Hills Gas	Tri-State Electric	$350	-	-
Clark County, Nevada	Southwest Gas	NV Energy Electric	$600	-	-
Washoe County, Nevada	NV Energy Gas	NV Energy Electric	$600	-	-
Bernalillo County, New Mexico	NM Gas	PNM	$825	$300	$165

3.4. Renewable Natural Gas

RNG is methane gas (the same chemical as fossil gas) produced through the anaerobic digestion or thermal gasification of feedstocks. RNG can be produced from a variety of feedstocks, including organic waste (e.g., food waste, manure, energy crops, agricultural residues), energy crops (i.e., crops grown for the production of RNG), and non-biogenic waste (e.g., construction debris). The potential for RNG use in building decarbonization is limited by both the availability of feedstocks and demand from other sectors such as the transportation, electric generation, and industrial sectors. The consulting firm ICF International estimated RNG production potential in 2040 based on assumptions about feedstock availability and utilization.[35] ICF estimates that 751–2,074 trillion Btu of RNG will be available in the western United States in 2040 from landfill gas, animal manure, water resource recovery facilities, food waste, agricultural residues, forest residues, energy crops, and municipal solid waste.[36] To estimate the amount of RNG available by state, we assumed that each state will have access to a portion of total RNG produced in the western United States proportionate to the amount of natural gas the consumed in the state relative to the western United States as a whole. This also assumes the RNG is readily transferrable across states, from where it is generated to where it is consumed. Table 7 displays high and low RNG

[35] ICF International. 2019. Renewable Sources of Natural Gas: Supply and Emissions Reduction Assessment. Prepared for the American Gas Foundation. Available at https://gasfoundation.org/wp-content/uploads/2019/12/AGF-2019-RNG-Study-Full-Report-FINAL-12-18-19.pdf.

[36] Western United States includes Mountain, West North Central, West South Central, Mountain, and Pacific regions.

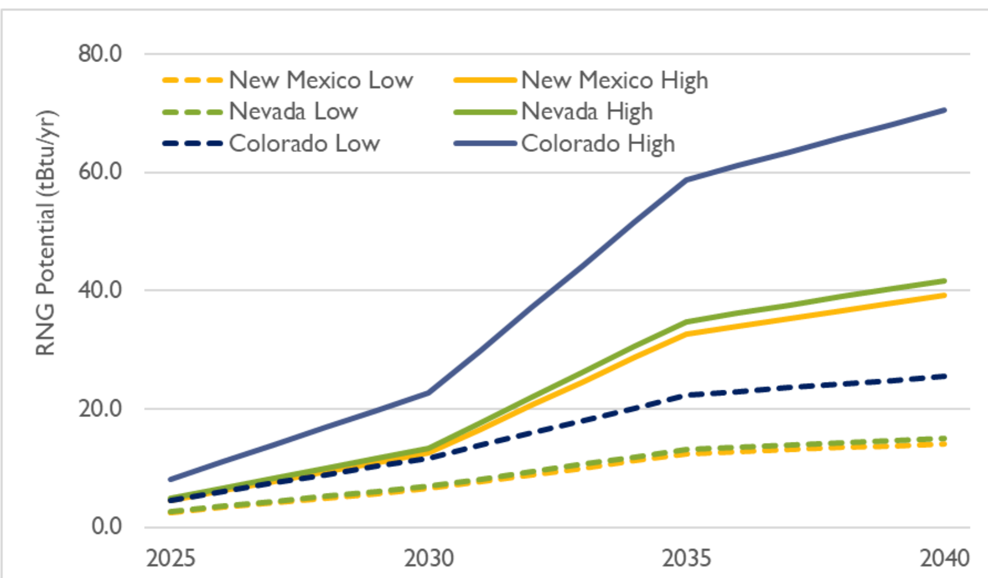
availability estimates in 2040 for New Mexico, Nevada, and Colorado. Note that while we present the total potential at the state level in this table, our BDA tool (discussed in Sections 3.1 and 3.6) estimates RNG potential for residential customers by utility, for which we scaled down the statewide potential by the share of residential gas sales.

Table 7. Modeled 2040 RNG availability for all sectors

	New Mexico	Nevada	Colorado
2021 Natural Gas Consumption (tBtu/year) [37]	286	305	516
High RNG Potential (tBtu/year)	39	42	68
Low RNG Potential (tBtu/year)	14	15	26

Based on these estimates, we developed RNG supply curves that reflect the potential pace of resource growth through 2040. Today, the majority of RNG produced is produced via anaerobic digestion at landfill gas facilities. We assumed that landfill gas sources will be used first to produce RNG and sold in the RNG market, followed by other anaerobic digestion feedstocks, including animal manure, waste-water recovery, and food waste. We assumed RNG produced via thermal gasification of feedstocks will not start to come online until 2030, reflecting the nascent nature of this technology.

Figure 9. RNG potential resource growth through 2040



[37] U.S. EIA. 2021. Natural Gas Consumption by End Use. https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_SLA_a.htm.

The emissions reduction potential of RNG depends on the feedstock from which it is produced. As shown in Table 8, RNG produced from animal manure has the greatest emissions reduction potential, whereas RNG produced from landfill gas and water resource recovery facilities have the least.

Table 8. Biomethane emissions

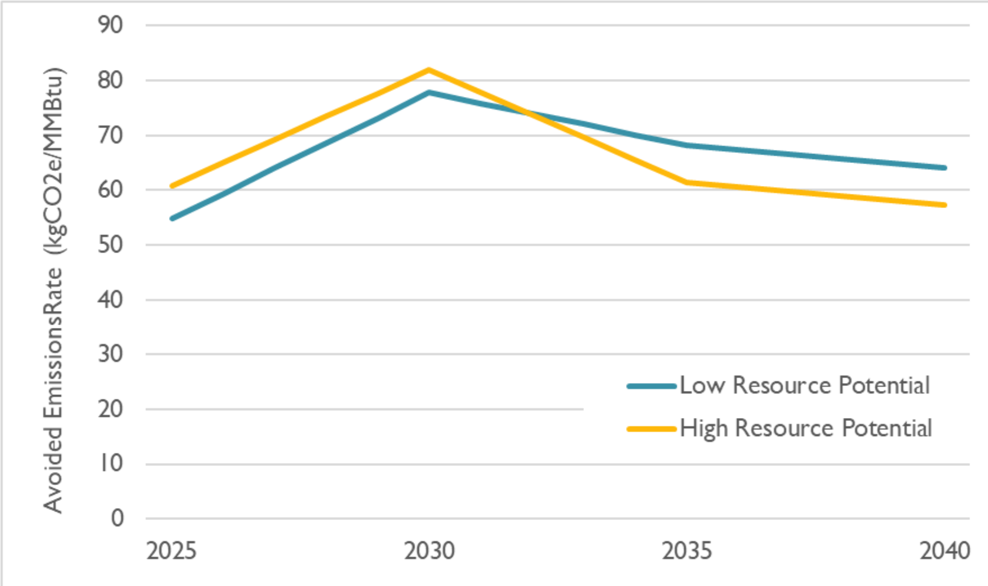
	Feedstock	Emissions (gCO_2e/MJ) [a]	Avoided Emissions ($kgCO_2e/MMBtu$) [b]
Anaerobic Digestion	Landfill Gas	55.7	9.7
	Animal Manure	-164.2	241.8
	Water Resource Recovery Facilities	55.8	9.7
	Food Waste	30.8	36.1
Thermal Gasification	Agricultural Residues	30.8	36.1
	Forestry and Forest Residues	30.8	36.1
	Energy Crops	30.8	36.1
	Municipal Solid Waste	30.8	36.1

Source: a. Emissions based on LCFS lifecycle estimates,[38] adjusted for pipeline compression. b. Avoided emissions are compared to emissions from pipeline natural gas.

Figure 10 shows projected average avoided emissions per MMBtu of RNG through 2040 under high resource and low resource potential scenarios. The change in average emissions is driven by the blend of feedstocks used in production each year. The avoided emissions rate increases until 2030, reflecting the increasing relative contribution of animal manure, which has the greatest avoided emissions. After 2030, avoided emissions per MMBtu decrease as other feedstocks with lower avoided emissions, such as agricultural residues and energy crops, make up a larger share of RNG production.

[38] California Air Resources Board. Temporary Pathways Table (Table 8). Available at: https://ww2.arb.ca.gov/resources/documents/lcfs-life-cycle-analysis-models-and-documentation.

Figure 10. Average RNG avoided emissions rate

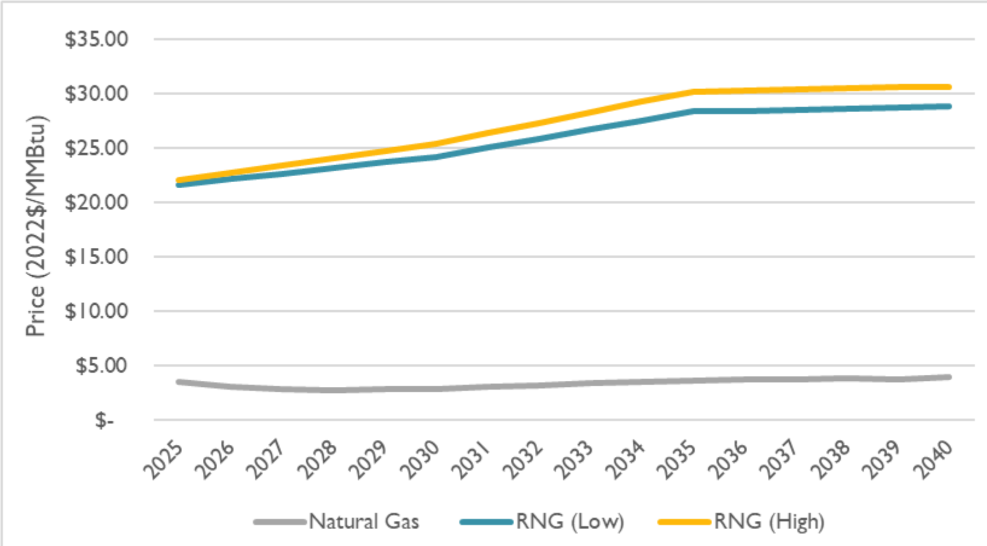


The price of RNG depends on various factors such as the availability and cost of feedstocks, state of market development, and production levels, which may have competing effects on prices. Our pricing estimates are therefore uncertain. ICF estimates that the lowest-cost feedstocks, landfill gas and waste-water resource facilities, can be produced for approximately $8 per MMBtu. However, the availability of low-cost resources is limited, and when higher-cost resources available at greater scale (or simply delayed due to technical immaturity) become the marginal resource, market prices should rise. ICF estimates that these higher-cost resources, such as animal manure and food waste, have costs starting at approximately $21 per MMBtu. As the market develops, some of these costs may decrease due to technological learning or economies of scale and additional feedstocks (i.e., those used with thermal gasification) could come online; these changes could apply downward pressure on prices. At the same time, there will also be increasing scarcity of lower-cost feedstocks relative to production, which could increase prices.

We reflect uncertainty in future RNG cost estimates by using a range. Figure 11 shows the projected price of RNG and natural gas through 2040.[39] We estimate that the cost of RNG will be between $18–$27 per MMBtu higher than natural gas. The RNG price forecast is based on the blend of feedstocks that will make up RNG production in each year, and their associated marginal prices. We developed marginal RNG price estimates, accounting for the fact that high cost RNG resources will set market prices.

[39] Natural gas prices based on AEO 2023 Henry Hub Spot Price.

Figure 11. Natural gas and RNG price forecast



3.5. Green Hydrogen

Hydrogen is a versatile energy carrier that offers diverse applications in several sectors. Historically, hydrogen has been produced thermochemically through steam reforming of methane and by coal gasification for industrial purposes such as fertilizer production and refining processes.[40] However, an increased focus on low-carbon energy has resulted in growing interest in producing hydrogen through water electrolysis, in which water molecules are split into their constituent parts (typically using a polymer electrolyte membrane or alkaline electrolyzer).[41] Unlike the traditional methods, electrolysis does not produce direct emissions; it only produces those emissions associated with the electricity used to power the process, and hydrogen combustion does not produce CO_2 or other GHGs.[42] Hydrogen produced through electrolysis powered by renewable energy is called "green hydrogen" and is considered zero emission.[43]

There has historically been a significant premium for green hydrogen, with prices reaching about $8 per kilogram of hydrogen, equivalent to over $70 per MMBtu.[44] However, as renewable energy prices have

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[40] U.S. Department of Energy. 2017. "Hydrogen: A Clean, Flexible Energy Carrier." *Office of Energy Efficiency & Renewable Energy.* February 21. Available at: https://www.energy.gov/eere/articles/hydrogen-clean-flexible-energy-carrier.

[41] Ibid.

[42] Hydrogen leaked directly to the atmosphere is considered an indirect GHG, with an estimated 100-year global warming potential of 12. See, e.g., Sand, M., Skeie, R.B., Sandstad, M. et al. A multi-model assessment of the Global Warming Potential of hydrogen. Commun Earth Environ 4, 203 (2023). https://www.nature.com/articles/s43247-023-00857-8.

[43] van Dorsten, B and De la Cruz, F.L. "Decoding the hydrogen rainbow." Wood Mackenzie. Available at: https://www.woodmac.com/news/opinion/decoding-the-hydrogen-rainbow/.

[44] International Energy Agency. 2022. "Global average levelised cost of hydrogen production by energy source and technology, 2019 and 2050." October 26. Available at: https://www.iea.org/data-and-statistics/charts/global-average-levelised-cost-of-hydrogen-production-by-energy-source-and-technology-2019-and-2050.

fallen dramatically, recent studies indicate that green hydrogen can be produced for as little as $3–5/kg.[45] Additionally, the recently enacted *Inflation Reduction Act* provides hydrogen producers with a $3/kg production tax credit (PTC) for hydrogen produced with near-zero emissions intensity. Final implementation of this PTC has yet to be established as of the writing of this paper, and several analyses have shown that the way this PTC is implemented will have a significant impact on the future hydrogen economy, including prices and emissions.[46]

The potential for green hydrogen use in building decarbonization is limited by several key factors. First, the clean hydrogen economy is nascent; as noted above the sector's future is highly uncertain, which makes planning for large-scale procurements challenging and risky presently. There also will certainly be significant competition to procure green hydrogen, especially in the near term. Incumbent consumers such as those in the refining and fertilizer industries will likely be at the front of the line to use green hydrogen as costs become competitive with fossil-based hydrogen and they work to decarbonize their own businesses.[47]

Of significant importance to this analysis are the challenges and risks of blending hydrogen into gas transmission and distribution networks. Notably, hydrogen is a tiny molecule with a low volumetric energy density (about one-third that of methane gas).[48] Because of its small size, hydrogen is very leaky and poses concerns to pipeline infrastructure and safety.[49] Even at very low blends of only 1 percent hydrogen by volume, there are substantial effects on pipeline steel such as embrittlement, fatigue, and fracture.[50] This presents major safety concerns because hydrogen is much more flammable than methane, and due to increased leaks can combust much more readily.[51] Additionally, the leakiness results in economic impacts as well since more energy is lost before being consumed.

Indeed, the body of literature surrounding hydrogen blending impacts on the natural gas system suggests that a realistic upper bound for hydrogen blending in the natural gas system without any major retrofits to the system is about 10 percent hydrogen by volume; there are wide knowledge gaps at

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[45] BloombergNEF. 2020. "Hydrogen Economy Outlook: Key messages." March 30. Available at: https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf.

[46] Ricks, W *et al*. 2023. "Minimizing emissions from grid-based hydrogen production in the United States." 2023 Environ. Res. Lett. 18 014025. January 6. Available at: https://iopscience.iop.org/article/10.1088/1748-9326/acacb5;
Esposito, D *et al*. 2023. "Smart Design of 45V Hydrogen Production Tax Credit will Reduce Emissions and Grow the Industry." April 2023. Available at: https://energyinnovation.org/wp-content/uploads/2023/04/Smart-Design-Of-45V-Hydrogen-Production-Tax-Credit-Will-Reduce-Emissions-And-Grow-The-Industry.pdf.

[47] For further discussion of the hierarchy of green hydrogen consumption, including the industries most and least likely to compete for it, see Michael Liebreich's "Clean Hydrogen Ladder" available here: https://www.linkedin.com/pulse/clean-hydrogen-ladder-v40-michael-liebreich/.

[48] University of California, Riverside and Gas Technology Institute for The California Public Utilities Commission (CPUC). 2022. "Hydrogen Blending Impacts Study." July 18. At page 37. Available at: https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M493/K760/493760600.PDF.

[49] Id. at p. 37.

[50] Id. at p. 67-68.

[51] Id. at p. 37.

blends of higher percentages.[52] However, several natural gas utilities are proposing hydrogen blending of up to 20 percent by volume.[53] Due to hydrogen's low volumetric energy density, a 20 percent blend by volume displaces only about 7 percent of natural gas and, subsequently, GHG emissions.[54]

Based on a thorough literature review, we developed assumptions regarding the green hydrogen blending potential in Colorado, New Mexico, and Nevada. Consistent with the above discussion, we included a high and low trajectory of hydrogen potential in the BDA tool. The default high green hydrogen trajectory assumes that utilities in western states can blend up to a maximum of 10 percent hydrogen by volume into their natural gas networks. The BDA tool also allows users to enter a custom blending limit to calculate a higher or lower potential, if desired (e.g., 20 percent). We assume that utilities can incrementally add hydrogen by volume per year, as they learn how the increased hydrogen effects their particular systems and customers (e.g., a 20-year ramp-up to 10 percent).[55]

As mentioned above, the future of green hydrogen, and particularly the cost to produce it, is highly uncertain.[56] We developed two green hydrogen price forecasts to reflect this uncertainty. The "high cost" trajectory reflects a future in which the IRS takes a stricter interpretation of the IRA, resulting in fewer projects receiving the PTC, or in which the capital cost of electrolyzers does not fall so rapidly. The "low cost" trajectory assumes a much more abundant supply of green hydrogen that leads to lower prices. Figure 12 below shows these cost trajectories. The dotted lines represent hydrogen costs without the IRA tax credits to show the impact of the IRA tax credits.

[52] Id. at p. 107-108.

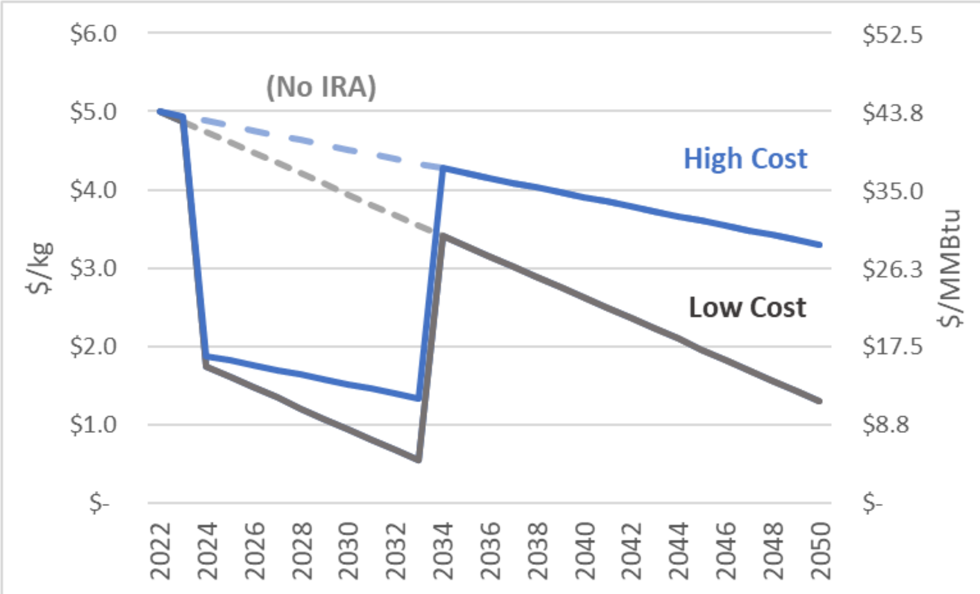
[53] See for example: National Grid. April 2022. "Our clean energy vision." Available at: https://www.nationalgrid.com/document/146251/download, Southwest Gas. April 2022. "Southwest Gas Announces Groundbreaking Hydrogen-Blending Pilot Program with University of Nevada, Las Vegas." Available at: https://www.swgas.com/en/news/swgas-announces-groundbreaking-hydrogen-blending-pilot-program, and SoCalGas. September 2022. "H2 Blending Project". Available at: https://www.socalgas.com/sustainability/hydrogen/h2-blending.

[54] Assuming the lower heating value of each gas (983 Btu/ft^3 for natural gas and 290 Btu/ft^3 for hydrogen gas) and that hydrogen has no global warming potential. However, hydrogen has considerable indirect warming effects that, although omitted from this analysis, are nontrivial. For more information, see Ocko *et al* (2022) here: https://acp.copernicus.org/articles/22/9349/2022/acp-22-9349-2022-discussion.html.

[55] This approach has been proposed by local distribution companies in New York, such as National Fuel Gas in Appendix A of its Initial Long-Term Plan submitted to the New York State Public Service Commission under Case 22-G-0610 on December 22, 2022.

[56] Ricks *et al.* (2023) and Esposito *et al.* (2023).

Figure 12. Hydrogen supply price trajectory



The estimates are based on International Energy Agency estimates for green hydrogen in 2019 and 2050.[57] We assume that green hydrogen can be procured for $5/kg on average today and will fall to between $3.3/kg and $1.3/kg in 2050 in the high- and low-cost cases, respectively. We applied the 10-year $3/kg PTC for projects beginning in 2024.

3.6. Key Results of Our Analysis for Each Utility Jurisdiction

Using the assumptions and inputs described above, the BDA tool allows users to develop and compare the potential and the costs of carbon abatement for three resources (heat pumps, RNG, and green hydrogen) for five gas utility jurisdictions in Colorado, Nevada, and New Mexico. To demonstrate the BDA tool, Synapse analyzed two scenarios for Xcel Energy Gas, Colorado's largest gas investor-owned utility. Synapse compared the costs of carbon emission abatement for different portfolios of resources to reach a hypothetical target of 60 percent reduction in 2020 emissions by 2040.

- **Scenario 1: High Electrification and Low Alternative Fuels** analyzes a scenario with high adoption of whole-home heat pumps and HPWH, where heat pump sales increase rapidly each year and reach 100 percent of space heating equipment sales in 2040. This scenario assumes a low RNG potential trajectory and low cost, and low green hydrogen potential trajectory and high cost.
- **Scenario 2, Moderate Electrification and High Alternative Fuels** analyzes a scenario with high potential for both RNG and green hydrogen, and a smaller role for heat pumps. The scenario assumes a custom high hydrogen blending limit of 20 percent, consistent with gas utility proposals in other states. This scenario also assumes some

[57] IEA 2022.

electrification of space and water heating, with only a 50-percent sales share of heat pumps in 2040. Of the customers adopting heat pumps, half of customers each year adopt a hybrid heat pump approach that retains the existing gas heating systems as supplemental/backup heating, and the other half adopt a whole-home heat pump. This scenario assumes high costs for RNG and low costs for green hydrogen.

These scenarios are intended to demonstrate the potential costs and emission reductions of various pathways, and the resource mixes may differ from current requirements under Colorado's Clean Heat Standard. For example, the Clean Heat Standard limits the amount of "recovered methane," or RNG from waste, that utilities can use to reduce emissions to approximately one-quarter of the total emission reductions required in 2025 and 2030; limitations for compliance years beyond 2030 will be determined by the Public Utilities Commission. The Clean Heat Standard also limits RNG to sources within the state of Colorado. Similarly, the Clean Heat Standard measures emission reductions on the gas utility's system, not net emission reductions across the gas and electric utilities, as this analysis demonstrates. *Anyone modeling compliance with a particular policy will need to ensure assumptions match the policy specifications.*

Neither scenario included the value of avoided pipeline methane leaks from electrification, because Colorado's Clean Heat Standard only counts methane leakage associated with the distribution system. Both scenarios assumed a moderate efficiency improvement trajectory for heat pump technologies, and heat pump and HPWH rebates of $2,200 and $800, respectively.[58]

Figure 13 and Figure 14 show the individual resource contributions to total avoided emissions through 2040. Both scenarios meet the target of over two million metric tons of avoided GHG emissions in 2040, or 60 percent of 2020 emissions.

[58] Direct testimony of Schoenheider, In the Matter of the Application of Public Service Company Of Colorado for Approval Of Its Combined Electric And Natural Gas Demand-Side Management and Beneficial Electrification Plan for Calendar Year 2023 (22A-0315EG), page 14 and 21 and the Public Utilities Commission of the State of Colorado. Comprehensive Settlement Agreement (No. 22A-0315EG), para 16.

Figure 13. Annual avoided GHG emissions by resource, Scenario 1

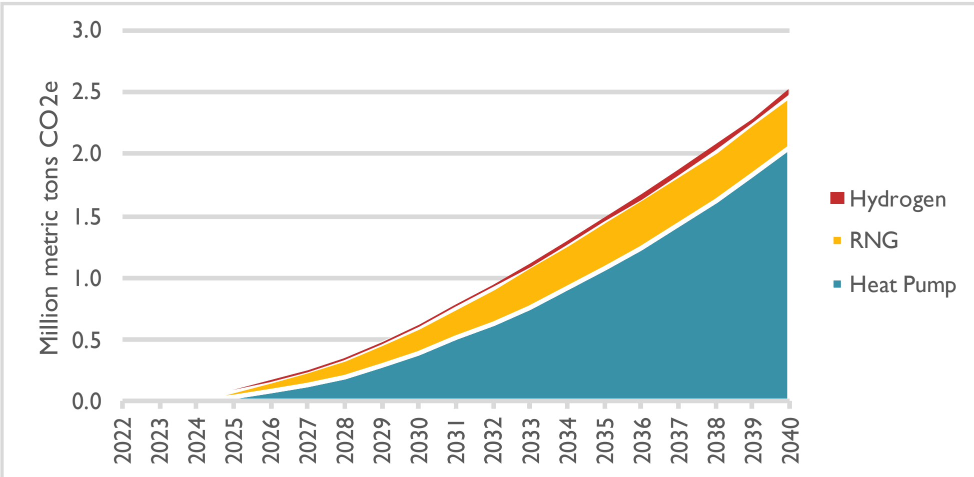


Figure 14. Annual avoided GHG emissions by resource, Scenario 2

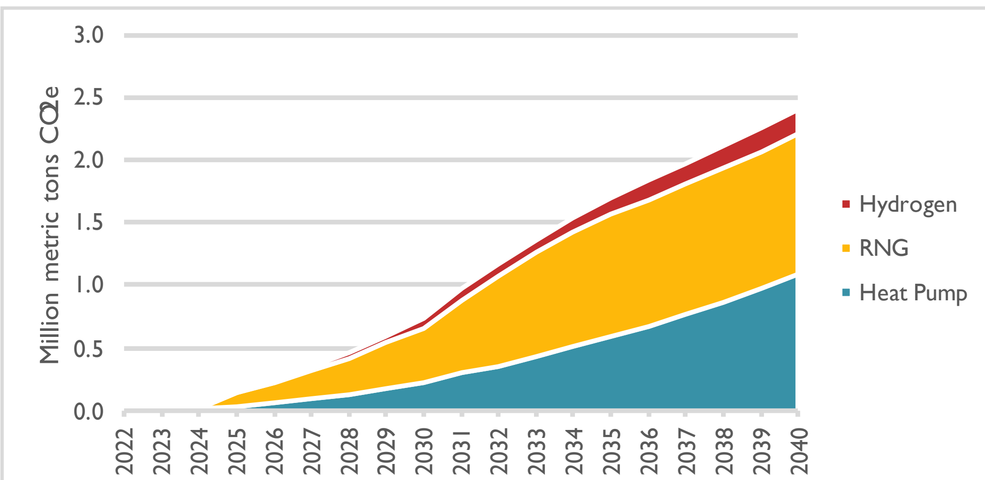


Figure 15 and Figure 16 show the annual cost of avoided emissions for each resource through 2040 for Scenario 1 and Scenario 2, respectively. Emissions reduction from heat pump incentives cost less than reduction from RNG and green hydrogen in all years except for a few years in Scenario 2 during which green hydrogen costs less than heat pump incentives due to the IRA incentives (Figure 16). Green hydrogen emissions reduction in Scenario 1 is initially cheaper than RNG (per ton) due to the IRA production tax credit, but it quickly becomes the most expensive resource per ton when the tax credit expires in 2034. On the other hand, green hydrogen prices in Scenario 2 are lower than the prices in Scenario 1 and stay lower than RNG prices for most of the years because RNG prices in Scenario 2 are higher than in Scenario 1. This is because Scenario 2 assumes a higher level of RNG resources with more expensive RNG stocks. Figure 17 shows the annual weighted average cost per ton of avoided emissions for each scenario. Both scenarios see an increase in the cost of carbon abatement over time, however Scenario 1 is much cheaper per ton in 2040 than Scenario 2.

Figure 15. Annual cost of avoided emissions by resource, Scenario 1

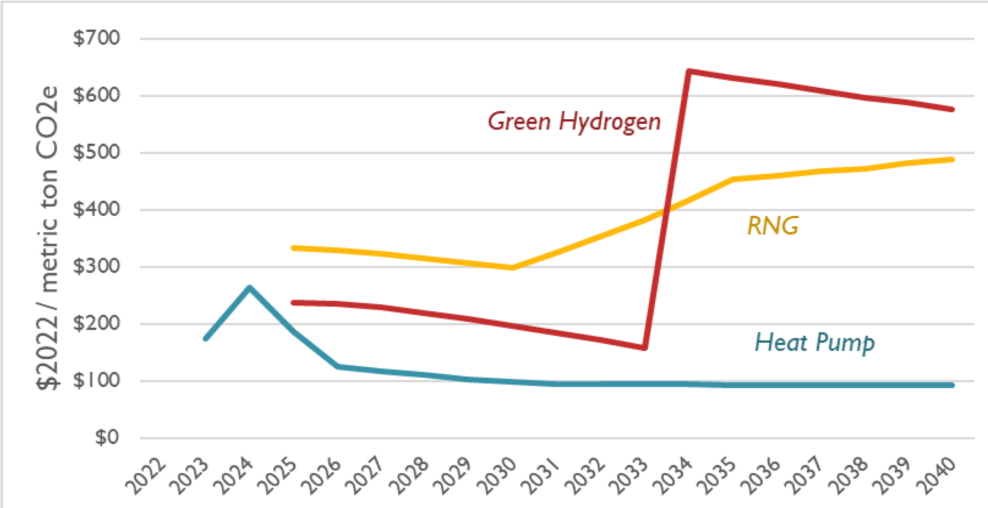


Figure 16. Annual cost of avoided emissions by resource, Scenario 2

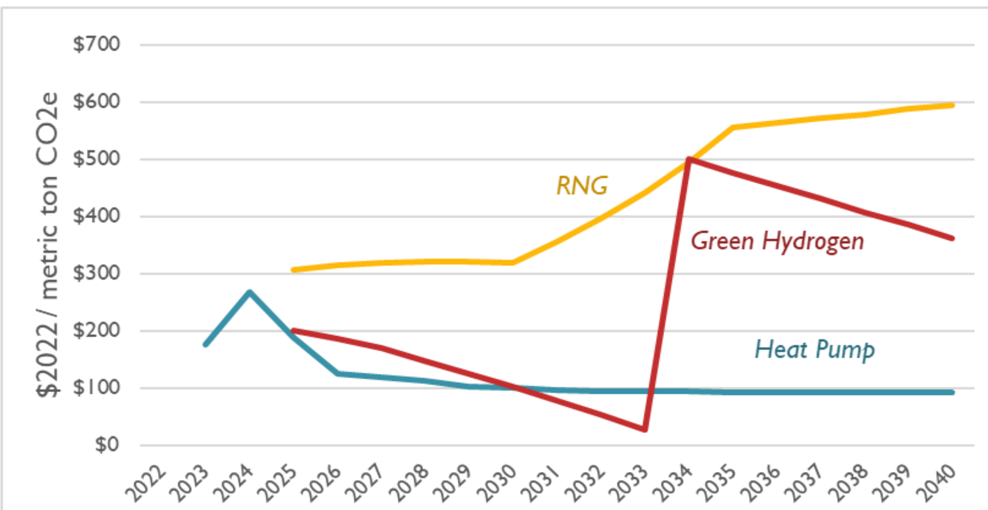


Figure 17. Annual average cost of avoided emissions by scenario

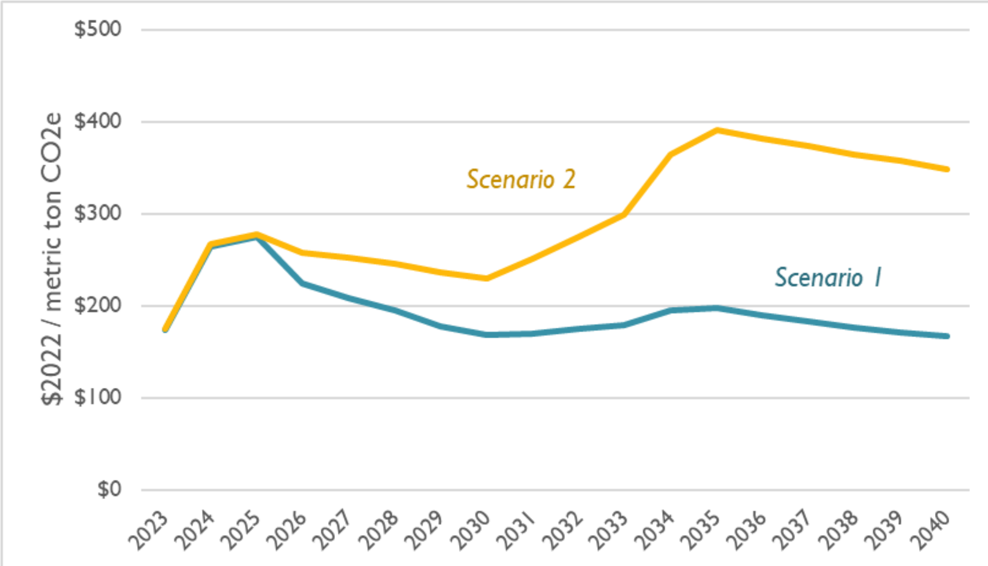


Table 9 summarizes the total present value (PV) of incremental utility costs, cumulative avoided emissions, and levelized utility cost per metric ton for each scenario. We discounted the total incremental utility costs using a real discount rate of 4.6 percent.[59] Overall, the Scenario 1 portfolio costs roughly half as much per ton of avoided emissions as Scenario 2. Note these cost estimates do not include (a) any changes in electric system costs or electric bill impacts in either scenario, (b) participant costs to adopt heat pumps, or (c) changes to annual capital, operating, maintenance, or fuel costs associated with the gas system due to building electrification.

Table 9. Emissions and costs by scenario through 2040

Scenario	**Incremental Cost (PV)** *(portfolio, all resources)*	**Total emissions saved** *metric tons CO2e*	**Portfolio levelized cost (PV)** *$/metric ton CO2e*
Scenario 1	$1,888,513,977	18,042,150	$182.02
Scenario 2	$3,818,006,834	19,866,267	$328.38

Furthermore, recall that these scenarios did not include the emissions reduction impact of avoided methane leaks from gas pipelines from electrification. Synapse conducted a sensitivity analysis to compare the cost per ton of emissions reductions for heat pumps for each scenario with and without methane leaks. To estimate the emissions impacts from avoided methane leaks, we assumed a methane leak rate of 2.3 percent based on a 2018 study by Alvarez et. al, and global warming potential factors of

[59] Based on Xcel Energy's current weighted average cost of capital of 6.7 percent from Colorado PUC Decision No C22-0642 and an inflation rate of 2 percent.

83 corresponding to a 20-year timeframe and 30 corresponding to a 100-year timeframe.[60] As shown in Table 10, accounting for avoided methane leaks reduces the cost per ton by nearly half. This is not because the utility costs for heat pumps are lower, but because the avoided emissions are greater.

Table 10. Heat pump cost of carbon abatement including and excluding pipeline methane leaks

Scenario	Value	No methane leaks	2.3% methane leak rate (20-year GWP impact)	2.3% methane leak rate (100-year GWP impact)
Scenario 1	*$/metric ton CO2e (PV)*	$94.42	$52.99	$73.63
	metric tons CO2e	13,224,118	23,468,486	16,924,508
Scenario 2	*$/metric ton CO2e (PV)*	$95.65	$53.53	$74.48
	metric tons CO2e	7,235,960	12,865,836	9,269,539

Synapse also conducted a sensitivity analysis of the effect of rebate amounts on the cost of carbon abatement via heat pumps. Heat pump cost per ton for each gas utility is shown in Table 11 below for two different rebate amounts, otherwise using the same model assumptions as Scenario 1. We assumed the high rebate to be $3,000 per unit for a heat pump and $600 for a HPWH, while the low rebate was $1,000 per unit for heat pumps and $300 for HPWH. We developed these ranges of rebates based on our review of the current heat pump and HPWH rebates available from the electric utilities whose jurisdictions overlap with the five gas utility jurisdictions selected for our analysis. As expected, an increase in utility rebate amounts results in a corresponding increase in cost per ton of avoided GHG emissions. Variations between utilities are due to varying emissions rates of electric utilities over time, different average COP for each state, and different customer demand potentials. Heat pump cost of carbon abatement is lowest in states with colder climates with greater demand for gas space heating like Colorado, where the heat pump displaces higher volumes of fossil gas. Southwest Gas has the highest cost per ton of avoided emissions from incentivizing heat pumps. This is in part due to the warmer climate and lower gas demand, and in part due to higher electricity grid emissions rates for NV Energy Electric compared to the other utilities. Notably, however, even with the high rebate level, Southwest Gas's cost to reduce emissions using heat pumps is lower than the costs using hydrogen or RNG.

[60] Alvarez et. al. 2018. "Assessment of methane emissions from the U.S. oil and gas supply chain." Science. DOI: 10.1126/science.aar7204. Available at: https://science.sciencemag.org/content/361/6398/186.

Table 11. Heat pump cost of carbon abatement by utility, high and low rebates, excluding pipeline methane leaks

Location	Gas Utility	Electric Utility	Low Rebate *\$/metric ton CO2e*	High Rebate *\$/metric ton CO2e*
Denver County, Colorado	Xcel Gas	Xcel Electric	\$40.18	\$107.63
Weld County, Colorado	Black Hills Gas	Tri-State Electric	\$43.06	\$115.33
Clark County, Nevada	Southwest Gas	NV Energy Electric	\$106.44	\$282.51
Washoe County, Nevada	NV Energy Gas	NV Energy Electric	\$45.64	\$121.13
Bernalillo County, New Mexico	NM Gas	PNM	\$50.10	\$133.87

4. Costs and Benefits of Commercial Building Decarbonization

This section provides a summary of Synapse's literature review of the costs and benefits of commercial building decarbonization measures. We focus on space and water heating end uses, with brief discussion of other end uses. This section also provides an overview of several decarbonization technologies and strategies that can contribute to decarbonization of thermal energy use in buildings. It then summarizes the costs of the leading technologies and concludes with a discussion of the associated benefits. Unlike the section on residential decarbonization measures, this section does not include any analysis of the impacts of commercial end-use decarbonization using the BDA tool; nor does this section include utility program costs for commercial decarbonization measures. Instead, the section provides information about full system installation costs for space and water heating decarbonization measures and the incremental measure costs relative to the cost of gas-equivalent, standard measures.

4.1. Commercial End-Use Consumption Estimates by State

Synapse developed commercial building-stock and end-use consumption estimates by building type and by state. This analysis highlights the areas of the largest GHG reduction opportunities, segmented by building types and end uses by state.

Data review

We evaluated various data sources, including EIA's Commercial Building Energy Consumption Survey (CBECS),[61] NREL's ComStock,[62] EIA's State Energy Data System,[63] and state- and utility-specific market

[61] U.S. EIA. 2023. *Commercial Buildings Energy Consumption Survey (CBECS) 2018 Survey Data*. Accessed May 3, 2023. Available at: https://www.eia.gov/consumption/commercial/data/2018/.

[62] NREL. 2023. *ComStock*. Accessed May 3, 2023. Available at: https://comstock.nrel.gov.

[63] U.S. EIA. 2023. *State Profiles and Energy Estimates*. Accessed May 3, 2023. Available at: https://www.eia.gov/state/?sid=US.

characterization and potential studies.[64] Synapse determined that jurisdiction-specific studies did not provide coverage of the entire building stock across each state and relevant fuels (utility studies typically include *either* natural gas or electricity, but not both). To ensure comprehensive and consistent data that can be compared across all three states and relevant fuels, Synapse selected the following data sources:

- **U.S. EIA CBECS 2018**:[65] The Commercial Buildings Energy Consumption Survey (CBECS) is a national sample survey that collects information on the stock of U.S. commercial buildings, their energy-related building characteristics, and their energy consumption and expenditures. Commercial buildings include all buildings in which at least half of the floorspace is used for a purpose that is not residential, industrial, or agricultural, so they include building types that might not traditionally be considered "commercial," such as schools, correctional institutions, and buildings used for religious worship. EIA first conducted CBECS in 1979 and currently publishes it on a quadrennial basis. The most recent survey is from 2018 and contains detailed information on 6,438 buildings.

- **NREL ComStock**:[66] The commercial building sector stock model, or ComStock, is a granular, bottom-up model that uses multiple data sources, statistical sampling methods, and building energy simulations to estimate the annual sub-hourly energy consumption of the commercial building stock across the United States. ComStock data identify where energy is consumed geographically, in what building types and end uses, and at what times of day. ComStock is based on detailed building data from three sources:

    - CoStar, a commercial building real estate intelligence broker

    - Homeland Infrastructure Foundation-Level Data (HIFLD), a Department of Homeland Security database that provides cross-agency information on critical infrastructure assets across the United States

    - U.S. EIA's CBECS

- **U.S. EIA State Energy Data System (SEDS)**: [67] SEDS provides historical time series of energy production, consumption, prices, and expenditures by state that are defined consistently over time and across sectors. Using SEDS, EIA develops estimates of energy consumption by energy sources, broad energy-consuming sectors, and by state. SEDS estimates energy consumption using data from surveys of energy suppliers that report

[64] Examples of studies Synapse reviewed include: Navigant Demand-Side Management Potential Study for Xcel Energy for 2018-2028 for the Publics Service Commission of Colorado; Colorado's 2021 Greenhouse Gas Pollution Reduction Roadmap; AEG 2020 Demand Side Management Potential Study for Public Service of New Mexico; Tetra Tech 2018 Demand Side Management Market Potential Study for NV Energy.

[65] U.S. EIA. 2023. *Commercial Buildings Energy Consumption Survey (CBECS) 2018 Survey Data*. Accessed May 3, 2023. Available at: https://www.eia.gov/consumption/commercial/data/2018/.

[66] NREL. 2023. *ComStock*. Accessed May 3, 2023. Available at: https://comstock.nrel.gov.

[67] U.S. EIA. 2023. *State Profiles and Energy Estimates*. Accessed May 3, 2023. Available at: https://www.eia.gov/state/?sid=US.

consumption, sales, or distribution of energy at the state level. Most of the SEDS estimates rely directly on collected state-level consumption data.

Methodology

Synapse developed commercial end-use consumption estimates by state, with detail by building use and fuel type. Our approach included a three-step process:

1. We prepared building stock data by building type and by state using ComStock data for all modeled major building types (14 total). For all other building types (8 total), we allocated known floor area for the Census Mountain Division from CBECS across the 8 states in the division; proportionate allocation to state-level estimates from ComStock.
2. We then developed end-use energy load profiles for all building types (22 total) by fuel type using CBECS microdata for the Mountain Division.
3. Finally, we apply the profiles' end-use energy load across the estimated floor area by state and by building type to develop total end-use energy estimates.

Synapse compared our results to EIA state-level energy use for commercial buildings to check the accuracy of our estimates. Synapse's estimate of Colorado energy use was within 1 percent of the EIA estimate; Nevada and New Mexico were 4 percent and 18 percent different than the EIA total, respectively. While Synapse's estimate for New Mexico has somewhat larger error, energy use can swing substantially year-over-year due to changes in the weather or other anomalies such as an economic recession or the Covid-19 pandemic.

Results

Table 12 provides estimates of floor area by building type for the dominant types. For additional detail on other building types, refer to Appendix A. The five most common building types—education, office, warehouse, retail, and public assembly—represent nearly half of the total building area in each state. Thus, it is important to identify decarbonization pathways and highlight case examples for each type.

Table 12. Floor area by commercial building type and by state

Building type group (ordered by floor area)	Building type	Gross floor area (sqft)		
		Colorado	New Mexico	Nevada
Education	Primary school	132,211,564	47,795,159	60,579,128
	Secondary school	68,510,409	25,201,721	22,805,963
	Other education	28,436,762	9,384,814	15,989,272
	Small hotel	18,327,669	8,596,193	26,094,685
Office	Large office	36,267,437	8,781,937	8,585,657
	Medium office	110,529,764	20,188,429	32,503,048
	Small office	85,790,841	36,769,455	44,817,471
Warehouse and Storage	Warehouse	205,288,105	27,412,702	131,453,143
Mercantile	Retail standalone	72,843,987	32,777,657	40,173,202
	Retail stripmall	74,575,677	23,068,865	51,904,703
Public assembly	Public assembly	146,114,970	48,221,449	82,156,753

All other building types	All other building types	1,008,137,445	370,118,389	615,985,803
Total		**1,968,706,961**	**649,720,577**	**1,106,954,142**

The potential emissions reductions from electrifying commercial space heating, water heating, and cooking are substantial: Assuming 100 percent emissions-free electricity displaces natural gas use for these three end uses, the annual avoided emissions for Colorado, Nevada, and New Mexico are 2.5 million metric tons of CO2e (MMTCO2e), 1.5 MMTCO2e, and 0.6 MMTCO2e, respectively.

Table 13 presents end-use commercial energy consumption by fuel type and by end use for each state. Table 14 disaggregates the natural gas consumption by end use. Appendix A provides greater detail, including end-use energy by fuel type for each building type. Electricity represents the largest share of building energy use across the three states (56 percent), followed by natural gas (33 percent). Space heating is the largest end use of energy (34 percent), of which natural gas accounts for nearly two-thirds of the consumption. Cooking and water heating are the next-largest uses of natural gas. In commercial buildings, decarbonization efforts should focus on these largest end uses of fossil fuels, as the electricity grid is decarbonizing relatively rapidly.

The potential emissions reductions from electrifying commercial space heating, water heating, and cooking are substantial: Assuming 100 percent emissions-free electricity displaces natural gas use for these three end uses, the annual avoided emissions for Colorado, Nevada, and New Mexico are 2.5 million metric tons of CO2e (MMTCO2e), 1.5 MMTCO2e, and 0.6 MMTCO2e, respectively.[68]

Table 13. Energy consumption by fuel type and by end use, billion Btu

Energy consumption	Colorado	Nevada	New Mexico
By fuel			
Electricity	82,190	47,583	29,307
Natural gas	47,255	28,933	17,570
Other fuels	17,380	9,443	5,950
Total	146,825	85,959	52,827
By end use			
Heating	51,495	28,921	17,488
Lighting	18,941	10,723	6,404
Ventilation	15,428	9,139	5,963
Cooking	11,228	7,810	4,946
Cooling	7,826	4,438	2,674
Refrigeration	6,498	3,945	2,260
Water heating	5,243	3,576	2,201
Computing	6,148	3,631	2,320
Office equipment	1,143	652	397
Miscellaneous	22,873	13,125	8,175
Total	146,825	85,959	52,827

[68] Based on an emission factor of 0.053 metric ton of CO_2 per MMBtu of on-site gas combustion.

Table 14. Natural gas consumption by end use, billion Btu

End use	Colorado	Nevada	New Mexico
Heating	32,505	18,631	11,066
Cooling	34	15	12
Water heating	3,832	2,676	1,665
Cooking	9,812	6,932	4,346
Misc.	1,072	680	482
Total	47,255	28,933	17,570

4.2. Commercial Building Decarbonization: Technologies, Costs, and Benefits

Synapse conducted a literature review of the costs and benefits of commercial building decarbonization measures with a focus on the most prevalent building types. Consistent with our review and analysis of the residential sector in Section 2 and Section 3, we summarize available information on space and water heating end uses, with brief discussion of other end uses. This section provides an overview of several decarbonization technologies and strategies that can contribute to decarbonization of thermal energy use in buildings. It then summarizes the costs of the leading technologies and concludes with a discussion of the associated benefits.

This section does not address the possible use of RNG and green hydrogen blending as options to reduce emissions in the commercial building sector because these options are fully discussed in the preceding sections. RNG and green hydrogen potential is independent of the sectors in which the fuels are used, although there could be competition for this limited resource among different gas users. RNG and green hydrogen blended into the natural gas pipeline system would serve all downstream customers, including both residential and commercial customers. (Gas utilities could use accounting methods to assign the costs and benefits of the fuels to different customer groups or classes.)

Decarbonization technologies and strategies

Heat Pumps for Space Heating

Advances in heat pump technology—including cold-climate heat pumps, high-efficiency models, and decreases in cost over time—have made heat pumps a reliable and often cost-effective technology to replace fossil-fuel-based heaters. Annual heat pump sales in the United States increased by a factor of 2.3 between 2012 and 2021.[69] Numerous types of heat pumps are available in the market today. Heat pumps are primarily categorized by the heat source they draw from and how the heat is distributed in the buildings. Predominant technologies include air-source heat pumps (ASHPs), ground-source heat pumps (GSHPs), water-source heat pumps (WSHPs), and air-to-water heat pumps (AWHPs).

[69] Air-Conditioning, Heating, and Refrigeration Institute. *Air-Source Heat Pumps*. Accessed May 3, 2023. Available at: https://www.ahrinet.org/analytics/research/historical-data/central-air-conditioners-and-air-source-heat-pumps.

Air-Source Heat Pumps

ASHPs are the most common heat pump technology for space heating. These systems transfer heat between a building and the outside air. For this reason, the efficiency and heating capacity of ASHPs decreases in cold weather and conventional ASHPs may use backup electric resistance heating. However, cold climate ASHPs that are readily available in the market can provide ample heat even under freezing temperatures without a backup heater.[70]

ASHP systems include various configurations, such as:

1. **Ducted split-system heat pumps** have an outdoor condenser and an air handling unit in the building to deliver heating or cooling through ducts similar to forced-air gas furnaces. Ducted ASHPs can be a suitable alternative to the aging gas furnaces prevalent in residential and small-to-medium commercial buildings.
2. **Packaged or rooftop unit (RTU) heat pumps** have all the components necessary for heating, cooling, and air circulation combined into a single system—usually mounted directly onto the building. RTUs are the most ubiquitous space heating technology for commercial buildings in the United States, serving over 48 billion square feet of floor space.[71] One-for-one replacement of gas-fired RTUs with heat-pump RTUs could quickly electrify a vast pool of existing buildings, with limited upfront cost or technical challenges.[72]
3. **Mini-split ductless heat pumps** use outdoor condensers and refrigerant pipes to deliver heating or cooling to each room where an indoor unit is installed. Because they use small refrigerant pipes and are relatively easy to install, they are suitable for heating system retrofits where ducts are not available. They also use variable speed compressors, which allow them to operate more efficiently and quietly than standard ducted ASHPs and to provide superior temperature controls.
4. **Variable refrigerant flow (VRF) heat pumps** distribute heating and cooling to numerous indoor units through a main refrigerant line from a single outdoor system. VRFs can be configured to provide heating and cooling simultaneously in different rooms by adding a heat recovery system, and thus are beneficial for buildings with diversely loaded zones. VRFs are generally suitable for medium-to-large commercial buildings, but especially for mid- and high-rise multifamily buildings, offices, schools, and lodging.
5. **Packaged terminal heat pumps** are all-in-one systems installed on an exterior wall. They are often installed in hotels and small apartment units. Compared to other heat pump systems, packaged terminal heat pumps are less efficient.

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[70] A Vermont field study observed that cold climate ASHPs operated at outdoor temperatures of 5°F with a COP of 1.6 and at –20° F with a COP above 1.0. See: Cadmus (2017). *Evaluation of Cold Climate Heat Pumps in Vermont.* Prepared for the Vermont Public Service Department. Page 24. Available at: https://publicservice.vermont.gov/sites/dps/files/documents/Energy_Efficiency/Reports/Evaluation%20of%20Cold%20Climate%20Heat%20Pumps%20in%20Vermont.pdf.

[71] U.S. EIA. 2022. Commercial Building Energy Consumption Survey, 2018. Available at: https://www.eia.gov/consumption/commercial/data/2018/index.php?view=characteristics.

[72] Fathollahzadeh, M. H. and A. Tilak. 2022. The Economics of Electrifying Buildings: Medium-Size Commercial Retrofits. RMI. Available at: https://rmi.org/insight/economics-of-electrifying-buildings-mid-size-commercial-retrofits/.

Ground-Source Heat Pumps

GSHPs transfer heat between buildings and the ground using a series of buried pipes or wells. This approach provides better performance than ASHPs in cold temperatures because the ground has a higher temperature than outdoor air during the winter. This factor allows GSHPs to achieve COPs in the range of 3 to 5 for closed-loop systems.[73] GSHPs also typically provide better cooling performance than ASHPs in hot weather because the ground is cooler than outdoor air. GSHPs are more costly than ASHPs because they require excavation, trenching, or drilling to install underground pipes. However, total lifecycle costs for GSHPs can be lower than ASHPs or fossil-based heating equipment because they use less energy.[74]

Traditional GSHP systems serve a single building; however, a few jurisdictions in the United States—including Massachusetts, New York, and California—are piloting approaches to GSHP systems shared by a cluster of buildings. This approach is often called *networked geothermal* or *geo-micro-districts*. Networked geothermal systems provide superior efficiency, with COPs of 5 or even higher.[75]

Water-Source Heat Pumps

WSHPs use a water source—such as a well, lake, pond, aquifer, or wastewater system—as a heat source or heat sink. As with GSHPs, this technology can achieve higher efficiencies than other technologies because the water provides an excellent heat reservoir.

Air-to-Water Heat Pumps

Like ASHPs, AWHPs exchange heat between a building and the outdoor air. However, AWHPs use a water-based system to transfer heat within the building instead of forced air. AWHPs can play an important role in decarbonizing existing residential and commercial buildings with hot water heating systems (such as gas or fuel oil boilers) because the AWHP can connect into the hot water distribution system, avoiding costly system replacement.

Heat Pump Water Heaters

Various HPWH technologies are available on the market today. The most popular HPWH technology is a hybrid HPWH, which integrates a heat pump, backup electric resistance coils, and a hot water storage tank into a single unit. Another HPWH technology is a split heat pump water heater with an outdoor compressor. These systems offer more flexibility for placing the indoor unit within the living space.

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[73] U.S. Environmental Protection Agency and U.S. Department of Energy. 2022. *ENERGY STAR Most Efficient 2022 — Geothermal Heat Pumps*. Accessed May 3, 2023. Available at: https://www.energystar.gov/products/energy_star_most_efficient_2020/geothermal_heat_pumps.

[74] U.S. Department of Energy. 2022. *Choosing and Installing Geothermal Heat Pumps*. Accessed May 3, 2023. Available at: https://www.energy.gov/energysaver/choosing-and-installing-geothermal-heat-pumps.

[75] Buro Happold Engineering. 2019. *Geo Micro District: Feasibility Study*. Prepared for HEET. Available at: https://heet.org/wp-content/uploads/2019/11/HEET-BH-GeoMicroDistrict-Final-Report-v2.pdf.

Large-scale HPWHs are available for commercial buildings.[76] HPWH configurations for commercial buildings can be quite different from those for single-family homes, because commercial buildings have greater variation in water use and building layout and can utilize a wider range of heat sources.

Solar water heaters, which capture thermal energy from the sun and use it to heat water for domestic use, are another option for low-carbon water heating. In most regions of the United States, solar water heaters have the potential to supply only part of a building's water heating load and must be paired with another heat source. Freezing temperatures present maintenance challenges.

Other End Uses

Electric resistance and induction cooktops are already widely available to consumers and have many benefits compared to gas alternatives. In addition to reducing GHG emissions, induction cooking can offer more precise cooking temperatures and shorter cook times than gas stoves, as well as easier cleaning and reduced burn risk. Electric ovens, griddles, and fryers are also available to replace gas cooking equipment. Electric clothes dryers use resistive heating or heat pumps to dry clothes, instead of burning natural gas or propane. While data are lacking for commercial buildings, 79 percent of homes in the Mountain South census division already use electricity for clothes drying.[77]

District Energy Systems

Eliminating emissions from district energy systems requires incorporating carbon-free energy sources. A primary option is to use renewable electricity to power heat pumps, heat-recovery chillers (cooling equipment that captures and repurposes rejected heat), electric boilers, or a combination of these technologies. Air-to-water, ground-source, and water-loop heat pumps can efficiently provide hot water to a district heating system.[78] Another decarbonization approach that is gaining traction in various jurisdictions is installing low-temperature, networked geothermal systems to heat and cool groups of buildings.[79] In addition to these electrification measures, district energy systems can also utilize waste heat, solar thermal energy, and alternative fuels. Additionally, district energy can work as a large thermal battery to absorb excess renewable energy (such as wind power overnight) using heat pumps and thereby facilitate the integration and deployment of renewable generation.[80]

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[76] Redwood Energy. 2022. *A Pocket Guide to All-Electric Retrofits of Commercial Buildings*. Available at: https://www.redwoodenergy.net/research/redwood-energys-pocket-guide-to-all-electric-commercial-retrofits.

[77] U.S. Energy Information Administration. 2020. "Residential Energy Consumption Survey." *Table HC3.7.* Available at: https://www.eia.gov/consumption/residential/data/2020/.

[78] Lund, H., Werner, S., Wiltshire, R., Svendsen, S., Thorsen, J.E., Hvelplund, F. and Mathiesen, B.V., 2014. 4th Generation District Heating (4GDH): Integrating smart thermal grids into future sustainable energy systems. Energy, 68, pp.1-11.

[79] Buro Happold Engineering. 2019. GeoMicroDistrict Feasibility Study. Prepared for HEET. Available at: https://heet.org/energy-shift/geomicrodistrict-feasibility-study/.

[80] U.N. Environment Programme. 2015. District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable Energy. Available at: https://www.unep.org/resources/report/district-energy-cities-unlocking-potential-energy-efficiency-and-renewable-energy.

Decarbonization Technology Costs

Synapse estimated the incremental capital cost to electrify commercial buildings. We identified appropriate baseline and replacement measures with costs using data from the California Electronic Technical Reference Manual (eTRM).[81] We adjusted material and labor costs to national averages using RSMeans locational factors. Note that the cost data presented here reflect the cost of implementing different technologies and are not the utility program costs (as used in the BDA and residential sector analysis presented in Section 3).

Table 15 and Table 16 present total cost and incremental cost data for water heating and space heating measures based on average material and labor costs in the United States. To estimate state- or city-specific costs, we multiplied the national average costs by the locational cost factors that we obtained from an HVAC industry data source called *RSMeans*.[82] Note, incremental costs are the difference between baseline like-for-like replacement of fossil-fuel-using equipment and the total cost of the decarbonization measure. Because heat pumps provide both space heating and cooling, the baseline measure costs include like-for-like replacement of both heating and cooling equipment.

The up-front capital cost of installing heat pump water heaters and heat pumps for space heating is higher than the comparable natural gas technologies. The median incremental cost across the systems we evaluated is 99 percent for heat pump water heating and 24 percent for space heating. However, heat pump technologies are becoming less expensive with time.[83]

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[81] California Electronic Technical Reference Manual (eTRM), http://www.caltf.org/etrm-overview.

[82] Location Factors from 2021 RSMeans data Cost Book, Available at: https://www.rsmeans.com/media/wysiwyg/quarterly_updates/2021-CCI-LocationFactors-V2.pdf.

[83] Jadun, P., McMillan, C., Steinberg, D., Muratori, M., Vimmerstedt, L. and Mai, T. 2017. *Electrification futures study: End-use electric technology cost and performance projections through 2050.* National Renewable Energy Lab. Available at: https://www.nrel.gov/docs/fy18osti/70485.pdf.

Table 15. Commercial heat pump water heater installation costs, relative to the baseline appliance (2022$)

Heat Pump Water Heater Description (Electric)	Baseline Water Heater Description (Natural Gas)	Measure Labor	Measure Material	Full Measure Cost	Baseline Labor Cost	Baseline Material Cost	Full Baseline Installation Cost	Incre-mental Cost	Per
50 gal, UEF = 3.30	Tankless, UEF = 0.81	$489	$1,891	$2,380	$339	$1,059	$1,398	$982	Each
50 gal, UEF = 3.50	Tankless, UEF = 0.81	$489	$1,891	$2,380	$339	$1,059	$1,398	$982	Each
50 gal, UEF = 3.75	Tankless, UEF = 0.81	$489	$1,977	$2,467	$339	$1,059	$1,398	$1,069	Each
50 gal, UEF = 3.30	Storage, 30 gal, UEF = 0.60	$489	$1,891	$2,380	$305	$757	$1,062	$1,318	Each
50 gal, UEF = 3.50	Storage, 30 gal, UEF = 0.60	$489	$1,891	$2,380	$305	$757	$1,062	$1,318	Each
50 gal, UEF = 3.75	Storage, 30 gal, UEF = 0.60	$489	$1,977	$2,467	$305	$757	$1,062	$1,405	Each
50 gal, UEF = 3.30	Storage, 40 gal, UEF = 0.64	$489	$1,891	$2,380	$321	$817	$1,138	$1,242	Each
50 gal, UEF = 3.50	Storage, 40 gal, UEF = 0.64	$489	$1,891	$2,380	$321	$817	$1,138	$1,242	Each
50 gal, UEF = 3.75	Storage, 40 gal, UEF = 0.64	$489	$1,977	$2,467	$321	$817	$1,138	$1,329	Each
50 gal, UEF = 3.30	Storage, 50 gal, UEF = 0.63	$489	$1,891	$2,380	$339	$1,088	$1,426	$953	Each
50 gal, UEF = 3.50	Storage, 50 gal, UEF = 0.63	$489	$1,891	$2,380	$339	$1,088	$1,426	$953	Each
50 gal, UEF = 3.75	Storage, 50 gal, UEF = 0.63	$489	$1,977	$2,467	$339	$1,088	$1,426	$1,040	Each
80 gal, UEF = 3.30	Storage, 75 gal, UEF = 0.59	$568	$2,771	$3,338	$406	$2,285	$2,692	$646	Each
80 gal, UEF = 3.50	Storage, 75 gal, UEF = 0.59	$568	$2,913	$3,481	$406	$2,285	$2,692	$789	Each
80 gal, UEF = 3.75	Storage, 75 gal, UEF = 0.59	$568	$3,260	$3,828	$406	$2,285	$2,692	$1,136	Each
65 gal, UEF = 3.30	Storage, 60 gal, UEF = 0.61	$524	$2,316	$2,840	$359	$1,088	$1,446	$1,394	Each
65 gal, UEF = 3.50	Storage, 60 gal, UEF = 0.61	$524	$2,398	$2,922	$359	$1,088	$1,446	$1,475	Each
65 gal, UEF = 3.75	Storage, 60 gal, UEF = 0.61	$524	$2,651	$3,174	$359	$1,088	$1,446	$1,728	Each
75–100 gal, UEF = 3.0	Storage, 80 gal, Et = 0.80	$18	$134	$152	$34	$50	$84	$68	kBtuh
≥ 100 gal, COP = 4.3	Storage, 100 gal, Et = 0.80	$13	$168	$181	$32	$47	$79	$101	kBtuh
≥ 100 gal, COP = 4.3	Tankless, 76–200 kBtuh, Et = 0.80	$13	$168	$181	$32	$8	$39	$142	kBtuh
≥ 100 gal, COP = 4.3	Tankless, > 200 kBtuh, Et = 0.80	$13	$168	$181	$40	$16	$56	$125	kBtuh

Sources: RSMeans; California Electronic Technical Reference Manual (eTRM), http://www.caltf.org/etrm-overview.
Incremental cost = measure labor + measure material – baseline labor – baseline material
kBtuh = thousand British thermal units per hour; UEF = uniform energy factor; Et = thermal efficiency; COP = coefficient of performance

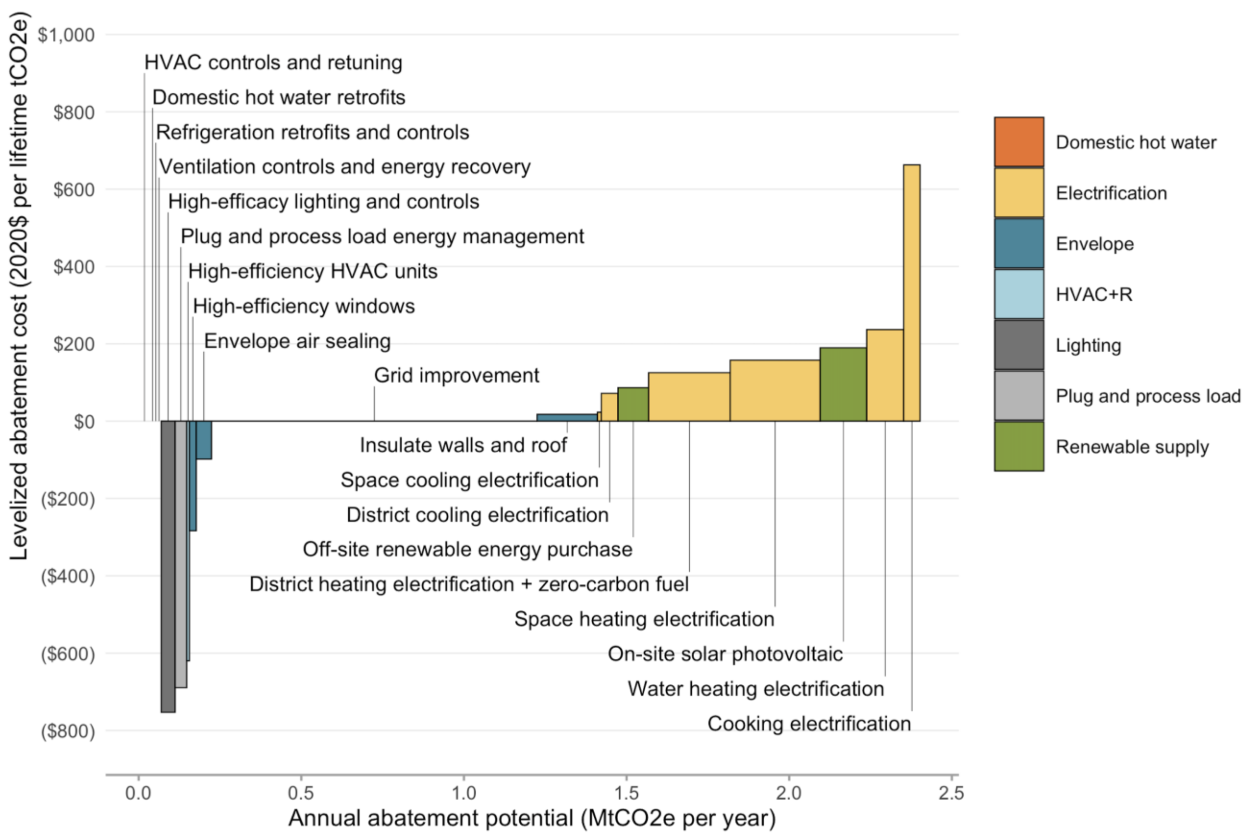
Table 16. Commercial heat pump installation costs, relative to the baseline appliance (2022$)

Heat Pump Description (Electric)	Baseline Heating Description (Natural Gas)	Measure Labor	Measure Material	Full Measure Cost	Baseline Labor Cost	Baseline Material Cost	Full Base Cost	Incre-mental Cost	Per
Packaged, < 65 kBtuh, SEER16 HSPF8.5	Packaged, < 65 kBtuh with furnace	$503	$1,542	$2,045	$422	$1,182	$1,604	$441	Ton
Packaged, < 65 kBtuh, SEER17 HSPF9.0	Packaged, < 65 kBtuh with furnace	$503	$1,969	$2,472	$422	$1,182	$1,604	$868	Ton
Packaged, 1 stage, < 65 kBtuh, SEER15 HSPF8.2	Packaged, < 65 kBtuh with furnace	$503	$1,180	$1,683	$422	$1,182	$1,604	$79	Ton
Packaged, 2 stage, < 65 kBtuh, SEER15 HSPF8.2	Packaged, < 65 kBtuh with furnace	$503	$1,180	$1,683	$422	$1,182	$1,604	$79	Ton
Split, < 65 kBtuh, 15 SEER HSPF8.7	Split < 65 kBtuh with furnace	$503	$1,146	$1,649	$422	$909	$1,331	$319	Ton
Split, < 65 kBtuh, SEER16 HSPF9.0	Split < 65 kBtuh with furnace	$503	$1,165	$1,668	$422	$909	$1,331	$338	Ton
Split, < 65 kBtuh, SEER17 HSPF9.4	Split < 65 kBtuh with furnace	$503	$1,487	$1,990	$422	$909	$1,331	$660	Ton
Split, < 65 kBtuh, 18 SEER HSPF9.7	Split < 65 kBtuh with furnace	$503	$1,778	$2,281	$422	$909	$1,331	$950	Ton
Packaged, 135 to 239 kBtuh, IEER15.5 COP3.2	Packaged, 135–239 kBtuh with furnace	$369	$766	$1,135	$238	$887	$1,125	$10	Ton
Packaged, 240 to 760 kBtuh, IEER14.0 COP3.4	Packaged, 240–760 kBtuh with furnace	$366	$906	$1,271	$226	$901	$1,127	$144	Ton
Packaged, 65 to 134 kBtuh, IEER16.0 COP3.4	Packaged, 65–134 kBtuh with furnace	$423	$825	$1,248	$309	$814	$1,123	$126	Ton

Sources: RSMeans; California Electronic Technical Reference Manual (eTRM), http://www.caltf.org/etrm-overview.
Incremental cost = measure labor + measure material – baseline labor – baseline material
kBtuh = thousand British thermal units per hour; COP = coefficient of performance; HSPF = Heating Seasonal Performance Factor; SEER = Seasonal Energy Efficiency Ratio;, IEER = Integrated Energy Efficiency Ratio

In prior work, Synapse estimated the levelized abatement cost of commercial space heating to be $158 per ton as the grid approaches 80 percent clean electricity;[84] water heating and cooking reduce emissions at a cost of $237 and $663 per ton, respectively (2020 USD).[85, 86] As shown in Figure 18, these electrification measures represent a large fraction of the building decarbonization potential. The U.S. EPA estimates the social cost of CO_2 emissions will be $230 (2020 USD) per ton in 2030 (using a 2.0 percent discount rate) and will double over the following half century.[87] This indicates that commercial space heating and water heating electrification are or will soon be societally cost-effective means of GHG mitigation.

Figure 18. Levelized abatement curve for commercial buildings, 80 percent clean electricity supply



[84] Eash-Gates, P, K. Takahashi, D. Goldberg, A. Hopkins, S. Kwok. 2021. *Boston Building Emissions Performance Standard*. Prepared by Synapse Energy Economics for City of Boston. Available at: https://www.synapse-energy.com/sites/default/files/Boston_Performance_Standard_Technical_Methods_2021-02-18_20-013.pdf. Note again that these costs are not utility program costs, which would generally be a fraction of the incremental cost.

[85] Ibid.

[86] These values are shown in $2020 to be consistent with the dollar value used in the original report.

[87] U.S. EPA. 2022. *EPA External Review Draft of Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances.* Available at: https://www.epa.gov/system/files/documents/2022-11/epa_scghg_report_draft_0.pdf.

Source: Eash-Gates, P, K. Takahashi, D. Goldberg, A. Hopkins, S. Kwok. 2021. Boston Building Emissions Performance Standard. Prepared by Synapse Energy Economics for City of Boston. Available at: ***https://www.synapse-energy.com/sites/default/files/Boston_Performance_Standard_Technical_Methods_2021-02-18_20-013.pdf***

Benefits of electrification

Reducing use of fossil fuels in buildings not only lowers GHG emissions, but it also provides co-benefits which may also be differentiators between electrification and lower-GHG combustion fuels. Importantly, switching away from combustion reduces indoor and outdoor air pollutants that contribute to and exacerbate a variety of negative health and environmental impacts.[88,89] This is true for a range of pollutants: nitrogen oxides (NO_X), carbon monoxide (CO), methane (CH_4), nitrous oxide (N_2O), volatile organic compounds (VOC), trace amounts of sulfur dioxide (SO_2), and particulate matter (PM). Further, these combustion byproducts include precursors of ground-level ozone or photochemical smog. As a result, electrifying commercial building heating and water heating would provide additional co-benefits for air quality.

Burning gas in buildings causes adverse health impacts (e.g., increased respiratory symptoms, asthma attacks, and hospital admissions in people with asthma), largely due to the associated NO_X emissions.[90] Reductions in indoor and outdoor air pollution improve health outcomes. Such benefits include lower rates of mortality, cardiovascular disease, respiratory disease, emergency room visits, restricted physical activity, and lost work. The need for reducing indoor air pollution is underscored by recent work showing the prevalence of unvented combustion in low-income areas and the negative health impacts that this can cause.[91]

Code requirements for venting combustion byproducts from fossil fuels in commercial kitchens are substantial. Many electric kitchen appliances do not require any ventilation system and can perform multiple functions; such equipment can save space, reduce installation costs, and lower energy costs for ventilation and conditioning of makeup air.[92] Induction cooking equipment also offers a wide range of benefits: reduced risk of burns to employees; improved food quality; reduced cleaning labor; lower utility bills; and cooking faster, hotter, and more efficiently.[93]

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[88] Lin, W., Brunekreef, B. and U. Gehring. 2013. "Meta-analysis of the effects of indoor nitrogen dioxide and gas cooking on asthma and wheeze in children." *International journal of epidemiology*, 42(6), pp.1724-1737.

[89] Buonocore, J.J., Salimifard, P., Michanowicz, D.R. and J.G. Allen. 2021. "A decade of the US energy mix transitioning away from coal: historical reconstruction of the reductions in the public health burden of energy." *Environmental Research Letters*, *16*(5), p.054030.

[90] Seals, B., Krasner, A. 2020. *Health Effects from Gas Stove Pollution*. Rocky Mountain Institute, Physicians for Social Responsibility, Mothers Out Front, and Sierra Club. Available at: https://rmi.org/insight/gas-stoves-pollution-health/.

[91] Holm, S.M., Balmes, J., Gillette, D., Hartin, K., Seto, E., Lindeman, D., Polanco, D. and E. Fong. 2018. "Cooking behaviors are related to household particulate matter exposure in children with asthma in the urban East Bay Area of Northern California." *PloS one*. Available at: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0197199.

[92] Redwood Energy. 2022. *A Pocket Guide to All-Electric Retrofits of Commercial Buildings*. Available at: https://www.redwoodenergy.net/research/redwood-energys-pocket-guide-to-all-electric-commercial-retrofits.

[93] Ibid.

Replacing existing gas heating equipment with heat pumps can also add cooling to buildings that do not already have cooling equipment. Thus, space heating electrification has the potential to reduce heat-related illness in the region, an area of increasing risk due to climate change. According to CBECS 2018, approximately 17 percent of commercial building floor area in the Mountain Census Division lacks air conditioning.[94] Related, HPWH can provide free cooling and dehumidification to interior spaces,[95] which is especially beneficial for commercial buildings with high internal heat loads.

Finally, building decarbonization initiatives can create jobs through paired investments in workforce development and training programs that target residents of communities where building investments are most needed. Compared with investment in fossil fuels, renewables and building retrofits create between two and three times as many jobs for the same quantity of spending.[96]

Summary

In sum, commercial buildings use natural gas predominantly for space heating, water heating, and cooking. Electrifying those end-uses and reducing natural gas use can provide substantial emission reductions. In the three states, Colorado, Nevada, and New Mexico, replacing natural gas use for those three end uses with electric equipment could reduce annual emissions by 2.5 MMTCO2e, 1.5 MMTCO2e, and 0.9 MMTCO2e, respectively. The types of equipment systems that use fossil fuels in commercial buildings are more diverse in the commercial sector than the residential sector, and the incremental capital cost per system is higher; nonetheless, the resulting emission reductions are cost-effective when compared with the social cost of carbon. In addition, by avoiding combustion of natural gas, electrification can improve indoor air quality, outdoor air quality, and health outcomes.

[94] U.S. EIA. 2023. *Commercial Buildings Energy Consumption Survey (CBECS) 2018 Survey Data*. Accessed May 3, 2023. Available at: https://www.eia.gov/consumption/commercial/data/2018/.

[95] Redwood Energy. 2022. *A Pocket Guide to All-Electric Retrofits of Commercial Buildings*. Available at: https://www.redwoodenergy.net/research/redwood-energys-pocket-guide-to-all-electric-commercial-retrofits.

[96] Garrett-Peltier, H., 2017. "Green versus brown: Comparing the employment impacts of energy efficiency, renewable energy, and fossil fuels using an input-output model." *Economic Modelling*, *61*, pp.439-447.

Appendix A. Detailed Commercial Building Data

Appendix A presents detailed building area information by state for each building type.

Table 17. Floor area by commercial building type by state

Building type group	Building type	Gross floor area (sqft)		
		Colorado	New Mexico	Nevada
Education	Primary school	132,211,564	47,795,159	60,579,128
	Secondary school	68,510,409	25,201,721	22,805,963
	Other education	28,436,762	9,384,814	15,989,272
Food sales	Food sales	16,676,047	5,503,496	9,376,520
Food service	Full-service restaurant	21,833,486	9,015,818	11,617,084
	Quick service restaurant	4,476,949	1,896,013	3,601,517
Healthcare	Hospital	19,562,514	21,321,827	24,157,735
	Outpatient	28,157,169	9,209,465	16,325,870
Lodging	Large hotel	83,489,401	45,403,299	66,213,145
	Small hotel	18,327,669	8,596,193	26,094,685
Mercantile	Retail standalone	72,843,987	32,777,657	40,173,202
	Retail stripmall	74,575,677	23,068,865	51,904,703
Office	Large office	36,267,437	8,781,937	8,585,657
	Medium office	110,529,764	20,188,429	32,503,048
	Small office	85,790,841	36,769,455	44,817,471
Public assembly	Public assembly	146,114,970	48,221,449	82,156,753
Public order and safety	Public order and safety	25,494,792	8,413,894	14,335,077
Religious worship	Religious worship	90,690,511	29,930,047	50,992,981
Service	Service	118,430,028	39,084,753	66,590,210
Warehouse and Storage	Warehouse	205,288,105	27,412,702	131,453,143
Other	Other	554,277,420	182,924,860	311,656,178
Vacant	Vacant	26,721,459	8,818,723	15,024,801
Total		**1,968,706,961**	**649,720,577**	**1,106,954,142**

Table 18, Table 19, and Table 20 present commercial end-use data by state, broken down by fuel type and building type.

Table 18. End-use energy consumption by building type and fuel, Colorado

Building type	Floor area (sqft)	Electricity										Natural gas					Other fuels		
		Heating use	Cooling use	Ventil-ation use	Water heating use	Lighting use	Cooking use	Refrig-eration use	Office equip. use	Com-puting use	Misc. use	Heating use	Cooling use	Water heating use	Cooking use	Misc. use	Heating use	Water heating use	Misc. use
Education	229,158,735	210	715	1,427	129	1,576	183	315	101	460	2,661	2,667	34	633	784	227	2,131	94	13
Food sales	16,676,047	59	126	245	7	245	100	1,491	8	17	261	286	0	63	274	12	51	0	11
Food service	26,310,435	95	183	345	60	242	457	620	17	19	366	689	0	206	1,518	4	35	0	5
Healthcare, inpatient	19,562,514	12	136	511	33	169	53	81	17	177	466	764	0	139	228	167	205	24	25
Healthcare, outpatient	28,157,169	30	62	765	13	392	23	60	35	114	341	796	0	18	74	27	78	2	4
Lodging	101,817,069	47	247	2,083	114	648	191	577	94	1,221	1,223	478	0	1,388	3,753	10	52	57	18
Mercantile, malls	74,575,677	406	343	864	391	1,582	56	492	42	114	927	1,192	0	428	731	42	15	0	3
Mercantile, other	72,843,987	20	609	1,812	25	1,210	122	234	21	45	1,157	1,116	0	20	504	9	-4	0	1
Office	232,588,042	428	716	2,872	67	1,810	50	245	166	1,730	2,290	1,815	0	164	256	91	1,311	30	30
Public assembly	146,114,970	159	2,040	973	8	1,118	87	228	63	306	1,633	4,345	0	41	1,283	370	3,101	20	9
Public order and safety	25,494,792	59	232	171	0	235	39	31	13	55	295	919	0	173	78	37	59	0	4
Religious worship	90,690,511	28	224	183	8	236	37	45	14	17	158	865	0	21	208	25	20	0	0
Service	118,430,028	149	512	284	12	905	3	236	37	107	832	3,603	0	24	0	0	414	0	9
Warehouse and storage	205,288,105	76	666	336	47	1,009	5	660	52	124	1,223	2,523	0	25	12	21	28	0	13
Other	554,277,420	534	979	2,558	174	7,547	10	1,182	462	75,454	7,297	10,375	0	490	108	31	8,995	95	243
Vacant	26,721,459	11	3	0	0	17	0	0	0	0	280	73	0	0	0	0	177	0	1
Total	1,968,706,961	2,321	7,792	15,428	1,090	18,941	1,416	6,498	1,143	79,961	21,411	32,505	34	3,832	9,812	1,072	16,668	321	390

Table 19. End-use energy consumption by building type and fuel, Nevada

Building type	Floor area (sqft)	Electricity										Natural gas					Other fuels		
		Heating use	Cooling use	Ventil-ation use	Water heating use	Lighting use	Cooking use	Refrig-eration use	Office equip. use	Com-puting use	Misc. use	Heating use	Cooling use	Water heating use	Cooking use	Misc. use	Heating use	Water heating use	Misc. use
Education	99,374,363	91	310	619	56	683	79	137	44	199	1,154	1,157	15	274	340	98	924	41	6
Food sales	9,376,520	33	71	138	4	138	56	839	5	10	147	161	0	35	154	7	29	0	6
Food service	15,218,601	55	106	200	35	140	264	359	10	11	212	399	0	119	878	2	20	0	3
Healthcare, inpatient	24,157,735	15	167	631	41	209	65	99	21	219	576	943	0	171	282	207	253	30	31
Healthcare, outpatient	16,325,870	17	36	444	8	227	13	35	20	66	198	462	0	10	43	16	45	1	2
Lodging	92,307,830	43	224	1,888	103	588	174	523	85	1,107	1,109	433	0	1,259	3,402	9	47	52	17
Mercantile, malls	51,904,703	283	239	602	272	1,101	39	342	29	79	645	830	0	298	509	29	10	0	2
Mercantile, other	40,173,202	11	336	999	14	667	68	129	12	25	638	615	0	11	278	5	-2	0	0
Office	85,906,176	158	265	1,061	25	669	19	91	61	639	846	670	0	60	95	34	484	11	11
Public assembly	82,156,753	89	1,147	547	4	629	49	128	36	172	918	2,443	0	23	721	208	1,743	11	5
Public order and safety	14,335,077	33	130	96	0	132	22	18	7	31	166	517	0	97	44	21	33	0	2
Religious worship	50,992,981	16	126	103	4	133	21	25	8	10	89	486	0	12	117	14	11	0	0
Service	66,590,210	84	288	160	7	509	2	133	21	60	468	2,026	0	14	0	0	233	0	5
Warehouse and storage	131,453,143	48	427	215	30	646	3	423	34	79	783	1,615	0	16	8	13	18	0	8
Other	311,656,178	300	550	1,438	98	4,244	6	665	260	42,426	4,103	5,833	0	275	61	17	5,057	53	137
Vacant	15,024,801	6	2	0	0	10	0	0	0	0	158	41	0	0	0	0	99	0	0
Total	1,106,954,142	1,282	4,423	9,139	702	10,723	878	3,945	652	45,133	12,209	18,631	15	2,676	6,932	680	9,007	199	237

Table 20. End-use energy consumption by building type and fuel, New Mexico

Building type	Floor area (sqft)	Electricity										Natural gas					Other fuels		
		Heating use	Cooling use	Ventil-ation use	Water heating use	Lighting use	Cooking use	Refrig-eration use	Office equip. use	Com-puting use	Misc. use	Heating use	Cooling use	Water heating use	Cooking use	Misc. use	Heating use	Water heating use	Misc. use
Education	82,381,695	75	257	513	46	566	66	113	36	165	957	959	12	227	282	82	766	34	5
Food sales	5,503,496	19	42	81	2	81	33	492	3	6	86	94	0	21	90	4	17	0	4
Food service	10,911,830	39	76	143	25	100	189	257	7	8	152	286	0	85	630	2	15	0	2
Healthcare, inpatient	21,321,827	13	148	557	36	184	58	88	18	193	508	833	0	151	249	182	223	26	28
Healthcare, outpatient	9,209,465	10	20	250	4	128	8	20	12	37	112	261	0	6	24	9	26	1	1
Lodging	53,999,492	25	131	1,104	60	344	102	306	50	647	649	253	0	736	1,990	5	28	30	10
Mercantile, malls	23,068,865	126	106	267	121	489	17	152	13	35	287	369	0	132	226	13	5	0	1
Mercantile, other	32,777,657	9	274	815	11	545	55	105	9	20	521	502	0	9	227	4	-2	0	0
Office	65,739,822	121	202	812	19	512	14	69	47	489	647	513	0	46	72	26	371	9	8
Public assembly	48,221,449	53	673	321	3	369	29	75	21	101	539	1,434	0	14	423	122	1,023	7	3
Public order and safety	8,413,894	20	77	57	0	78	13	10	4	18	97	303	0	57	26	12	20	0	1
Religious worship	29,930,047	9	74	61	3	78	12	15	4	6	52	285	0	7	69	8	7	0	0
Service	39,084,753	49	169	94	4	299	1	78	12	35	275	1,189	0	8	0	0	137	0	3
Warehouse and storage	27,412,702	10	89	45	6	135	1	88	7	17	163	337	0	3	2	3	4	0	2
Other	182,924,860	176	323	844	57	2,491	3	390	153	24,902	2,408	3,424	0	162	36	10	2,968	31	80
Vacant	8,818,723	4	1	0	0	6	0	0	0	0	93	24	0	0	0	0	58	0	0
Total	649,720,577	758	2,662	5,963	399	6,404	600	2,260	397	26,680	7,545	11,066	12	1,665	4,346	482	5,664	137	148