BENEFICIAL ELECTRIFICATION IN COLORADO

Market Potential
2021-2030

FINAL REPORT

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1 Executive Summary

For the Colorado Energy Office (CEO), GDS Associates, Inc. (GDS) completed a modeling analysis of the market potential for beneficial electrification in Colorado. The project began in late December 2019 and ran through early March 2020. In the analysis, GDS explored the potential for beneficial electrification to offset greenhouse gas emissions from Colorado consumer's direct use of fossil fuels from 2021-2030. The focus of the study was on beneficial electrification in the residential and commercial building sector, with consideration for the industrial sector and non-road transportation sector. Electrification of transportation, which has been addressed in other studies, was not included in this study.

Beneficial electrification is an emerging trend across the United States. With the electricity sector making major movements in many states to reduce reliance on coal and other fossil fuels, electricity is being looked to as a solution for reducing the consumption of *other* fossil fuels—and their associated greenhouse gas emissions. Replacing equipment and appliances that burn natural gas, propane, fuel oil, gasoline, or diesel fuels, with energy-efficient electric technologies will reduce greenhouse gas emissions in the near term. As the grid continues to decarbonize, beneficial electrification will produce even greater reductions in greenhouse gas emissions over the long term.

Colorado is making major strides in decarbonizing its electricity sector and reducing greenhouse gas pollution. In December of 2018, Xcel Energy committed to reducing electricity-based carbon emissions to 80 percent of its 2005 emissions by 2030 and to generate 100 percent clean energy by 2050.[1] House Bill 1261, signed in May of 2019, commits Colorado in striving to achieve a 50 percent reduction in statewide greenhouse gas pollution by 2030 and 90 percent reduction by 2050.[2] In 2019, Governor Polis also signed Senate Bill 19-236,[3] modernizing the Public Utilities

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[1] https://www.xcelenergy.com/environment/carbon_reduction_plan
[2] https://leg.colorado.gov/sites/default/files/2019a_1261_signed.pdf
[3] https://leg.colorado.gov/sites/default/files/2019a_236_signed.pdf

Commission (PUC), which helped pave the way for decreasing Colorado's carbon emissions from the electricity grid and other critical sources of emissions by codifying into law Xcel Energy's carbon-reduction commitment. The law also provides an opportunity for other utilities to develop and submit to the PUC for approval, clean energy plans that achieve a carbon dioxide emission reduction of 80 percent below 2005 levels by 2030. In addition, the legislation also requires a utility to use the social cost of carbon in its calculation of benefits associated with beneficial electrification plans.

In January 2020, Tri-State Generation & Transmission Association (Tri-State), an electric generation and transmission cooperative servicing Colorado and three other states, announced its Responsible Energy Plan, which commits the company to reducing carbon emissions from Colorado generating plants by 90 percent by 2030, with Colorado electricity sales having 70 percent lower emissions by 2030. Additionally, the Platte River Power Authority, which supplies power to four Colorado communities, has stated a goal of getting to 100 percent non-carbon energy mix by 2030.[4] With these commitments to develop a cleaner, carbon-free electrical system, Colorado is well on its way to leveraging beneficial electrification to further reduce emissions from Colorado's energy sector.

In the residential and commercial building sectors, Lawrence Berkeley National Laboratory (LBNL) estimates the technical potential for electrification to be "nearly 100% of all energy use."[5] Space heating and water heating are major end-uses for natural gas and propane in residential and commercial buildings. Cooking is also a large user of natural gas and propane in the commercial sector. The implication is that, with off-the-shelf technologies, there is no technical reason that nearly all of Colorado's use of natural gas or propane for space heating, water heating, and

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[4] https://www.prpa.org/media-releases/platte-river-board-passes-energy-policy/

[5] Lawrence Berkeley National Labs. Electrification of Buildings and Industry in the United States. p. 15
http://ipu.msu.edu/wp-content/uploads/2018/04/LBNL-Electrification-of-Buildings-2018.pdf

cooking cannot be electrified over the long term, assuming the State enacts strong policy support to overcome market barriers.[6]

The primary technology opportunity to beneficially electrify space heating and water heating is through heat pumps. The current generation of heat pumps used for space heating are more efficient and work better at cold temperatures than those of only a decade ago. Heat pump water heaters have less history in the market but are commonly promoted through utility demand-side management programs, with efficiencies that substantially exceed those of electric resistance water heaters. This study finds both of these technologies to be viable options for early efforts to electrify current residential and commercial sector uses of natural gas and propane.

Electrifying the industrial sector will be more challenging than the residential or commercial sectors and will require research and innovation, in part due to the nature and diversity of processes and technologies employed. LBNL[7] cites a study by the Electric Power Research Institute (EPRI) indicating that by 2030, only 3.6 percent of the United States' industrial sector has technical potential for electrification, a stark contrast to residential and commercial buildings. Colorado has a diverse industrial sector, spanning companies associated with food processing, forestry, agriculture, paper products and wood products, and oil and gas, to name but a few.[8] Each of these industries has its own ways of utilizing fossil fuels in their processes. While some industrial facilities can benefit from the available technologies used in commercial buildings, the demand for high heat in many processes does not always lend itself to the use of heat pumps. In some cases, solutions other than electrification may be needed to mitigate greenhouse gas emissions. These include renewable natural gas or an electric-to-hydrogen solution that facilitates the use of combustion to achieve high temperatures.

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[6] Market barriers that affect the technical adoption of electrification include issues such as electrical panel capacity limitations found in some homes or space constraints for installing electrification technology.

[7] Lawrence Berkeley National Labs. Electrification of Buildings and Industry in the United States. p. 20 http://ipu.msu.edu/wp-content/uploads/2018/04/LBNL-Electrification-of-Buildings-2018.pdf

[8] Colorado Energy Office (2017). Industrial Energy Efficiency and Distributed Generation Opportunities in Colorado. Prepared by Energetics.

Despite these challenges, many industrial processes and agricultural end-uses are good candidates for beneficial electrification. This includes the oil and gas industry which can electrify compressor stations and pumping equipment, and has the opportunity to reduce the direct venting of methane. For Colorado's natural gas industry, some end-uses, including those that currently direct-vent natural gas as part of their operation – can be electrified. The electrification of direct-vented natural gas for pipeline operations may have an important effect on Colorado's overall carbon footprint, with an example provided in a technology snapshot in Section 4.6.[9] Electric arc furnaces, ultraviolet sterilization, converting diesel well pumps to electric pumps, and a host of other opportunities exist for the industrial sector.

Non-road electrification also has potential in both the commercial and industrial sector. Non-road electrification describes transportation-related equipment that is not used on roads and highways. It covers the use of gasoline, diesel, or propane engines that provide services within a facility. One example is battery-powered forklifts that can be used in place of propane-powered forklifts. Another example is truck-stop electrification which avoids the need for highway-going delivery vehicles to operate their diesel engines to support heating and cooling needs while at a truck stop. Large gantry cranes can be electrified, avoiding the need for using diesel engines to raise and lower goods and materials. While difficult to quantify due to the diversity and lack of market data, the non-road technology area is an opportunity for electrification in the commercial and industrial sectors with available off-the-shelf technologies.

1.1 BENEFICIAL ELECTRIFICATION AND GREENHOUSE GAS EMISSIONS REDUCTION

Colorado has a high technical potential for beneficial electrification in the residential and commercial sectors between 2021 and 2030. While the achievable results are lower due to the expected adoption rate of electrification technologies, under the High Electrification scenario, we

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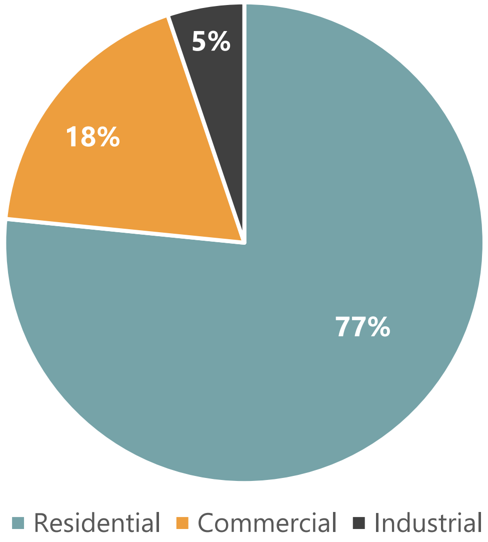
[9] Direct emissions of methane have 21 times the effect on carbon emissions (CO2e) compared to combusting methane.

estimate that by the end of 2030, beneficial electrification can reduce natural gas consumption by over six percent and propane consumption just under ten percent. This would result in approximately 3.5 million tons less of carbon dioxide equivalent (CO_2e)[10] emissions by the end of 2030 and would increase 2030 sales of electricity approximately two percent. The lifetime CO_2e emissions reduction for electrification measures adopted by the end of 2030 is estimated to be approximately 16.2 million tons. Figure ES-1 illustrates the share of lifetime cumulative CO_2e emissions reductions by sector in the High Electrification scenario for electrification measures that we forecast as being installed under the High Electrification scenario.[11]

FIGURE 1-1 SECTOR SHARES OF LIFETIME CUMULATIVE EMISSIONS REDUCTIONS FROM MEASURES INSTALLED BETWEEN 2021 AND 2030



The Moderate Electrification scenario forecasts approximately half the measure adoption and half the resulting emissions reductions as the High Electrification Scenario. The study assumes that adopters of electrification technologies continue to use the same or better electrification technologies into the future and therefore that CO_2e reductions would continue beyond the useful lives of their initial electrification adoption.

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[10] Carbon dioxide equivalent accounts for differing global warming potentials of gaseous emissions.

[11] The lifetime of electrification measures last beyond the 2021-2030 decade. As a result, the ongoing reduction in carbon emissions last beyond the decade, reflected in the lifetime cumulative emissions reduction.

Below we present our key findings and recommendations regarding beneficial electrification in Colorado that emerged from the analysis.

1.2 KEY FINDINGS AND RECOMMENDATIONS

Through this beneficial electrification study, the modeling and analysis led to several key findings and recommendations.

Table 1-1 summarizes the key findings and recommendations with an expanded discussion of each following.

TABLE 1-1 BENEFICIAL ELECTRIFICATION KEY FINDINGS AND RECOMMENDATIONS

Key Finding	Recommendation
Colorado has substantial market potential to develop beneficial electrification over the 2021-2030 decade and beyond.	Colorado should enact policies to encourage the adoption of beneficial electrification technologies, especially related to heat pumps for space heating and water heating.
Over the next ten years (2021 to 2030) Colorado has the potential to cumulatively reduce net carbon emissions by approximately 3.5 million tons of CO2e through beneficial electrification. For measures installed in this timeframe, the potential for net lifetime emissions reductions exceeds 16 million tons of CO2e.	To maximize emissions reductions, Colorado should adopt policies that ensure the decarbonization of the state's electricity grid while monitoring the pace of electrification to ensure that it is achieving a beneficial outcome for CO2e emissions.
Electrifying propane-fueled end uses is highly cost-effective.	Colorado should prioritize policies and efforts to electrify propane-fueled end-uses while creating general electrification opportunities and awareness.
Colorado can take advantage of the work that other regions in the U.S. have undertaken to improve heat pump technology and grow the market for electrification technologies. These efforts may allow Colorado to move from a fossil-fuel dominated energy market for space heating and water heating more quickly and with fewer challenges than others.	Colorado should leverage the program design and technology specifications already developed by other regions, states, and utilities. These include efforts in the Pacific Northwest and Northeastern United States.
There is limited market intelligence on fossil fuel end-uses and saturations that is publicly available. To-date, utility market saturation studies have not deeply investigated electrification opportunities.	Colorado should develop market intelligence and track the adoption of beneficial electrification over time to facilitate long-term market development efforts.
Capturing the full potential of beneficial electrification will require a fundamental transformation and long-term transition that will need to take place over multiple decades.	Colorado should take a coordinated market transformation approach toward beneficial electrification that includes electric utilities, local jurisdictions, the private sector, and the State in order to achieve the long-term decarbonization goal.

Below we expand on the key findings and recommendations presented in Table 1-1 adding discussion on the findings and context for the recommendations.

KEY FINDING NO. 1: ***Colorado has substantial opportunities to develop beneficial electrification over the 2021-2030 decade and beyond.***

From a technical standpoint, nearly all of Colorado's space heating and water heating services provided by fossil fuel could be converted to electricity. The residential market has the greatest opportunity for these technology changes to be cost-effective, based on the modified Total Resource Cost test[12] (mTRC) and social cost of carbon utilized in this study. Additionally, the residential market may be best positioned to develop programmatic solutions due to the sector's use of standardized technologies repeated from home to home. This standardization of technologies and repeated sales spread across the residential sector will enable tastes, preferences, and market practices to develop, growing the market for beneficial electrification.

The commercial sector is also well positioned to adopt beneficial electrification. Many of the same technologies found in the residential sector can be applied to the commercial sector, including water heating and space heating equipment. However, the diversity of heating and cooling systems, considerations of natural gas costs, and potential integration of technologies into more complex commercial systems may limit the potential over the next ten years relative to the residential sector.

The industrial sector is expected to have the least adoption of electrification opportunities relative to its fossil fuel loads. Diverse needs, including processes requiring high temperatures, limit the ability for heat pumps and related beneficial electrification technologies to provide an equivalent

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[12] Colorado's mTRC is used by utilities for analyzing the cost effectiveness of energy efficiency measures and programs.

end-use service. Processes requiring a high temperature rise may be unsuitable for heat pumps, while any electrification from fossil fuels can require substantial industrial process overhauls or changes to the nature of a product.[13] Technology innovation may be needed to develop electrification solutions for the industrial sector. That said, there are technologies appropriate for industrial uses, such as industrial heat pumps as well as the technologies associated with the commercial sector for space heating and domestic water heating.

Non-road transportation solutions are an immediate opportunity for some electrification technologies. However, there is limited data on the current level of energy consumption for the diverse end-uses that fall within this category. This category includes propane-powered forklifts that can be converted to electricity, as well as truck-stop electrification in which diesel fuel used by parked trucks becomes electrified to provide necessary services. This category lends itself to standardized technologies that are becoming more common in the market. Technology standardization facilitates repeated sales that ease the marketing and adoption of technologies.

Propane users stand to benefit the most from adopting electrification technologies for space heating and water heating. The use of propane for space heating and water heating exhibits a high degree of cost-effectiveness for both the residential and commercial sectors due to the cost of propane relative to electricity. As an early first-step, encouraging beneficial electrification among propane users appears to be a key opportunity.

Table 1-2 below describes the 2030 annual CO2e reductions that are possible under the technical, economic, and two adoption scenarios (described further in the report). The 2030 results reflect a substantially greener grid (80 percent CO2 emissions reductions from 2005 levels). The level of annual reductions increases from 2021 to 2030, with higher annual reductions possible after 2030, assuming ongoing beneficial electrification technology adoption.

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[13] https://www.energy.gov/sites/prod/files/2014/05/f15/heatpump.pdf

TABLE 1-2 CO2E REDUCTION POTENTIAL UNDER BENEFICIAL ELECTRIFICATION SCENARIOS

Potential Scenario	2030 Cumulative CO2e Reduction (short tons)
Technical Potential	31,147,459
Economic Potential	20,797,877
High Electrification	3,499,843
Moderate Electrification	2,085,315

In 2030, the technical potential for annual emissions reduction is approximately 30 percent of forecasted 2030 emissions associated with electricity production and the combustion of natural gas and propane in Colorado. Additional potential exists after 2030 and ongoing adoptions of beneficial electrification would continue to expand the reduction in CO2e emissions. Significantly, the High Electrification and Moderate Electrification emissions reductions pose minimal risk to Colorado's electrical infrastructure, leading to an approximate one to two percent increase in electricity consumption in 2030.

RECOMMENDATION NO. 1: ***Colorado should adopt policies to encourage beneficial electrification technologies, especially related to heat pumps for space heating and water heating. However, many other opportunities exist. Beneficial electrification efforts should include non-road technologies and be used to educate the market and stimulate the demand for electrifying the diverse non-road end-uses.***

KEY FINDING NO. 2: ***Over the next ten years (2021 to 2030) Colorado has the potential to reduce net carbon emissions by over 3.5 million tons of CO2e through beneficial electrification. As electrification adoptions increase, the net lifetime CO2e reduction of electrification measures installed by the end of 2030 is over 16 million tons of CO2e. The greatest opportunity can be expected in the second half of the decade, assuming that the first half is viewed as focusing on "market preparation" to drive higher adoption rates through 2030 and beyond.***

Our analysis assumes Colorado's electricity grid reduces its overall emissions by 80 percent in 2030 compared to a 2005 baseline and continues downward toward zero emissions in 2050. This base case emissions profile is combined with load forecasts without beneficial electrification to inform and emissions rates that the beneficial electrification scenarios will impact. The emissions reduction benefit is based on the emissions associated with the adoption of electrification technology less the emissions avoided by not utilizing fossil fuels for the same end use. For the State or an individual utility, if decarbonization does not occur, there is a risk that electrification may not be beneficial. However, under the scenarios, we found that the State can expect a general reduction in carbon emissions, even if the State or an individual utility only achieves a 50 percent reduction from 2005 electricity emissions. While Colorado is well positioned to utilize beneficial electrification to decrease emissions due to current legislation and utility plans, progress toward that goal will inform just how beneficial electrification ultimately is and what technologies are the most beneficial.

The High Electrification scenario envisions substantial market adoption of available and cost-effective beneficial electrification technologies. The study assumes an adoption rate based on the compound annual growth rates of heat pumps in the Pacific Northwest and the Northeastern U.S. as well as the adoption of plug-in hybrid and electric vehicles in Colorado. The Moderate Electrification scenarios find that adoption rates may be modest relative to overall natural gas sales, particularly in the 2021-2025 timeframe. Both scenarios assume that some level of programmatic effort will be made to transform the market over the decade, with the first five years being critical for market development and early deployment. By the end of the decade, both scenarios result in natural gas savings similar to mature natural gas energy efficiency programs, relative to the forecasted natural gas sales absent beneficial electrification.[14] The modeling found that the annual impact of beneficial electrification on natural gas consumption is between 0.4 percent (Moderate Electrification) and 1.1 percent (High Electrification) in 2030. This amounts to between 1.1 million dekatherms (Dth) and 3.4 million Dth in 2030, respectively for each of the two scenarios. In both scenarios, the assumed adoption rates will provide Colorado with an opportunity to observe the progress achieved toward reducing electricity emissions, minimizing

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[14] Based on a review of ACEEE's 2019 State Energy Efficiency Scorecard, found at: https://www.aceee.org/sites/default/files/publications/researchreports/u1908.pdf

the risk that moving forward with electrification could lead to increases in carbon emissions. Given the large potential benefit of future electrification, early steps now will help pave the way while also not exposing the State to high risks in regard to carbon emissions. The opportunity exists to correct course should outcomes differ from expectations.

RECOMMENDATION NO. 2: ***To maximize emissions reductions, Colorado should adopt policies that ensure the decarbonization of the state's electricity grid while monitoring the pace of electrification to ensure that electrification is achieving a beneficial outcome for CO2e emissions.***

KEY FINDING NO. 3: ***The electrification of propane end-uses is highly cost effective. Natural gas prices reduce cost-effective electrification options compared to propane.***

In the case of propane space heating and water heating, we found that shifting from propane to electric technologies was cost-effective across nearly all modeled technology cases using the Colorado mTRC test and social cost of carbon. In the case of natural gas users, many, though fewer technology cases were found to be cost effective under the cost effectiveness testing. As a result, propane users were modeled to have a higher rate of adoption of electrification technologies than natural gas users.

There are many factors influencing the mTRC test, with the cost difference between propane and natural gas being the driver of differences in technology cost-effectiveness and subsequent adoption. As an example, natural gas prices for a high efficiency, 95 percent AFUE[15] furnace are approximately $4.00 per delivered MMBtu in Colorado. In contrast, propane prices result in

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[15] AFUE refers to the Annual Fuel Utilization Efficiency, the measure of a furnace's efficiency in converting fuel to energy.

roughly $21.00 per delivered MMBtu for the same furnace. As beneficial electrification will increase electricity consumption while saving either propane or natural gas, electricity consumption costs must compete against the price of these fuels as a component of cost-effectiveness.

This study finds that based on current fuel prices, transitioning from natural gas to beneficial electrification requires benefits beyond just the difference in price between gas and electricity, such as air conditioner efficiency savings, to pass cost-effectiveness testing with a benefit to cost ratio greater than 1.0. By way of example, a high efficiency cold climate heat pump can achieve a winter-season COP[16] of approximately 3.5. All else held equal, the heat pump would need to deliver heat at a cost that is lower than a propane or natural gas alternative. The cost per delivered MMBtu of this example heat pump is roughly $8.20 based on Xcel Energy's residential winter electricity prices. This price of delivered heat is higher than the natural gas option but lower than the propane option. In addition, Colorado law, recognizing that lower carbon emissions is a social good, requires the use of a social cost of carbon when evaluating proposals from regulated electric utilities to implement beneficial electrification programs. Under this approach, the study finds that many opportunities for natural gas beneficial electrification are cost effective or nearly cost-effective when considering all costs and benefits. Indeed, some Colorado homes and businesses are choosing electrification options now, indicating value propositions not captured by energy economics alone.

In the case of propane, we found little difference between the technical and economic potential to beneficially electrify propane end-uses. For natural gas, there is a substantial technical potential to reduce natural gas consumption and associated carbon emissions from 2021 through 2030, though our analysis found less economic potential using Colorado's mTRC and social cost of carbon. As a result, the ultimate adoption of beneficial electrification and the associated offset of natural gas consumption forecasted for the next decade are lower than might otherwise occur

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[16] The COP is the coefficient of performance and represents the amount of heat output relative to the amount of electricity required to operate the heat pump. A COP of 3.5 means a heat pump outputs 3.5 times the amount of energy required to operate the heat pump.

were natural gas prices higher. We also found that many beneficial electrification space heating measures only pass the cost effectiveness test when savings associated with air-conditioning efficiency are included in the analysis, suggesting an important link between beneficial electrification and ongoing efforts to increase energy efficiency in Colorado.

RECOMMENDATION NO. 3: ***Colorado should prioritize targeting residential and commercial propane customers for electrification due to the cost-effectiveness of electrifying many propane-fueled end-uses and the opportunity to save customers money and reduce greenhouse gas emissions. Experience with propane users should be leveraged to help inform efforts to build consumer awareness and to electrify natural gas end-uses. Colorado should help natural gas customers adopt cost-effective electrification technologies and support the development of technologies that may become cost-effective in the future.***

KEY FINDING NO. 4: ***Colorado can take advantage of the work that other regions in the U.S. have undertaken to improve heat pump technology, the market for heat pumps, and related electrification technologies. These efforts may allow Colorado to begin to move from a fossil-fuel dominated energy market for space heating and water heating with fewer challenges than others.***

While space-heating heat pumps have been in the marketplace since the 1970s, they are more common in warmer climates. Several efforts in the U.S., including those of the Northwest Energy Efficiency Alliance (NEEA) and its member utilities, as well as those by the Northeast Energy Efficiency Partnership (NEEP) and utilities in the Northeast, have led to technology and market adoption improvements over the last five years. NEEA has spent a decade working to improve ductless heat pump technologies and transforming the marketplace in the Pacific Northwest to encourage heat pump adoptions. NEEP has developed and promoted its cold-climate heat pump specification and supported efforts to grow the market availability of those cold-climate heat pumps. While modest in market penetration,[17] both NEEA and NEEP regions are experiencing growing adoption of high-performance heat pumps. In only the last year, Massachusetts has helped manufacturers develop integrated controls that facilitate ductless heat pump integration with fossil fuel heating systems to allow for dual-fuel space heating.

With these regional efforts helping transform heat pump technology, Colorado can leverage similar program concepts and heat pump technological improvements to move its market toward adopting beneficial electrification technologies.

RECOMMENDATION NO. 4: ***Colorado should leverage the program design and technology specifications already developed by other regions, states, and utilities.***

KEY FINDING NO. 5: ***Colorado has limited publicly available market data on equipment saturation of fossil fuel end-uses. The available utility market saturation studies have not deeply investigated electrification opportunities.***

Market data is needed to understand the current state of beneficial electrification in Colorado and to inform long-term market progress tracking. While conducting research to support this project, GDS engaged with five Colorado electric utilities, three of which also have natural gas service territories. In reviewing the available data, GDS found that potential studies and market saturation studies provided limited or no perspective on the opportunity for beneficial electrification. Indeed, 4 CCR 723-4-4756(b) specifically prohibits natural gas utilities from promoting fuel switching to other fossil fuel derived energy sources as part of demand side management programs, negating

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[17] The specific share of the market is unknown for both NEEA and NEEP regions. While program and general market sales counts are known, the overall market share of HVAC or water heating sales represented by electrification is not.

value in researching such opportunities. Further, beneficial electrification is a relatively recent phenomenon that has emerged as electric utilities have begun making substantial progress and planning to reduce CO2e emissions in their power supply. Finally, energy efficiency programs have generally focused on "like for like" energy savings, in terms of energy sources, with some exception for customer-sited renewable energy systems. In short, there has not been a compelling reason to investigate electrification opportunities, resulting in limited market information about the current status or historical market trends.

Our research found one exception—in 2015, Colorado Springs Utilities (CSU) investigated the potential for fuel switching in its DSM potential study.[18] However, in that study the fuel switching was focused on moving customers from electricity *to* natural gas, the opposite of beneficial electrification. The CSU study is a useful example illustrating just how recent the concept of beneficial electrification is for the utility industry. In discussions with each of the five utilities, GDS learned that they do not perceive that the Colorado marketplace is making large movements toward electrification, suggesting that any effort by individual customers, market actors, or local programs is nascent.

RECOMMENDATION NO. 5: ***Colorado should develop market intelligence and track the adoption of beneficial electrification over time to facilitate long-term market development efforts. Such an effort should be based on a statewide approach that develops consistency in market research and tracking efforts to facilitate programs and policy making that may come from diverse entities, such as utilities and state or local government.***

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[18] CSU is a municipal utility, is not regulated by the Colorado Public Utilities Commission, and not subject to Gas Rule 4756(b).

KEY FINDING NO. 6: ***With a large portion of Colorado's natural gas and propane consumption driven by space heating and water heating needs, maximizing beneficial electrification will require policies that support market transformation. The industrial sector will require technology innovation that aligns with industrial sector practices and processes, many of which may be proprietary or customer-specific in use.***

The technical potential for beneficial electrification in Colorado's residential, commercial, or industrial buildings and processes is substantial. By the end of 2030, beneficial electrification could technically reduce carbon emissions associated with natural gas or propane consumption by approximately 47 percent and 49 percent for each fuel, respectively. However, without additional policy and program support, the impact over the next 10 years relative to the full technical potential for market adoptions and resulting emissions reductions, is likely to be minimal.

Achieving decarbonization goals through beneficial electrification requires a long-term view and persistent programmatic efforts to fundamentally shift market practices and preferences. Yet, near-term action will be crucial to set the stage for future success and to enable the sustained growth and compounding benefits of beneficial electrification. Colorado should support policy and program development, which may entail changing rules or regulations, addressing technology limitations, and market preferences.[19] NEEA's decade-long effort to transform the ductless heat pump market is illustrative and points to the need for a long-term commitment and coordination across organizations that can support beneficial electrification programs.

The experience of the renewable energy and energy efficiency industries provide important examples of the role that supportive policies can plan in transforming markets. Twenty years ago, utility-scale wind energy was just beginning to emerge. Today it is a major source of electricity. Similarly, only 10 years ago, the solar industry had only begun to mature, with major innovations and market adoptions driving what is now an increasingly common source of electricity. For

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[19] GDS is conducting separate research into market barriers and policy options as a companion to this report.

energy efficiency, LED lamps serve as an example of rapid technology innovation and adoption, illustrating the potential that policy and programmatic efforts can have to drive rapid market adoption. Each of these examples serve to indicate the importance of the combination of policies and programs to drive the market. None of the changes occurred overnight. Beneficial electrification can be expected to succeed with a similar path.

KEY RECOMMENDATION NO. 6: ***Colorado should take a coordinated market transformation approach toward beneficial electrification. Such an effort should include at least Colorado's electric utilities, local jurisdictions, and the State in order to achieve the long-term decarbonization goal.***

2 Introduction

This study presents the results of a beneficial electrification market assessment. The study provides an estimate of technical, economic, and achievable potentials for Colorado to electrify buildings to reduce greenhouse gas emissions. The study framework is linked to recent Colorado legislation and utility plans that will see a substantial reduction in greenhouse gas emissions in the electricity sector over the coming decade (2021-2030).

2.1 BACKGROUND

Colorado is making substantial progress in decarbonizing its electricity sector. In 2019, Governor Polis signed landmark legislation (SB 19-236) to address avoiding the worst impacts of climate change.[20] This legislation mandated that electric utilities with over 500,000 customers reduce emissions by 80 percent of 2005 levels by 2030, with a target of 100 percent emissions reductions by 2050. Additionally, the legislation codified the concept of beneficial electrification as electrification of an end-use if that electrification:

- Reduces system costs for the utility’s customers;
- Reduces net carbon dioxide emissions; or
- Provides for a more efficient utilization of grid resources.

The legislation also directed the Public Utilities Commission to apply a social cost of carbon (SCC) in the benefit-cost calculation of beneficial electrification programs and required public utilities to include SCC as a cost-effectiveness factor in electric resource planning.

As the state decarbonizes its electricity grid, Colorado has the opportunity to further reduce its carbon footprint by shifting other energy uses from fossil fuels to the cleaner grid. Quite simply, with a low-carbon electricity supply, converting end-uses of carbon emitting fuels to electricity provides a pathway for further carbon reductions. Beneficial electrification solves a major

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[20] https://leg.colorado.gov/sites/default/files/2019a_236_signed.pdf

challenge of reducing the carbon footprint from the use of fossil fuels since it is difficult with current technologies to cost-effectively scale renewable forms of combustion fuels. Renewable natural gas and hydrogen could theoretically provide a renewable source of combustion fuels but are currently in a nascent market position or still in the research stage of development. Electricity, however, is widely available, has an existing distribution system, and in Colorado, is expected to substantially reduce its carbon footprint by 2030. Hence, electrification can offer a pathway to reducing the use of fossil fuels and their resulting carbon emissions.

Electricity can provide many of the same services that fossil fuels provide. It can heat spaces, processes, and water. It can provide an energy source for transportation. It may be able to reduce direct methane emissions in the oil and gas sector. In general, the uses of fossil fuels is via combustion. Heat from the combustion is used directly or indirectly in an engine. Electricity can be used to provide the same service in many cases.

With electrification technologies able to meet the needs for space heating and water heating in the residential and commercial building sectors, LBNL estimates that the technical potential for electrification in residential and commercial buildings is "nearly 100% of all direct energy use."[21] The implication for residential and commercial buildings is that, with off-the-shelf technologies, there is no technical reason that Colorado's use of natural gas or propane for space heating, water heating, and cooking cannot be electrified.

Heat pump technologies are available now for efficient, electrified space heating and water heating. Compared to electric resistance heating, heat pumps are able to provide heat between roughly two and four times the efficiency of electric resistance heating. As such, there is an efficiency component to beneficial electrification—converting electricity into heat using electric resistance would require two to four times as much electricity as using heat pumps.

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[21] Lawrence Berkeley National Labs. Electrification of Buildings and Industry in the United States. p. 15
http://ipu.msu.edu/wp-content/uploads/2018/04/LBNL-Electrification-of-Buildings-2018.pdf

Moreover, heat pumps are improving. Once considered to be a "warm climate" heating option, heat pumps can now operate efficiently at cold outdoor temperatures. While all heat pumps have become more efficient over the decades, the advent of cold-climate heat pumps has ushered in a new era of high-performance technology. Cold-climate heat pumps are able to maintain substantial heating capacity at 5 degrees F and colder.[22] These heat pumps use cold outdoor air to add heat to a home, with an additional benefit of providing very efficient air-conditioning during the summer.

With heat pumps as a major driver of beneficial electrification opportunities, but keeping other technologies and sectors in mind, the CEO hired GDS to provide a market assessment of the potential for electrification to provide benefits to Colorado from 2021 through 2030, including economic benefits as well as carbon reduction benefits.

2.2 STUDY GOALS

The goals of the study were:

☐ Estimate the technical, economic, and achievable potentials for beneficial electrification in Colorado from 2021-2030
☐ Identify key technologies, sectors, or customer segments that may be able to benefit the most from beneficial electrification between 2021-2030
☐ Estimate the effect of beneficial electrification on fossil fuel and electricity sales as well as the net carbon emissions (CO2 equivalent) that could result from beneficial electrification
☐ Analyze the potential using the framework of utility demand-side-management potential studies and cost-effectiveness approaches
☐ Provide recommendations for CEO, Colorado utilities, or others to consider for next steps

Below we summarize our results and explain the approaches used to draw our findings and recommendations.

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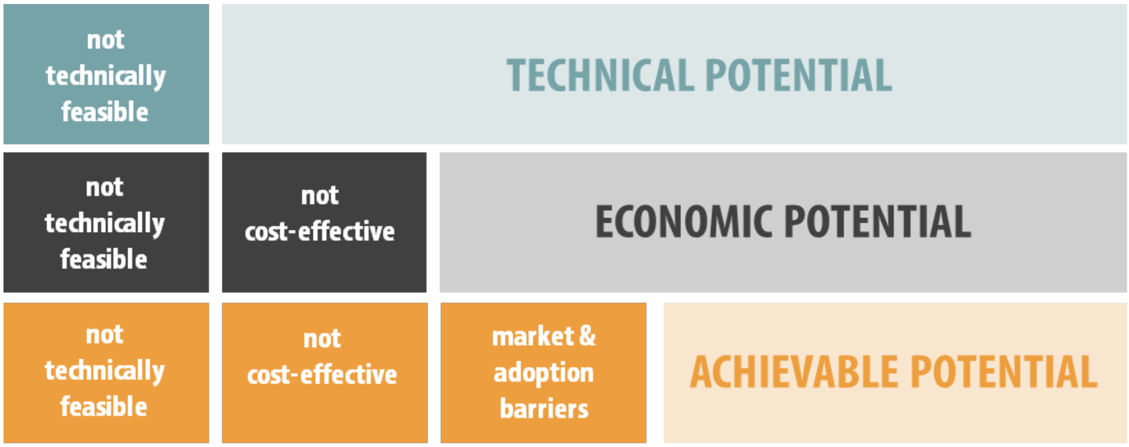
[22] For more information, please see: https://www.energy.gov/eere/buildings/articles/cold-climate-air-source-heat-pumps-innovative-technology-stay-warm-winter or https://neep.org/ashp

3 Approach

GDS worked with CEO and Colorado utilities to gather information, data, and perspectives on the current state of electrification in Colorado. GDS also reviewed recent existing industry literature related to electrification opportunities and the historical adoption of electrification technologies. Combined with these resources, data from the U.S. Energy Information Administration (EIA) was used to forecast a Base Case use of natural gas, propane, and electricity from 2021 through 2030.[23] These data sources and analyses were then used to understand cost-effectiveness and model adoptions of beneficial electrification technologies using an energy efficiency potential study framework that follows the National Action Plan for Energy Efficiency (NAPEE)[24] and National Standard Practice Manual (NSPM)[25] general principles to determine potential estimates. Figure 3-1 illustrates the general framework that begins with technical potential, followed by economic, and achievable potentials.

FIGURE 3-1 RELATIONSHIP BETWEEN FORMS OF BENEFICIAL ELECTRIFICATION POTENTIAL



With this framework, we developed four scenarios across the residential, commercial, and industrial sectors, covering the technical, economic, and two achievable potentials—one for a

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[23] The forecasts used in this model occurred before the COVID-19 pandemic.
[24] https://www.epa.gov/sites/production/files/2015-08/documents/napee_report.pdf
[25] https://nationalefficiencyscreening.org/national-standard-practice-manual/

High Electrification Scenario and the other for a Moderate Electrification Scenario—for beneficial electrification in Colorado.

The High Electrification Scenario was developed utilizing an adoption curve that would result in a maximum of 14 percent market penetration by 2030 for each individual technology case in residential and commercial buildings.[26] We based this curve on historical adoptions of heat pumps in the Pacific Northwest and the Northeastern United States, and electric vehicles in Colorado, and applied it to the residential and commercial sectors using a Bass-diffusion model[27]. We note that the 14 percent saturation rate is similar to an economy-wide target for electrification identified in a study commissioned by the Environmental Defense Fund with input from Western Resource Advocates that would see Colorado moving toward achieving its carbon reduction goals.[28] From 2021-2030, the total market adoption rate of beneficial electrification is less than 14 percent, reflecting that not all end-uses can be cost-effectively electrified, and some users may choose dual-fuel options that only partially offset fossil fuel consumption. For the commercial sector this is particularly evident for large natural gas boiler systems, for which cost-effective technology options were not identified. With fewer cost-effective technologies than the residential sector, particularly for space heating, less natural gas and propane commercial consumption is expected to be electrified by 2030. For the Moderate Electrification scenario, the study used the same general curve to set a maximum saturation of seven percent in 2030. Adoptions proceed at roughly half the pace of the High Electrification scenario.

For the industrial sector, a literature review was used to understand general electrification potential, with a linear adoption rate used to achieve a saturation rate of 1.2 percent by 2030 in the High Electrification scenario and 0.6 percent in the Moderate Electrification scenario. This is

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[26] This adoption curve is an assumption that likely would vary by technology (e.g. space heating vs water heating), partial displacements of fossil fuels, and market condition (end-of-life replacements vs early replacements). There is limited historical precedent for electrification in recent times to inform specific adoption curves for what is, in many cases, newer technology.

[27] A Bass-diffusion curve is an S-shaped curve that describes how products and innovations are adopted by markets.

[28] Michael J Bradley & Associates, "Colorado's Climate Action Plan Emission Targets: Illustrative Strategies and GHG Abatement Potentials," February 18, 2020. Provided by Colorado Energy Office.

explained in more detail in the Industrial Sector section, but results in a lower cumulative adoption rate than either the residential or commercial sectors.

4 Results

In its analysis of Colorado's residential, commercial, and industrial sectors, GDS found that substantial technical and economic potential for beneficial electrification exists in Colorado. In the modeled adoption rates, GDS implicitly assumed the presence of policy and program support. The achievable potential from 2021 to 2030 is modest relative to the technical or economic potential, reflecting the current dominant position that fossil fuels have in Colorado for providing space heating and water heating. The industrial sector and non-road sector also have some potential, but with very limited market data and diverse challenges, our results suggest caution at assuming wide-spread and rapid electrification for industrial and non-road applications.

Table 4-1 describes our conclusions regarding the overall technical, economic and achievable potential impact of electrification on reducing the demand for natural gas and propane, as well as the impact on the state's electricity sales.[29] The technical and economic potential are substantial—by 2030, 47 percent of 2030 forecasted natural gas sales and 49 percent of forecasted propane sales were found to have technical potential to be electrified. The economic potential for natural gas is 31 percent of the forecasted Base Case 2030 natural gas sales, while the 2030 economic potential for propane is nearly the same as its technical potential, indicating high cost-effectiveness for electrifying propane end-uses. The effects on the sales of electricity indicate an increase in 2030 electricity sales of 20 percent under the technical potential scenario and 12 percent under the economically achievable scenario. However, we do not expect the full economic, much less the technical, potential to be achievable by 2030.

When considering adoptions of beneficial electrification, the results are less than the full economic potential. As described further in the report, the adoption rate of beneficial electrification will not result in all economically viable options to occur by 2030. Under the High Electrification scenario, overall natural gas sales in 2030 are expected to be reduced by 6.2 percent, while 2030 propane

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[29] These terms are explained further in the report. The economic potential is based on the modified TRC cost effectiveness test as well as applying the social cost of carbon based on current Colorado law.

sales are expected to be reduced by 9.7 percent (indicating a greater rate of adoption by propane users). The Moderate Electrification scenario shows 2030 natural gas and propane sales being reduced to slightly more than half of the High Electrification scenario. The impact on electricity sales in either the High or Moderate Electrification scenarios is fairly minor - approximately two percent and one percent by 2030, respectively, over the Base Case.

This minor increase in electricity sales indicates similarly negligible effects on electricity grid capacity. One concern with rapid electrification adoption is the ability for the electricity grid to meet the demand. Our analysis finds that from 2021 to 2030, the adoption of beneficial electrification technologies is not likely to stress the current infrastructure and ability to deliver electricity. While additional renewable electricity resources will be needed to meet the additional demand to achieve decarbonization targets, the effect appears to be relatively minor over the next ten years.

TABLE 4-1 CUMULATIVE IMPACTS FROM BENEFICIAL ELECTRIFICATION

	NATURAL GAS SALES		PROPANE SALES		2030 NET CO2e REDUCTION[30]
Potential Scenario	**2025 Reduction**	**2030 Reduction**	**2025 Reduction**	**2030 Reduction**	**Cumulative Short Tons**
Technical Potential	24%	47%	24%	49%	31,147,459
Economic Potential	13%	31%	24%	48%	20,797,877
High Electrification	1.6%	6.2%	2.9%	9.7%	3,499,843
Moderate Electrification	1.1%	3.3%	2.1%	5.3%	2,085,318

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[30] Technical and Economic Potential CO2e emissions reductions assume the same emissions rate as used in the High and Moderate Electrification adoption scenarios and implicitly assume adequate renewable electricity production would be added such that the average emissions rate would not change from the Base Case. The estimated Technical and Economic emissions impact should be viewed as indicators of CO2e reduction levels relative to the adoption scenarios.

Under these results are differing conclusions about technologies and contributions from the residential, commercial, and industrial sectors. For example, the residential sector shows a technical potential of reducing annual natural gas CO2e emissions by 74 percent of forecasted 2030 natural gas sales, while the commercial sector shows a 52 percent technical potential. Below, we summarize the current consumption of each fuel by sector—an important framework before describing the results from each of the sector-level analyses.

In terms of increased electricity consumption on the grid, we expect that there may be some increase in the winter peak. With Colorado being a summer-peaking state, over the next ten years, it is possible that the difference between the summer and winter peak will narrow due to electrification. The specific effect is uncertain and highly dependent on the nature of the measures that would ultimately be adopted. However, space heating is a major portion of the expected adoptions, suggesting some incremental growth to the winter peak during cold, winter nights.

While there may be some effect on peak electricity demands, electrification technologies can provide electric utilities with an opportunity to manage their loads. Over the next ten years, assuming greater penetrations of electrical water heating and space heating technologies, Colorado's electric utilities will be able to learn the specific effects of greater electrification and also consider options to test methods of control. Based on a recent LBNL study of demand response options,[31] the NEEP[32] identified methods by which heat pump water heaters and heat pumps used for space heating (and by extension air-conditioning) could provide utilities with load shaping or other demand response resources, noted in Table 4-2.

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[31] Lawrence Berkeley National Laboratory, "Final Report on Phase 2 Results: 2025 California Demand Response Potential Study," March 1, 2017. http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6442451541
[32] Northeast Energy Efficiency Partnership, "Northeastern Regional Assessment of Strategic Electrification," July 2017. https://neep.org/sites/default/files/Strategic%20Electrification%20Regional%20Assessment.pdf

TABLE 4-2 LOAD SHAPING OPPORTUNITIES FOR ELECTRIFICATION TECHNOLOGIES

Technology/Opportunity	Shape	Shed	Shift
Heat Pump Water Heaters	X	X	X
Heat Pump Space Heating	X	X	

The LBNL study describes each type of load shaping opportunity as:

- *Shape:* captures demand response that reshapes customer load profiles through price response or on behavioral campaigns—"load-modifying demand response"—with advance notice of months to days.
- *Shed:* describes loads that can be curtailed to provide peak capacity and support the system in emergency or contingency events—at the statewide level, in local areas of high load, and on the distribution system, with a range in dispatch advance notice times.
- *Shift:* represents demand response that encourages the movement of energy consumption from times of high demand to times of day when there is surplus of renewable generation. Shift could smooth net load ramps associated with daily patterns of solar energy generation.

Heat pumps clearly provide electric utilities with several load flexibility options. Although not considered as part of the modeling in this study, the ability to manage loads that emerge due to beneficial electrification will help minimize electricity grid impacts.

4.1 STATE-LEVEL BASE CASE AND ELECTRIFICATION ENERGY CONSUMPTION AND CARBON EMISSIONS

GDS developed forecasts of energy consumption for the residential, commercial, and industrial sectors for 2021 through 2030. These forecasts were based on a combination of data GDS received from several Colorado utilities and the use of forecasts from the EIA[33]. EIA forecasts for the Mountain region were calibrated to Colorado based on historical state-specific EIA data and the

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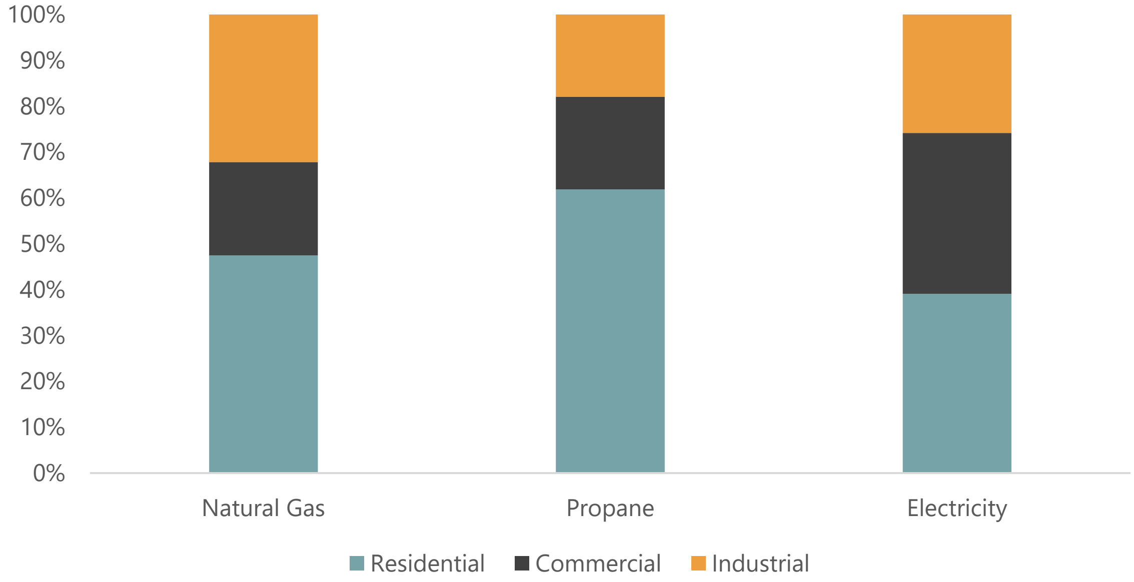
[33] https://www.eia.gov/

expected growth in the residential and commercial sectors as shared by several Colorado utilities.[34]

Figure 4-1 illustrates the relative share that each sector is expected to contribute to the consumption of natural gas, propane, and electricity in 2030. The forecast represents a Base Case, which does not include the changes that would occur under the beneficial electrification scenarios. The relative shares are generally consistent throughout the forecast period.

FIGURE 4-1 SECTOR SHARE OF ENERGY CONSUMPTION IN 2030, BASE CASE



The residential sector is the highest consuming sector for each energy source. The industrial sector is the second highest consumer of natural gas but is third highest for propane and electricity. The relative shares of natural gas, propane, and electricity consumption across each sector as modeled for 2030 are nearly identical to the historical share of consumption in 2018 (based on EIA data).

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[34] This data was considered confidential by some utilities and is not reported. For the industrial sector, GDS relied solely on calibrated EIA data to account for gas-transport customers whose sales were not provided to GDS. Overall propane consumption is forecasted to remain flat from 2021-2030. GDS did not attempt to account for self-generation of electricity by customers; solar PV, wind, combined heat and power, and other possible on-site electricity generation technologies are not incorporated directly in the modeling.

RESULTS

The 2030 share for electricity in the Base Case (absent electrification) indicates that the residential sector share of electricity consumption increases by four percent in 2030, compared to 2018, with two percent less share for each of the commercial and industrial sectors. Natural gas and propane sales indicate the same share of consumption between the 2018 historical consumption and 2030 modeled consumption.

In terms of the relative importance of beneficial electrification to impact natural gas and propane sales as well as carbon emissions, Figure 4-1 illustrates that the residential sector is critical, consuming the largest proportion of natural gas and propane.

Figure 4-2 illustrates the carbon emissions expected to come from each energy source during the Base Case forecast period. For the electricity sector, the forecast assumes that Colorado's CO2e emissions will achieve its 80 percent reduction from its 2005 baseline. In Figure 4-2, propane can be seen as having a fairly small share of the overall CO2e emissions, while the contribution from electricity steadily declines.[35]

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[35] GDS assumed a linear decrease from CO2e emissions rates (CO2e per MWh) for electricity from 2018 through to forecast period.

FIGURE 4-2 FORECASTED SOURCES OF EMISSIONS, BY ENERGY SOURCE[36]

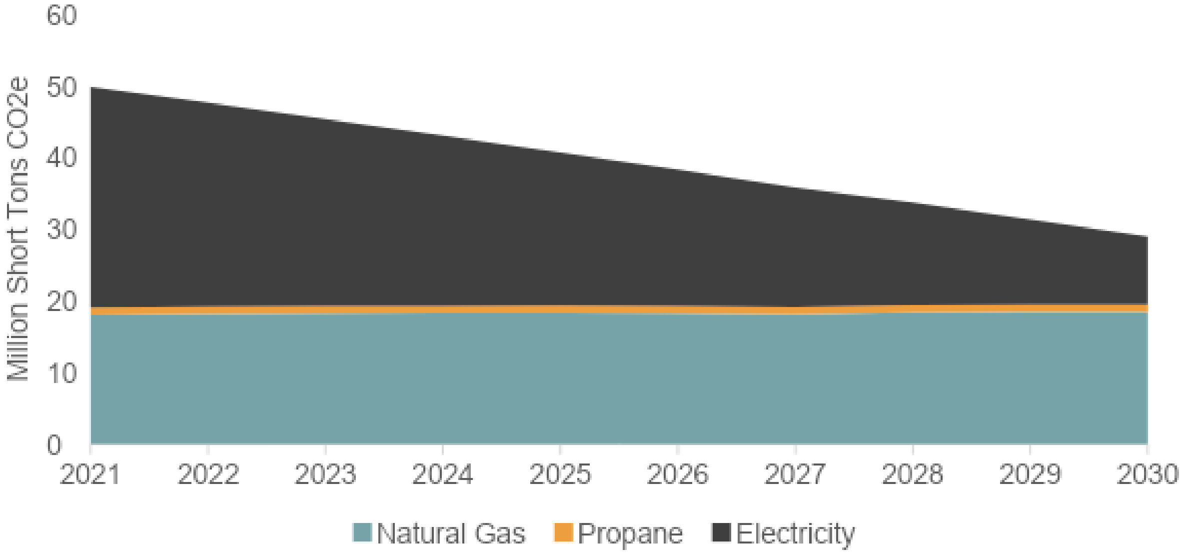

Figure 4-3 illustrates the contribution of CO2e from each sector in the Base Case, accounting for natural gas, propane, and electricity consumption. Overall emissions decrease, while the share from the commercial and industrial sectors appears to decrease more than the residential sector. The greater decrease for the commercial and industrial sectors is due to the relative share of residential natural gas and propane sales, while the commercial and industrial sectors use a relatively greater share of electricity compared to natural gas or propane, allowing the decreased carbon content of electricity to proportionally affect those sectors more than the residential sector.

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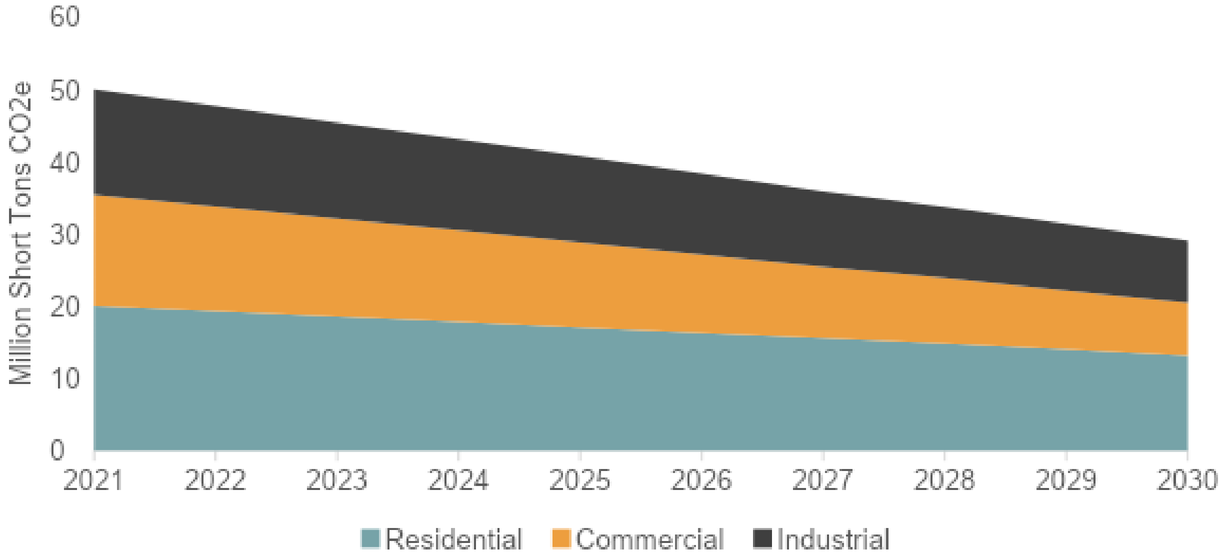
[36] The change in electricity-based emissions in Figure 4-2 is based on the 80 percent reduction by 2030 scenario.

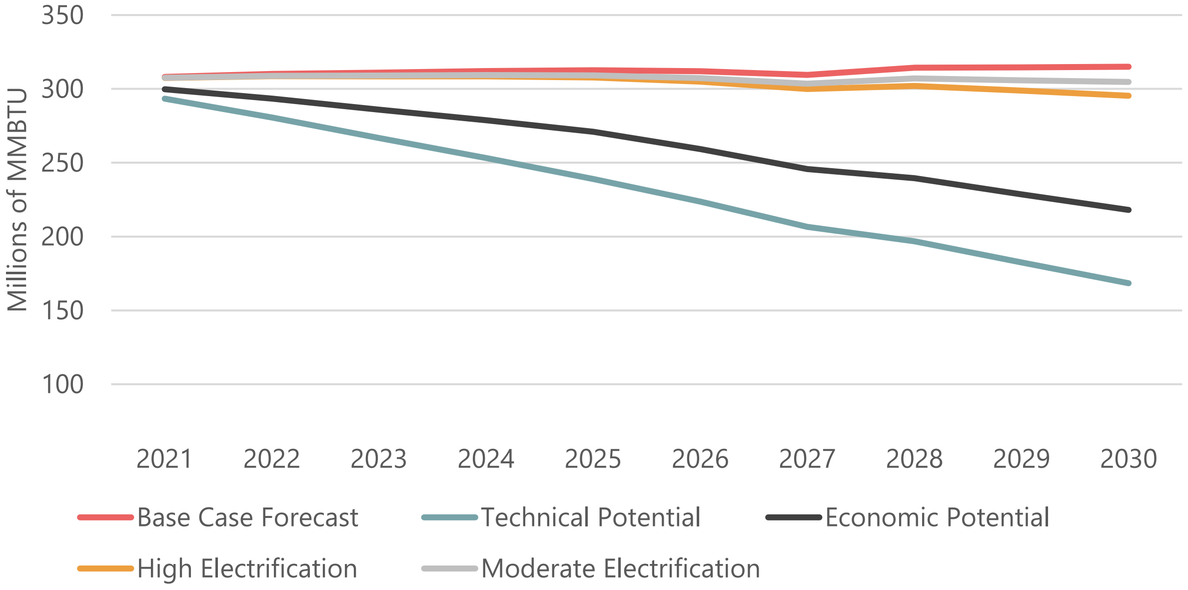
FIGURE 4-3 EXPECTED CARBON EMISSIONS FROM SECTORS 2021-2030



Given the relative share of carbon emissions and Base Case forecasts, the results presented in Figure 4-1 and Figure 4-3 indicate the importance of the residential sector and relative impact that residential beneficial electrification may have on Colorado's overall carbon emissions. This is not to say that only the residential sector matters, but rather that the residential sector may be important to focus on for future beneficial electrification efforts due to relatively higher shares of natural gas and propane consumption.

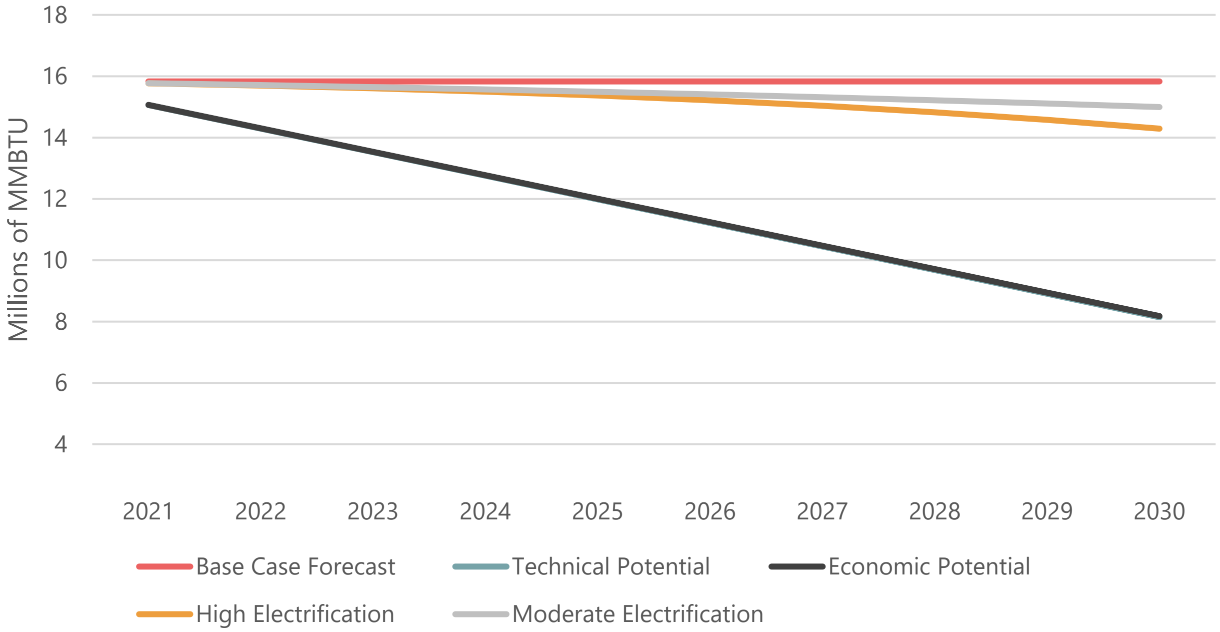
Figure 4-4 shows the cumulative effect of each scenario relative to the base case for Colorado natural gas sales.

FIGURE 4-4 COLORADO TOTAL NATURAL GAS SALES UNDER ELECTRIFICATION SCENARIOS



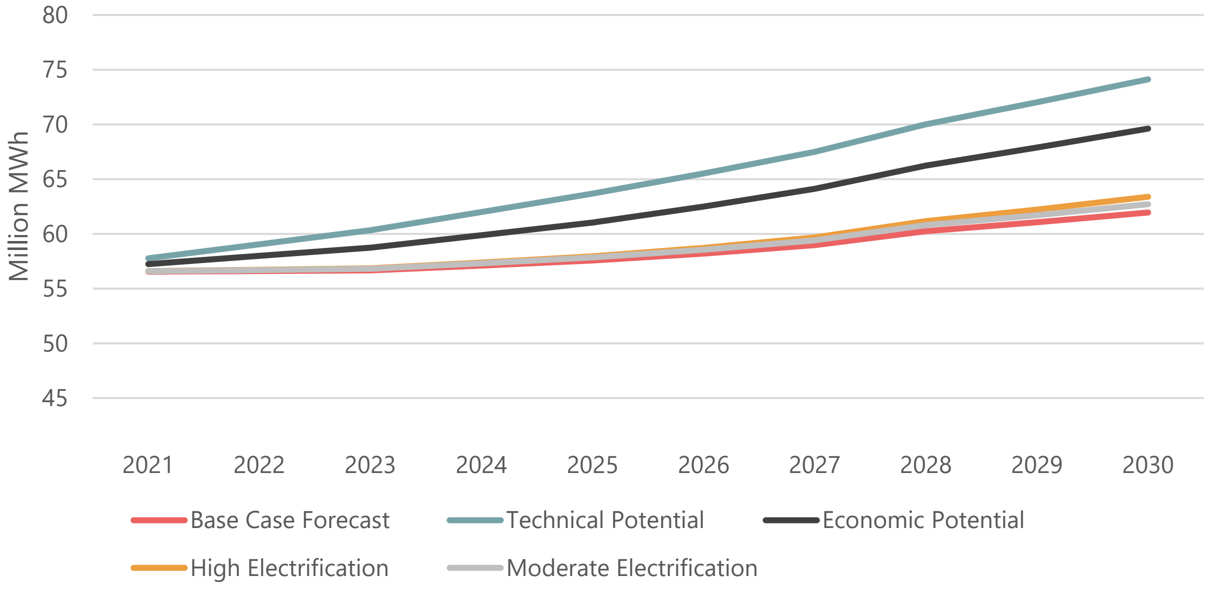
Similarly, in Figure 4-5, total propane sales are expected to decline, but at a greater rate than for natural gas. Additionally, the difference between the technical and economic scenarios shows little distinction, indicating that we found most conversions of propane end uses (primarily space heating and water heating) passed the cost-effectiveness test. As a result, the potential adoptions of electrification technologies are also expected to have a higher share than natural gas by 2030.

FIGURE 4-5 COLORADO TOTAL PROPANE SALES UNDER ELECTRIFICATION SCENARIOS



For electricity, sales are expected to increase over the Base Case. Figure 4-6 illustrates how each potential scenario is expected to affect total Colorado electricity sales. One can see that electric sales are expected to increase in the Base Case, with electrification having very minor effects in the High and Moderate Electrification scenarios. However, the economic and technical potentials exhibit a much higher effect on electricity sales by 2030, well above the forecasted Base Case.

FIGURE 4-6 COLORADO TOTAL ELECTRICITY SALES UNDER ELECTRIFICATION SCENARIOS



4.2 CARBON EMISSIONS SCENARIOS AND BENEFICIAL ELECTRIFICATION IMPACTS

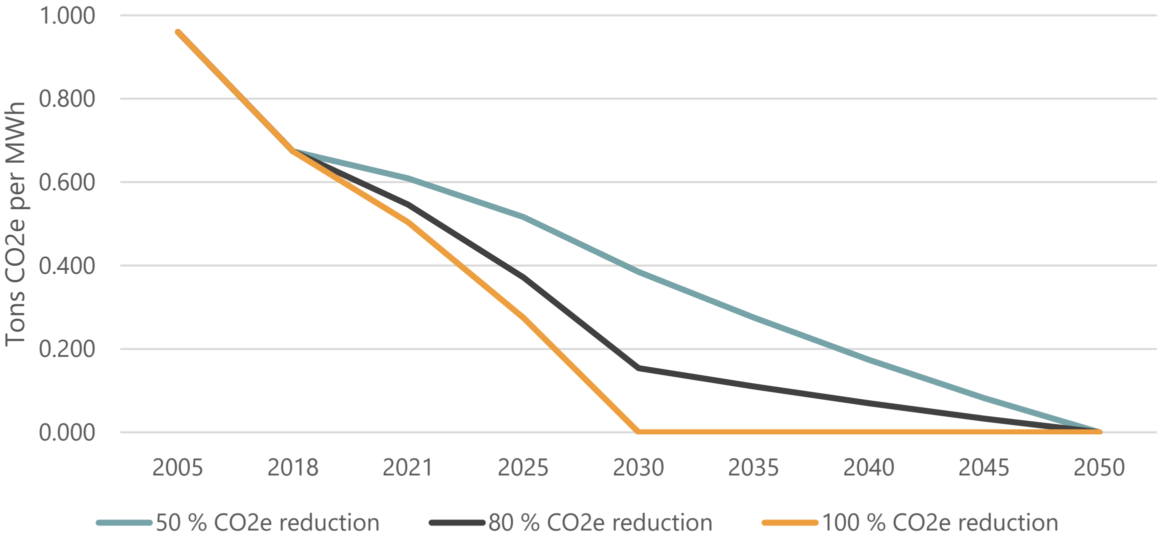
GDS modeled carbon emissions effects of electrification using three scenarios to compare CO2e emissions from the electricity sector that describe potential statewide emissions or utility-specific emissions that may occur based on current utility plans. All assume some level of CO2e emissions intensity reductions from the 2005 and 2018 historical statewide average and were modeled using a linear reduction in emissions. Specific utilities can be expected to differ and the reduction in emissions can be expected to occur in steps as coal plants are retired or other forms of fossil fuel generation reduce their generation of electricity. The three scenarios are:

- 100 percent carbon reduction in 2030, retained through 2050
- 80 percent reduction in carbon in 2030, with a year on year decline to 2050 (the base case, or central case)
- 50 percent reduction in carbon in 2030, with a year on year decline to 2050

The 80 percent reduction scenario (the Base Case) mirrors Xcel Energy’s commitment and the requirements in SB 19-236. It is also the carbon scenario we used to gauge cost-effectiveness of beneficial electrification and subsequent statewide adoptions under the High Electrification and Moderate Electrification scenarios. The 50 percent reduction and 100 percent reduction by 2030 scenarios are used to create a possible range of emissions reductions that other utilities may achieve and to compare the relative carbon emissions impact should beneficial electrification take place under the High Electrification and Moderate Electrification scenarios.

To model the effect of electrification, GDS converted historical CO2e emissions from the electricity sector in an emissions rate (tons of CO2e per MWh) using historical 2005 and 2018 data from EIA. Figure 4-7 illustrates the relative emission rate effect from 2005 through 2050. The emissions rate assumptions are based on the Base Case electricity consumption forecast and historical EIA emissions data to arrive at the necessary total emissions reduction required to achieve the emissions rate in each carbon scenario, relative to the 2005 baseline total electricity sector emissions. With electrification, it is important to note that the increase in electricity sales will require additional investments in clean energy resources in order to avoid increasing overall CO2e emissions. Due to the relatively modest effect on electricity sales modeled in this study – an increase of 2.3 percent in the High Electrification Scenario and 1.2 percent in the Moderate Scenario, GDS did not reanalyze the underlying emissions rate required to achieve the gross emissions reduction under these scenarios.

FIGURE 4-7 ELECTRICITY EMISSIONS RATE (TONS CO2E PER MWH)



To understand the implication of the declining emissions in any of the carbon scenarios and the impact that electrification would have on net CO2e, GDS analyzed the minimum electricity efficiency required to achieve the same emissions output compared to an MMBtu of natural gas being combusted. In trading reductions in emissions from the combustion of fossil fuels for emissions from the electricity grid, a minimum efficiency in the new electrical equipment is needed to at least result in no net emissions increase. Most heat pumps have average heat delivery or removal efficiencies substantially above 100 percent, while electric resistance equipment typically has a heat delivery efficiency of approximately 100 percent. Other equipment or climate factors can vary the efficiencies relative to natural gas combustion, but in general, using a heat pump to deliver heat will result in fewer emissions from consumption of electricity than electric resistance heating. The analysis produced a snapshot of break-even efficiencies across the three scenarios. With 0.058 tons of CO2e emitted by combusting natural gas, the same amount of heat from an electrical appliance would need to produce the same or less CO2e.

Figure 4-8 illustrates the results of the analysis using lifetime emissions rates that may be experienced in Colorado should the above scenarios take place. The results do not exactly track the emissions scenarios as the lifetime emissions rate (tons CO2e per MWh) change. As a result of ongoing decreases in electricity CO2e emissions, an electrical appliance installed at some point over the next decade would show progressively lower net emissions over the life of the product. Figure 4-8 indicates that as Colorado's electricity supply continues to reduce its carbon emissions, the efficiency of electrical equipment required to achieve a net carbon reduction is likewise reduced.

FIGURE 4-8 ELECTRICAL EFFICIENCY REQUIRED TO ACHIEVE BREAK-EVEN CO2E IMPACTS

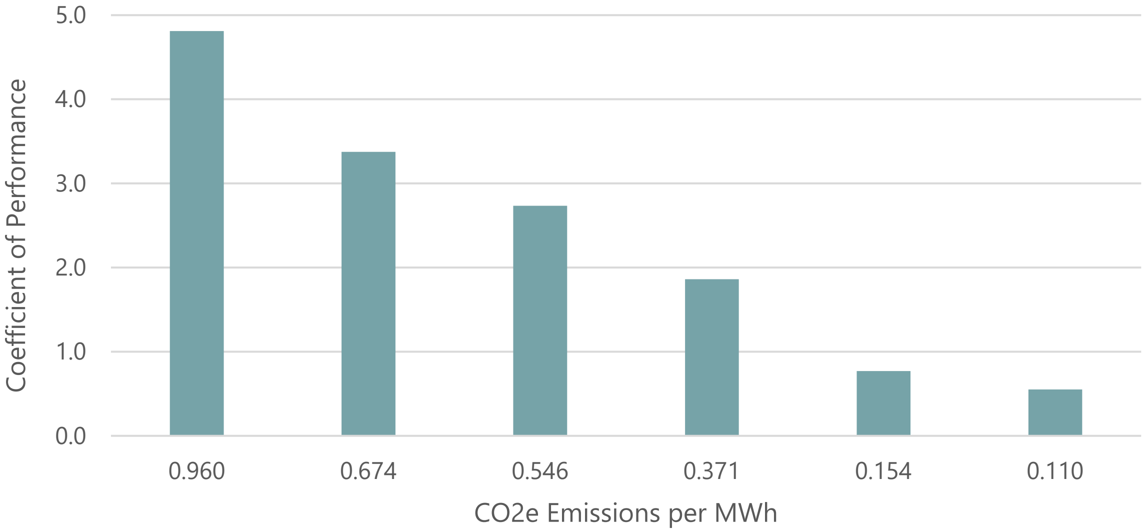


Figure 4-8 illustrates that were Colorado to maintain its 2005 electricity emissions rate (estimated at 0.960 tons of CO2e per MWh), a heat pump would require a coefficient of performance[37] (COP) well above even modern heat pumps—a COP of 4.8. The 2018 emissions rate (estimated at 0.674 tons of CO2e per MWh), were it to be constant for the life of an electrical appliance, allows for a COP of 3.4 as a break-even efficiency, a more realistic break-even number for modern heat pumps (though still high). GDS estimates that in 2021, the Colorado emissions rate will be 0.546 tons of CO2e per MWh in the Base Case, allowing a heat pump to achieve a COP of 2.7 were the emissions rate to be maintained over the life of the measure – an achievable efficiency for many cold-climate

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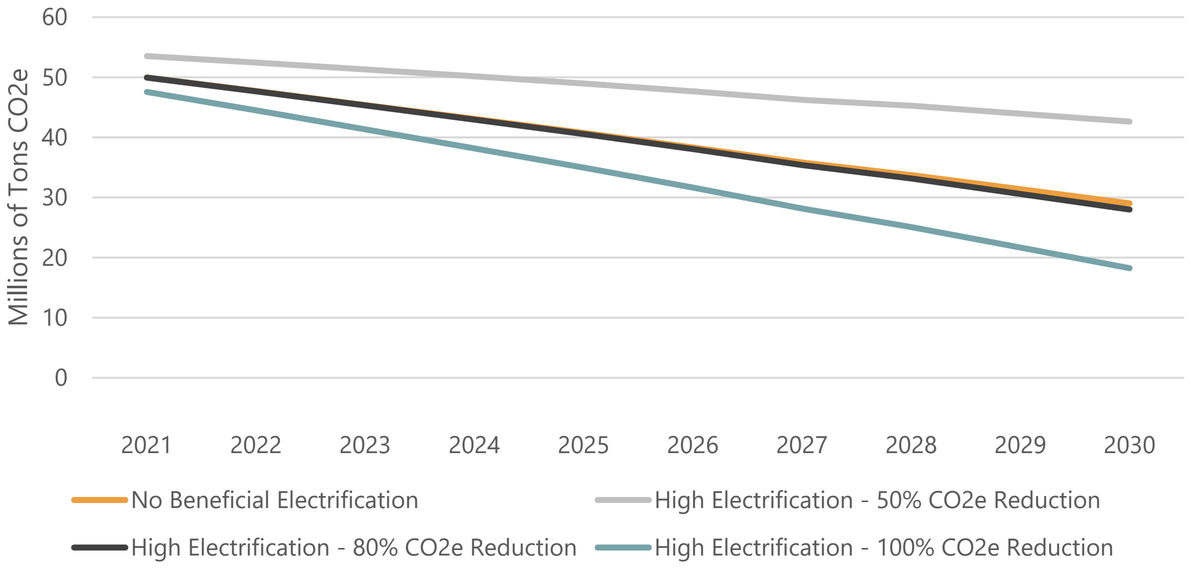
[37] The coefficient of performance (COP) describes how much heat energy is provided by a heat pump relative to the amount of electrical energy input. It shows that a heat pump can provide an efficiency greater than 100 percent. In contrast, electric resistance heat is approximately 100 percent efficient, indicating a COP of 1.0.

heat pumps and strong indicator that with ongoing decarbonization of the electricity grid, electrification with heat pumps will be broadly beneficial.

Overall, the presence of beneficial electrification can have an important, though modest, effect on emissions over the 2021-2030 timeframe. The much larger effect is on the underlying decarbonization of the electricity grid. To understand the relative importance, GDS applied the assumptions regarding the adoption of beneficial electrification under the Base Case – an 80 percent reduction in electricity grid emissions – to the other two decarbonization scenarios. In all three cases, the combined statewide emissions from natural gas, propane, and electricity consumption decline. The minor difference between the High Electrification scenario and the Base Case illustrates that, regardless of the electricity decarbonization scenario, electrification poses limited risk in unintendedly increasing overall statewide carbon emissions over the next decade.

FIGURE 4-9 TOTAL CO2E FROM NATURAL GAS, PROPANE, AND ELECTRICITY CONSUMPTION



The more substantial benefit of electrification can be expected to occur after 2030. Indeed, our modeling indicates that the High Electrification Scenario could reduce Colorado's net cumulative emissions by over 3.5 million short tons of CO2e by the end of 2030, assuming the Base Case 80 percent reduction in CO2e. However, over the lifetime of the measures that would be installed by the end of 2030, the reduction in emissions total over 16 million tons of CO2e.[38] While Figure 4-9 shows a smaller impact by 2030, reaching that level of electrification has substantial impacts beyond 2030 due to the ongoing emissions effects of measures installed from 2021 through 2030, all of which would be expected to continue operating and reducing net CO2e emissions beyond 2030.

Overall, the results for the High and Moderate Electrification scenarios model annual adoptions to approach or exceed current mature natural gas energy efficiency programs by 2030. The High Electrification scenario estimates that in 2030, that year's addition of beneficial electrification technology impacts approximately 1.1 percent of the estimated Base Case natural gas sales. The Moderate Electrification scenario estimates that 0.7 percent of 2030 natural gas sales are impacted by beneficial electrification technology being adopted in 2030. The Moderate Electrification Scenario aligns with Xcel Energy's 2019-2020 natural gas energy efficiency program targets.[39] Over the 2021-2030 decade, the beneficial electrification adoption model rises to these levels, with later years in the decade approximating a mature natural gas energy efficiency program and earlier years reflecting growth in market preparation, awareness, and acceptance.

Below we describe the details of each sector-level analysis with more granular breakouts that describe end-use or subsector estimates of beneficial electrification potential and adoptions.

4.3 END-USE SHARE OF ELECTRIFICATION

In our analysis and forecasting we found two key end-uses that can contribute to the vast majority of beneficial electrification impacts from 2021-2030—space heating and water heating in existing residential and commercial buildings. These two end-uses are key consumers of natural gas and propane, constituting 46 percent (space heating) and 31 percent (water heating) of fossil fuel

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[38] This assumes that all further electrification efforts cease and only the equipment installed by the end of 2030 continues to operate—a conservative view. Emissions reduction would be far higher were electrification efforts to continue and grow.

[39] https://www.xcelenergy.com/staticfiles/xe-responsive/Company/Rates%20&%20Regulations/Regulatory%20Filings/DSM-Plan.pdf

reduction in the High Electrification scenario. New construction of residential and commercial buildings is also an important source of building electrification, covering 13 percent of fossil fuel savings. For new construction, the end-uses are dominated by space heating and water heating end-uses. Table 4-3 compares the results across end-uses in 2030.

TABLE 4-3 END USE CONTRIBUTIONS TO BENEFICIAL ELECTRIFICATION IN 2030 – HIGH ELECTRIFICATION SCENARIO

	MMBtu Savings in 2030	Percent of 2030 MMBtu Savings
Existing Residential and Commercial Buildings	17,111,844	81%
Space Heating	9,728,356	46%
Residential	6,972,454	33%
Commercial	2,755,902	13%
Water Heating	6,645,575	31%
Residential	5,451,695	26%
Commercial	1,193,880	6%
Other Existing Residential and Commercial End-Uses	737,913	3%
Residential and Commercial New Construction	2,854,502	13%
Industrial	1,231,554	6%
Total	**21,197,900**	**100%**

In addition to the construction of new buildings, we also expect that the industrial sector will adopt heat pumps for water heating and space heating. Modeling for the industrial sector did not attempt to break-out end uses.

Underpinning the analysis of beneficial electrification in Colorado are effects on end-uses for the residential, commercial, and industrial sectors. Below we describe the results for each sector's analysis, drawing out the more granular results that lead to the aggregated results presented above.

4.4 RESIDENTIAL SECTOR RESULTS

GDS analyzed the potential for beneficial electrification by investigating space heating, water heating, clothes dryers, and cooking end-uses. For existing homes, we modeled the cost-effectiveness and adoption of measures whether replaced at the end of their useful life or if a consumer decided to replace working equipment that still had one-third of its life remaining. The analysis also considered cost-effectiveness factors for all-electric new homes, multifamily dwellings, and if a low-income household adopted a beneficial electrification technology.[40] For multi-family homes, the EIA data did not indicate any presence of propane use. As such, multi-family homes were only modeled for natural gas savings.

At a high level, GDS found that many space heating and water heating beneficial electrification technologies are cost-effective. Additionally, we observed that there is not a major distinction between the mTRC results and the consideration of whether a household may be low-income or not. While there are some specific exceptions (described below, in the end-use category discussion), it leads to the conclusion that the non-energy benefit resource multiplier used for low-income households is not a major driver determining cost-effectiveness of beneficial electrification. This is not to say that low-income households may not receive higher non-energy benefits from electrification—simply that those benefits do not drive cost-effectiveness conclusions about any given technology or purchase condition. As a result, the overall potential for electrification is split between low-income and non-low-income proportional to the current population in Colorado.

Table 4-4 presents the results of our beneficial electrification achievable potential analysis for the residential sector for both the High Electrification and Moderate Electrification scenarios, differentiating results between low-income and non-low-income households. The new construction segment is included to add context to the relative percentages but was not

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[40] Under the modified TRC test, low-income households received a multiplier of 1.5 of the value of gas savings, reflecting recent Colorado treatments of non-energy impacts. Non-low-income households receive a non-energy benefit multiplier of 1.2. This is described in the Technical Appendix.

differentiated by income category. Additionally, the modeling did not include new homes with propane in the forecast of new construction electrification opportunities. For natural gas, low-income households have an opportunity to provide between 20 and 25 percent of the fossil fuel energy savings potential by the end of the decade.

TABLE 4-4 CUMULATIVE RESIDENTIAL POTENTIAL BY INCOME AND NEW CONSTRUCTION, 2030

	HIGH ELECTRIFICATION		MODERATE ELECTRIFICATION	
Household Type	**Natural Gas**	**Propane**	**Natural Gas**	**Propane**
Non-Low-Income	58%	79%	56%	79%
Low-Income	23%	21%	23%	21%
New Construction	19%	N/A	20%	N/A
Total	100%	100%	100%	100%
MMBtu reduced, 2030	14,452,607	1,171,196	7,551,499	636,751
Cumulative 2030 Total CO2e net reduction (short tons)[41]	2,567,351		1,537,356	
Measure Life Total CO2e net reduction (short tons)[42]	12,461,592		6,454,545	

We found that residential new construction using all electric homes could contribute to approximately 20 percent of natural gas electrification savings. The remaining 80 percent of savings come from existing homes, differentiated by their income categories in Table 4-4, above.

Table 4-5 presents the relative share of natural gas and propane savings by residential end-use. The study shows that space heating is the largest contributor to savings potential for both natural gas and propane homes, with water heating providing considerable savings opportunities. Our

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[41] CO2e emissions are presented as the aggregate of propane and natural emissions using tons per MMBtu emissions factors. Those factors are 0.05849 MMBtu/ton of natural gas and 0.06775 MMBtu per ton of propane. Net emissions factor the changing electricity grid profile over time through 2030 using the Base Case emissions rate changes, found in the Technical Appendix.

[42] Measure life CO2e reductions are reductions associated with beneficial electrification measures installed through 2030, but with emissions effects counted for the life of the measures, which extend beyond 2030.

analysis finds that clothes dryers and cooking appliances can provide *some* electrification opportunities but are not major sources of electrification potential in either the High or Moderate Electrification scenarios. As noted above, new all-electric homes could provide approximately 20 percent of the residential sector's electrification potential for natural gas but are not considered for propane savings due to uncertainty regarding the expected number of propane heated new homes. This is not to say that new homes that would otherwise use propane cannot contribute electrification benefits, but rather could not be modeled with the available data across the ten-year period.

TABLE 4-5 CUMULATIVE RESIDENTIAL POTENTIAL BY END-USE AND NEW CONSTRUCTION, 2030

	HIGH ELECTRIFICATION		MODERATE ELECTRIFICATION	
Existing End-Uses	**Natural Gas**	**Propane**	**Natural Gas**	**Propane**
Clothes Dryers	0.4%	0.4%	0.4%	0.4%
Cooking	2%	3%	2%	3%
Space Heating	44%	56%	45%	56%
Water Heating	34%	40%	32%	40%
New Construction	19%	N/A	20%	N/A
Total	100%	100%	100%	100%
Cumulative MMBtu through 2030	14,452,607	1,171,196	7,551,499	636,751

The GDS modeling found that a substantial share of Colorado homes could be expected to adopt beneficial electrification in either the High Electrification or Moderate Electrification scenarios. For the High Electrification scenario, the modeling revealed the following approximate numbers across single family and multifamily dwellings:

- Over 142,000 homes adopting heat pumps for space conditioning
- Over 195,000 homes adopting heat pump water heaters
- Nearly 78,000 homes switching from gas or propane to induction cook tops
- Just over 27,000 homes adopting heat pump clothes dryers
- Just under 30,000 all-electric new homes, with about 80 percent being single family

While these counts are not specific expectations, they are the result of the modeling across multiple residential end-uses.

GDS analyzed the modeling results to draw out the relative savings coming from single family and multifamily homes. GDS was unable to obtain data to address the presence of propane in multifamily homes, and as explained above, new homes of any type. We modeled propane under the assumption that all existing propane homes were single-family existing homes. Table 4-6 describes the annual savings of natural gas between single-family and multi-family homes, reflecting the number of measures that were modeled to have been installed by the end of 2030.

TABLE 4-6 CUMULATIVE RESIDENTIAL POTENTIAL BY HOME TYPE, 2030

Home Type	High Electrification Natural Gas Only	Moderate Electrification Natural Gas Only
Existing Homes		
Single Family	66%	66%
Multi-Family	14%	14%
New Homes		
Single Family	15%	16%
Multi-Family	4%	4%
Total	**100%**	**100%**
Total Cumulative MMBtu	**14,452,607**	**7,551,499**

Below we describe our findings related to each end-use and present findings that reflect on nuances within each end use, home type, or income category.

4.4.1 Clothes Dryers

GDS modeled the opportunity for beneficial electrification to replace clothes dryers with either electric resistance clothes dryers or heat pump clothes dryers. We found the following:

- Heat pump clothes dryers were cost-effective across all scenarios with two exceptions: early replacement of natural gas clothes dryers in non-low-income single family or multi-family households. These two exceptions were nearly cost-effective in 2021 and were found to be cost-effective by 2026.

- For propane (LP) [43] users, we only modeled the cost-effectiveness of clothes dryers for single family homes, but found any scenario to be highly cost-effective, implying cost-effectiveness for multi-family homes as well.
- We modeled electric resistance clothes dryers assuming an ENERGY STAR® certified clothes dryer was being installed. For those with a propane fueled clothes dryer, the electric resistance option was cost-effective, but less so than the heat pump clothes dryer.
- Electric resistance clothes dryers did not pass cost-effectiveness when replacing a natural gas-fired clothes dryer for any early-replacement scenario. For a natural gas dryer being replaced at the end of its useful life with an ENERGY STAR electric resistance clothes dryer, this measure passed cost-effectiveness, but by a very slim margin.

We attribute the analysis results to two major factors:

- Low prices for natural gas limit some opportunities, while higher cost LP makes any electrification of clothes dryers beneficial.
- Heat pump clothes dryers use substantially less electricity than electric resistance clothes dryers, creating lower impacts to the electric grid and reducing electricity consumption relative to electric resistance options. Being cost-effective for nearly all cases, heat pump clothes dryers may be the preferred beneficial electrification option over electric resistance dryers.

4.4.2 Cooking

GDS modeled the cost-effectiveness of using induction-style cooktops compared to cooktops that use natural gas or LP. In all cases, an induction cooktop was found to pass cost-effectiveness. While electric resistance cooktops are common, induction cooktops operate more efficiently and have many similar qualities in the cooking experience as natural gas or LP (e.g. temperature control). Induction cooktops also offer the safety of not having a hot surface by only creating heat

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[43] Liquefied Petroleum

within the cookware, not on the stove itself. Due to these features, we assumed that the adoption of electric resistance cooktops was not the right comparison for electrification, with induction cook-tops the better option for considering adoption across the residential segment.

In short, induction cooktops offer a cost-effective beneficial electrification option that appears to be cost-effective for the residential market. It also offers an electrification benefit compared to electric resistance cooktops in addition to other non-energy factors, such as safety and, compared to electric resistance cooktops, an improved cooking experience. That said, electric resistance cooktops should not be fully rejected as an option for beneficial electrification, however, their adoption rate may be lesser than induction cooktops which offer greater non-energy benefits.

4.4.3 Existing Homes Swimming Pool Heating

Residential swimming pools are not common. However, for homes that heat their pools, pool heaters can be substantial consumers of energy. GDS analyzed the opportunity to switch residential pool heaters from natural gas heaters to heat pumps. This option was not found to be cost-effective. In this scenario, we assumed that pools were already taking advantage of other efficiency technologies, such as covers, reducing the heat loss from the pool. For a residence that heats a pool with LP, we expect that shifting to a heat pump would be cost-effective. However, without greater information on the current market saturation of LP-heated residential swimming pools we were unable to include such an analysis in the study to reach a conclusion about the technical, economic, or achievable potentials.

4.4.4 Existing Homes Water Heating

Water heating is the second highest consumer of natural gas or LP in a typical home. The opportunities for beneficial electrification include either using an electric resistance water heater, a very common and inexpensive type of water heater, or a heat pump water heater. Heat pump water heaters use approximately one-half to one-third of the electricity to heat water compared to an electric resistance water heater. GDS modeled both technologies to understand the relative cost-effectiveness and potential for beneficial electrification adoption. We considered the factors of single family compared to multifamily options, as well as low-income and non-low-income households. We also considered the tradeoffs between electrifying tank-style water heaters and instantaneous fossil fuel-fired water heaters.

We found the following results:

- Heat pump water heaters were cost-effective in nearly all cases. The exception was for cost-effectiveness in 2021 for non-low-income homes (single family or multifamily) with natural gas tank-based water heaters (either replacing early or at the end of their useful life). By 2026, that exception was no longer the case and heat pump water heaters were cost-effective regardless of income type.
- Heat pump water heaters were cost-effective compared to instantaneous water heaters in all cases.
- Heat pump water heaters were highly cost-effective when compared to any type of LP water heating.
- Electric resistance water heaters were only cost-effective for LP users. They were not cost-effective for *any* natural gas scenario.

Overall, the results suggest that heat pump water heaters are a good option for beneficial electrification in the residential sector. Caution should be taken with electrifying using electric resistance water heaters due to cost-effectiveness consideration for natural gas users and potential impacts on the electricity grid. Electric resistance water heating technology is common and can be part of a utility's demand response program. Some speculate that electric resistance technology may be useful to consider as a medium of energy storage to utilize variable renewable power sources. Many of these same features can be found in heat pump water heaters, though with a lower time-sensitive effect and with greater sensitivity to cycling than with electric resistance technology. However, over the next ten years, the relatively modest adoption mitigates any near-term grid management considerations. Individual utilities may find different conclusions about the value of electric resistance water heaters based on their specific needs and the use of residential water heaters in demand response programs.

4.4.5Existing Homes Space Heating

GDS based its analysis of residential space heating cost-effectiveness on IECC Climate Zone 5 (CZ5), where fully 93.5 percent of Coloradoans live[44] as shown in Table 4-7 below. CZ5 spans most of the Front Range and eastern plains as well as six counties in the western half of the state. Climate zone 4 (CZ4) is located in the far south eastern portion of the state, with the central mountain region being made of up mostly Climate Zone 6 and 7 (CZ6 and CZ7), with several western counties also being in CZ6. There is limited information on the relative uses of LP compared to natural gas by climate zone, making it difficult to estimate the potential and adoption by climate zone. CZ5 is large enough that it can be used for representing the overall state.

TABLE 4-7 COLORADO 2018 POPULATION AND EXAMPLE LOCATIONS BY CLIMATE ZONE

IECC Climate Zone	2018 Population	Percent of CO Population	Example Cities or Counties
CZ4	36,398	0.6%	Otero, Baca, Las Animas
CZ5	5,324,653	93.5%	Denver, La Plata, Pueblo
CZ6	63,052	2.9%	Moffat, Chaffee, Conejos
CZ7	170,208	3.0%	Park, Jackson, Rio Grande

Other than total populations, GDS was unable to obtain information related to climate zone-based population factors. This includes the factors of low-income households, multifamily and single-family households, the amount of residential new construction in each climate zone, and the relative use of gas or LP in each climate zone. While state-level data was available for these factors, the use of CZ5 as the basis for cost-effectiveness allows for statewide factors to be applied to CZ5 to best represent an analysis of the statewide potential for beneficial electrification of space heating. GDS completed an analysis on the additional climate zones to analyze the relative effects of electrifying space heating in those climate zones, presented below.

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[44] GDS combined information on county populations from the Colorado State Demography Office, Vintage 2018, prepared October 2019 and Pacific Northwest National Labs, "Guide to Determining Climate Regions by County," August 2015 https://www.energy.gov/sites/prod/files/2015/10/f27/ba_climate_region_guide_7.3.pdf

RESULTS

Within CZ5, GDS modeled over 136 combinations of technology and market considerations. For the technologies, these included:

- A home with a furnace being replaced with a cold-climate central heat pump
- A home with a boiler being replaced by a cold-climate central heat pump
- A minisplit-style heat pump providing 100 percent of space heating needs, compared to a furnace
- A dual-fuel home using a minisplit-style heat pump to partially offset a furnace
- A ground source heat pump to provide 100 percent of space heating (single-family only)

These five technology options were analyzed with break-outs across the following factors:

- Single-family and multi-family
- Low-income and non-low-income households
- Early replacements and end-of-life replacements of HVAC equipment
- Natural gas and LP
- Homes with and without air-conditioning

The combinations present many potential applications of heat pumps for space heating. In the case of the ground source heat pump, these were not analyzed for an existing multi-family building due to uncertainty regarding the potential logistics of installing such a system. This is not to say that such opportunities do not exist, simply that we were unable to reasonably model it for purposes of identifying the potential.

The analysis led to the following results:

- For LP users, all 40 space heating cases were found to be cost-effective. Quite simply, the cost of LP overcomes any other considerations for purposes of the cost-effectiveness test. The results are strongly positive, with the ground source heat pump exhibiting the lowest cost-effectiveness ratio (but still over 1.5 for a non-low-income household without air-conditioning)

- Natural gas heated homes *without air-conditioning* are not cost-effective for electrifying their space heat. The savings associated with improved air-conditioning efficiency are key to electrifying space heating
- Ground source heat pumps in single-family homes with natural gas heat and air conditioning achieve a benefit-cost ratio over 1.0 by 2026, regardless of the presence of air-conditioning. Their cost-effectiveness in multifamily buildings is unknown but may be cost-effective as the cost of the in-ground portion of the system and other associated expenses are spread across multiple households
- For natural gas heated homes *with air-conditioning*, all combinations of technologies were found to be cost-effective, with air-conditioning efficiency savings tipping the technology options into being cost-effective in contrast to their counterparts without air conditioning.
- Of the natural gas heated homes with air-conditioning, the *least* cost-effective scenario was found to be for the use of a minisplit heat pump to provide *supplemental* heat when a furnace needed to be replaced. This is due to the need to consider the cost of the furnace as a portion of the overall equipment cost. The implication is that when a furnace needs to be replaced, it is more cost-effective to simply install a heat pump instead of a furnace.

Overall, the analysis found that over 2021-2030, many existing Colorado homes could be changed to heat pumps under many technology and market conditions using the mTRC cost-effectiveness test and social cost of carbon. For homes without air-conditioning, electrification is not cost-effective, pointing out the critical link between the overall efficiency of a home's HVAC system and the linkage of electrification to efficiency considerations.

4.4.6 New Homes

GDS investigated the cost-effectiveness of new homes to be built with all-electric space heating, water heating, cooking, and other end-uses. We assumed that such a new home would be designed with an all-electric condition in mind, eliminating the need for natural gas supply as well as a natural gas meter. For both natural gas and LP, we further assumed that indoor piping was not included in the design or costs. Overall cost savings are found by not having to run any natural gas piping by the host utility and that a builder would not have to charge for installing natural gas or LP pipes in the home. Due to data limitations, we did not forecast the potential of all-electric new homes that would otherwise be fueled by LP, but did conduct an economic analysis under the mTRC to understand the implications for LP savings.

Based on general industry research and anecdotal information provided from discussion with Colorado utilities, we assumed the following cost savings associated with an all-electric new home:

- $2,000 associated with utility and property installation of natural gas pipes and meters (natural gas homes only)
- $1,000 associated with installing indoor pipes to distribute natural gas or LP to end-uses

These cost savings reduce the incremental cost of electrification technologies—the same general technologies described above for existing homes, with the exception of a heat pump that only meets a portion of a home's space heating needs (and would therefore need a natural gas or propane supply). Should a new home be constructed to *partially* electrify, the cost conditions and considerations for a new home installing measures at the end of the existing measures useful lives would apply, a consideration we did not analyze separately for new homes.

The overall conclusions regarding new homes include:

- All-electric new single-family homes without air-conditioning (we expect a very rare likelihood) are not cost-effective for electrification unless the home would otherwise be heated with LP.
- We found that new multi-family homes heated with natural gas and without air-conditioning were slightly cost-effective. We expect this condition to be exceedingly rare. They were not included in the potential results.
- All-electric new homes with air-conditioning are cost-effective for single-family and multifamily homes. This is an area of substantial opportunity and represents 20 percent of the 2030 cumulative residential electrification potential. As with existing homes, it points to the importance of air-conditioner efficiency savings

For modeling the potential for all-electric residential new construction, we did not apply any potential to homes that would be served by LP, regardless of cost-effectiveness. The volume of residential LP consumption for existing homes is relatively small compared to natural gas. Further, GDS was unable to obtain data indicating a reasonable forecast for how many new homes may be constructed in Colorado that would be served by LP. As such, we elected to omit that potential in the estimate, but do find that they would be cost-effective due to the relative cost-effectiveness of all-electric homes that would otherwise use natural gas - an indication of a general opportunity.

4.4.7 Climate Zone Considerations for the Residential Sector

GDS analyzed how space heating results may differ across Colorado's climate zones. Rather than attempt to reanalyze all 136 combinations across three different climate zones, GDS tested the sensitivity to cost-effectiveness for a single natural gas measure that was cost-effective in CZ5. As noted above, nearly all technology and cases of single-family and multi-family homes were found to be cost-effective *if they had air-conditioning*.

We selected the case of a single family, non-low-income home, replacing their HVAC equipment early (1/3 of the useful life remaining). The electrification technology was a central heat pump providing 100 percent of space heating needs with a 16 seasonal energy efficiency rating (SEER) rating and 9.0 HSPF[45]. An early replacement is the *worst case scenario* from an economics standpoint, with the need to consider the full cost of the new equipment only being offset by the present value of the future expenditure of replacing the existing system. We found that there was little difference in the mTRC results, with results varying by +/- 0.02 across the climate zones.

The outcome of this climate zone analysis indicates that the results for CZ5 are generally applicable to all four of Colorado's climate zones. Given the prevalence of CZ5 for Colorado's population, the overall effect of differences in energy consumption are minor across the climate zone. There is some potential that system sizing may result in somewhat different cost elements, with system design considerations tailored to each climate zone being a consideration beyond

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[45] HSPF (heating seasonal performance factor)

the scope of this study. In general, changes in system sizing will affect both the natural gas system and heat pump system, somewhat offsetting each other. While more research may be appropriate for the myriad housing conditions and locations found throughout Colorado, we believe that with the general results found for CZ5, the results are appropriate to apply broadly to Colorado's residential sector.

4.5 COMMERCIAL SECTOR RESULTS

GDS analyzed the potential for beneficial electrification in the commercial sector by investigating space heating, water heating, clothes dryers and commercial kitchen electrification opportunities, as well as swimming pool heating. GDS used the latest Commercial Buildings Energy Consumption Survey[46] to understand the relative share that major end-uses have for natural gas and propane energy consumption in commercial buildings. Table 4-8 describes the share of natural gas and propane consumption associated with major end-uses.

TABLE 4-8 END USE SHARES OF BUILDING ENERGY CONSUMPTION

End-Use	Natural Gas	Propane
Space Heating	55%	45%
Water Heating	14%	23%
Cooking	28%	26%
Clothes Dryers	2%	6%
Pool Heating	1%	1%

Space heating, water heating, and cooking are the largest uses for natural gas and propane. Below we describe the findings for each end-use. For new construction, our model applied the same factors as an end-of-life replacement option. There is no distinction in the energy or cost criteria for new construction, with GDS not applying cost savings associated with an "all-electric new commercial building" due to wide ranges of possibilities regarding natural gas connection costs and internal natural gas or LP piping.

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[46] https://www.eia.gov/consumption/commercial/data/2012/ the West Mountain region was used for natural gas, while the propane share of end-use consumption used the West region.

Table 4-9 summarizes our results for the commercial sector's existing buildings electrification potential by end-use, with cumulative results in 2030. Electrifying space heating is the dominant opportunity - nearly two-thirds of the beneficial electrification opportunity is space heating. Natural gas water heating represents the next largest opportunity, making up 28 percent of the estimated natural gas savings electrification adoptions. Commercial cooking equipment makes up the balance of natural gas savings at approximately seven percent of the reduction in natural gas consumption.

For propane customers, space heating is also the dominant opportunity due to the relative cost-effectiveness of electrifying space heating for commercial building propane users. Water heating also provides a substantial share of the propane savings. Due to measure cost-effectiveness, switching from propane cooking equipment to electricity makes up 15 percent of the share of propane savings.

TABLE 4-9 CUMULATIVE ANNUAL SAVINGS FOR EXISTING COMMERCIAL BUILDINGS, 2030[47]

	HIGH ELECTRIFICATION		MODERATE ELECTRIFICATION	
Commercial End-Use	**Natural Gas**	**Propane**	**Natural Gas**	**Propane**
Existing Buildings				
Clothes Dryers	0%	1%	0%	1%
Cooking	7%	15%	7%	15%
Pool Heating[48]	0%	1%	0%	1%
Water Heating	28%	27%	28%	27%
Space Heating	65%	57%	65%	57%
Total MMBtu Existing Buildings	1,761,613	331,353	957,746	180,149
Cumulative 2030 Total CO2e net reduction (short tons)	970,422		618,766	
Measure Life Total CO2e net reduction (short tons)[49]	2,968,221		1,575,106	

For new commercial buildings GDS only modeled natural gas buildings. No information was available about the potential for new commercial buildings that would use propane. To arrive at the underlying natural gas consumption of new commercial buildings, we utilized Xcel Energy's forecast of new commercial accounts and applied the average 2018 natural gas consumption of existing commercial accounts to approximate how much natural gas the forecasted accounts would use.[50] This volume of natural gas was extrapolated to the state level by using the share of commercial natural gas sales associated with Xcel Energy and assuming the share and growth over the decade would apply across the state.

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[47] Column totals may not add to 100 percent due to rounding

[48] We do not present a section on swimming pool heating. While it was found to be cost effective to switch from a LP swimming pool heater to a heat pump it was not so for natural gas.

[49] Measure life CO2e reductions are reductions associated with beneficial electrification measures installed through 2030, but with emissions effects counted for the life of the measures, which extend beyond 2030.

[50] This forecast was developed prior to COVID-19. The near and long-term effects of COVID-19 on energy markets are not reflected in this study or its approach.

RESULTS

To analyze the potential for electrifying commercial natural gas end-uses, the same existing building measures and shares of natural gas end-use loads were assumed. To model the cost-effectiveness of specific measures, we treated each measure and its incremental cost as equivalent to an "end of useful life replacement" as analyzed with existing buildings. We did not model the potential for "all-electric" commercial buildings due to uncertainty about the technical opportunity, market decisions, and cost factors associated with avoiding the expense of connecting to a natural gas supply.

The results for new commercial buildings show opportunities for the adoption of electrification technologies and natural gas savings. Some caution is warranted at over-interpreting the results. In either the High or Moderate Electrification scenario, a modest shift in the number of new commercial buildings adopting beneficial electrification could alter the results. Using the adoption curve that was applied to existing commercial buildings, a total of 52,962 MMBtu of natural gas savings in the High Electrification scenario and 28,794 MMBtu in the Moderate Electrification scenario emerged. The specific end uses indicated opportunities for cooking, water heating, and space heating. However, the end-use break-down may be less useful than the overall savings effect (these are discussed in the end-use sections, below).

GDS took a data-driven approach to modeling the opportunity for beneficial electrification in the commercial sector. However, there are multiple factors that may influence beneficial electrification that cannot be easily modeled, such as the willingness for the commercial sector to electrify more of its load. Additionally, utility forecasts for new commercial accounts may differ from our assumption about the new commercial building natural gas load (in the Base Case). As a result, this forecast provides a projection for the adoption of electrification technologies, though individual and commercial segment decisions may drive different outcomes.

Below we discuss our findings for each of the commercial building end-uses.

4.5.1 Clothes Dryers

For clothes dryers, smaller units were used to model performance under the assumption that the existing natural gas or LP equipment would be replaced at the end of its useful life (the most cost-advantageous option from an economic perspective). Clothes dryers are estimated to contribute to approximately two percent of the appliance end-use category's natural gas use and six percent of propane use. Overall, clothes dryers are a relatively small contributor to natural gas or LP consumption but do have opportunities for electrification. These include electric resistance clothes dryers and heat pump clothes dryers, with heat pump clothes dryers being a relatively recent technology available in the U.S. market. For clothes dryers we assume that the relative energy consumption ratios between natural gas or LP dryers and electric resistance or heat pump clothes dryers represents a reasonable performance and incremental cost that can be generally applied to smaller and larger clothes drying technology. As such, the conclusions regarding cost-effectiveness may apply to larger institutional clothes dryers. That said, larger commercial laundry equipment may be difficult to electrify (e.g. institutional clothes dryers) and likely has much smaller market presence for LP users. Market data and technology information related to electrifying large institutional clothes dryers were not available for this study.

We found the following:

- Neither electric resistance nor heat pump clothes dryers are cost-effective compared to natural gas clothes dryers.
- For LP users, selecting a new heat pump or electric resistance clothes dryer is cost-effective and are viable beneficial electrification options.

For LP fueled clothes dryers, we expect that the market for clothes dryers tends to emphasize the smaller models of clothes dryers that were modeled, rather than large institutional clothes dryers that might be found in hotels or other institutional settings. Further research may be warranted to understand the potential for electrifying natural gas clothes dryers in institutional settings.

4.5.2 Cooking Equipment

Cooking in the commercial sector is a large consumer of energy. Approximately 28 percent of natural gas and 26 percent of propane use in the commercial sector is associated with cooking equipment. GDS modeled a variety of commercial cooking equipment based on current ENERGY STAR options for commercial cooking equipment. The measures include griddles, ovens, fryers, and steam cookers. For early replacement options, we assumed a commercial kitchen would replace a standard efficiency unit with an ENERGY STAR electric unit. For end-of-life or new construction equipment, we compared the ENERGY STAR natural gas unit performance to an ENERGY STAR electric equivalent.

We found the following:

- Switching from LP to electricity is cost-effective for each case of cooking equipment we analyzed. However, replacing a combination oven before the end of its useful life (or as new construction) marginally passes the mTRC test, suggesting some caution.
- For natural gas commercial customers, steam cookers are cost-effective for both early replacement and end of useful life (or new construction) installations. A combination oven replaced at the end of its useful life was also cost-effective for natural gas users.
- For natural gas customers, installing an ENERGY STAR electric version of a griddle, convection oven, or fryer was not cost-effective. Neither was the installation of a combination oven being replaced before the end of its useful life.

While GDS included all cost-effective measures in its estimate of the economic, High Electrification, and Moderate Electrification potentials, some caution may be warranted for some cooking measures. Many commercial chefs prefer to cook with natural gas and LP. The benefits include careful control of heat and general familiarity with how the equipment will affect food. While GDS applied its adoption rate approach to the cost-effective commercial cooking measures, overcoming hurdles related to current practices and familiarity may be key to achieving adoptions. While this is true of all beneficial electrification measures, it may be particularly important for cooking due to the direct engagement by professionals in using natural gas and LP equipment for their trade.

4.5.3 Water Heating

Water heating for domestic uses is a large consumer of natural gas and propane in the commercial sector. Approximately 14 percent of natural gas and 23 percent of propane consumption in the commercial sector is associated with heating water. We modeled the opportunity for beneficial electrification to impact water heating by focusing on commodity tank-based and instantaneous natural gas or LP water heaters to compare to heat pump water heaters and electric resistance water heaters. These commodity water heaters are estimated to consume 94 percent of the commercial market's water heating energy use.[51] Larger systems that rely on boilers were not considered due to uncertainty regarding cost and technology applicability.

We found that:

- Replacing LP water heaters with either electric resistance or heat pump water heaters was cost-effective in all combinations of the baseline water heating equipment. Whether an LP water heater would be replaced with an electric option at the end of its useful life or before, electrification was beneficial.
- For natural gas users considering a heat pump water heater, the analysis found that all were cost-effective whether the baseline technology was a tank-style or instantaneous gas water heater being replaced before or at the end of its useful life.
- For electric resistance water heaters that would displace natural gas, the only condition that would pass cost-effectiveness testing would be if an existing instantaneous natural gas water heater were at the end of its useful life.

The implication of these results points to heat pump water heaters as being broadly applicable across natural gas and LP users in the commercial sector. The same conditions exist for a new

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[51] https://www.eia.gov/consumption/commercial/data/2012/

commercial building, under which we assumed the same conditions as a water heater being replaced at the end of its useful life.

Some caution is warranted regarding promoting electric resistance water heaters under beneficial electrification; the cost-effective conditions are not universal. Some utilities include these water heaters in their demand response program as they can offer a form of thermal energy storage. Additionally, there is speculation that with high penetration of variable renewable energy systems on the electricity grid, electric resistance water heaters may be able to be used to absorb excess renewable energy, using the water heater as a method of thermal storage. Our analysis did not include these considerations in modeling electric resistance water heaters.

4.5.4 Space Heating

The commercial sector is diverse in the size and nature of its space heating equipment. To model space heating, several types of fossil fuel systems were modeled to represent general conditions in the commercial building market. From these, GDS developed options for electrification that included replacing smaller residential-sized equipment, packaged roof-top equipment, and systems often found in larger facilities, such as those using central boilers. For smaller systems, we analyzed both early replacements and end-of-life replacements. In the case of roof-top dual fuel packaged systems, we assumed an end-of-life replacement at the time the air-conditioner failed. Larger central systems with boilers were considered for end-of-life replacements. We acknowledge that the analysis does not capture all possible forms of space heating in commercial buildings. New technologies are emerging, such as large variable refrigerant flow systems, which may be suitable for new construction. At this point, the costs and design considerations are not generalizable enough to the broad commercial sector. Further research may be warranted for the commercial sector to understand customer or building-type-specific designs. To address the ongoing innovation in heat pump space heating equipment and diversity of the commercial sector, GDS assumed that cost-effective solutions would be available and adopted over the decade, allowing the share of commercial space heating to experience electrification potential and adoptions not reflected in specific technology cases.

As with the residential sector, we focused on climate zone five (CZ5). As described in the residential space heating section, above, CZ5 is home to 93.5 percent of Coloradoans. We assume that a similar level of commercial activity takes place in CZ5, making it a key area for beneficial electrification cost-effectiveness analysis. We did analyze climate zones 4, 6, and 7 for the same technologies and include a discussion on the results, below. However, for purposes of forecasting the statewide technical, economic, and High and Moderate Electrification scenarios, we only applied the results of CZ5.

We modeled 12 packages of space heating technologies and market conditions for both natural gas and LP. For natural gas, we also applied a generalized cost-effective assumption to space heating heat pumps (LP technology cases were generally cost-effective). These technology packages are listed below, in Table 4-10.

TABLE 4-10 COMMERCIAL SECTOR SPACE HEATING TECHNOLOGY PACKAGES

Baseline Technology	Electrification Technology
Central Air-Forced Furnace with DX cooling[52]	Central Heat Pump – 100% heating
Central Air-Forced Furnace with DX cooling	Central Heat Pump – 80% heating displacement
Central Air-Forced Furnace with DX cooling	Minisplit Heat Pump – partial displacement
Central Air-Forced Furnace with DX cooling	Ground Source Heat Pump – 100% heating
Roof-top unit with DX cooling and gas heat	Dual fuel heat pump with furnace – 60 MBH heat pump, 150 MBH furnace
3,500 MBH (thousand Btu per hour) boiler with 200 ton central water cooled chiller	200 ton water source heat pump with 2,800 MBH boiler
1,750 MBH boiler with hot water radiators, no cooling load	Ductless heat pumps with partial displacement (80%) of heat with cooling load added
3,500 MBH boiler with 200 tons DX cooling	Ground source heat pump
80% AFUE natural gas furnace	Generalized heat pump displacing 100% of natural gas use (COP = 2.5)
80% AFUE natural gas furnace	Generalized heat pump displacing 85% of natural gas use (COP = 3.0)

These are examples of many types of possible baseline technologies that could be found in the commercial sector and are potentially electrifiable. Within the commercial sector, packaged roof-top units (RTUs) are very common. EIA estimates that 42 percent of commercial sector space heating use comes from packaged systems. Our modeling of the roof-top unit being converted to a dual-fuel heat pump with partial displacement is meant to analyze an off-the-shelf technology that is broadly applicable to the commercial sector. These measure mixes are intended to capture the overall trade-offs of operational conditions and cost factors that may generally be available by electrifying commercial space heating. They should not be thought of as specific recommendations or the only possible mix of technologies. The generalized heat pump option captures the assumption that cost-effective adoptions will occur over the decade.

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[52] DX cooling refers to “direct expansion” cooling. Direct expansion cooling is a common style of air conditioning. Refrigerant in pipes is used to directly cool air. It is found in residential and commercial air conditioners. The alternative approach is to use a chiller in which water or coolant is first chilled by the refrigerant before conditioning the air.

Our modeling revealed the following results:

- For natural gas, only one specific technology passed the cost-effectiveness test: a minisplit heat pump introduced at the end of an air-conditioner's useful life. In this scenario, the existing furnace continues to provide space heat at the coldest temperatures, while the minisplit heat pump is sized to provide space cooling. As an end-of-life replacement for the air conditioner, this measure nearly passes cost-effectiveness.
- The packaged dual fuel roof-top unit (RTU) nearly passes cost-effectiveness for natural gas displacement when replacing an end-of life RTU. As noted above, packaged systems are very common in the commercial sector and worthy of further research and technology development.
- In contrast to natural gas, most instances of the commercial heating measures using LP were cost-effective, for all end-of-life or early replacement conditions. The exceptions were the large boiler systems. We expect that those are exceedingly rare for LP users, though have no market data to confirm whether that is the case.
- Air-conditioning savings matter. Moving to a modern cold climate high performance heat pump offers air-conditioning energy savings to the commercial sector, just as it does the residential sector. This points out the important linkage between the electrification of space heating and air-conditioning energy efficiency. In all the scenarios, base-case air conditioners were assumed to have a SEER of 13, with modern heat pumps having substantially higher SEER ratings, particularly minisplit heat pumps.

4.5.5 Climate Zone Considerations for the Commercial Sector

GDS modeled the above technologies for all four of Colorado's IECC climate zones. Xcel Energy's Denver equivalent full load hours were scaled to these climate zones by the ratio of heating degree days and cooling degree days (base 65) for the La Junta weather station (CZ4), Eagle weather station (CZ6), and Aspen weather station (CZ7). The technical specification of the equipment were not changed, nor were the market prices. It is possible that in some cases, heating loads may require larger heat pumps or air-conditioners, a scope of analysis outside this project. The purpose of the analysis was to investigate the relative performance one might expect and the cost-effectiveness results to identify if any climate zone indicated different results.

The following observations were found for the technology-specific packages:

- For CZ4, the dual fuel RTU became cost-effective, as did the partial displacement central heat pump (end-of-life), and both cases of partial displacement minisplit heat pumps (end-of-life and early replacement). The ground source heat pump replacing a boiler also became cost-effective. In general, CZ4 exhibited the greatest opportunity for space heating technology compared to other climate zones.
- For CZ6, the ductless minisplit providing partial heating displacement, and installed to replace an air conditioner at the end of its life was cost-effective (as with CZ5). No other natural gas systems were found to be cost-effective for CZ6. Otherwise for LP users, the same pattern as with CZ5 emerged.
- For CZ7, the results were the same as CZ5 and CZ6.

For commercial space heating, the low cost of natural gas creates a challenge for heat pumps to overcome cost-effectiveness limitations. It appears that one option is broadly applicable for commercial customers using natural gas—replacing an air-conditioner with a minisplit heat pump at the end of its useful life and using it to partially displace space heating. As a flexible technology, partial displacement minisplit heat pumps may be the best target for commercial sector electrification in the near-term. We saw that other forms of partial displacement were nearly cost-effective. The dual fuel RTU heat pump is an opportunity that may be appropriate for some cases and worthy of further investigation. Overall, large boiler systems will likely be challenging for beneficial electrification. These technology-specific observations do not discount the possibility that specific commercial customers or use-cases cannot be cost-effective. Anecdotal reports indicate some adoptions of heat pump technologies beyond what was modeled here. For this study, the anecdotal cases are challenging to extrapolate to a state-wide level. The generalized assumption that cost-effective heat pump options exist for the commercial sector and will be adopted during the next decade captures the opportunity and adoptions that cannot be detailed at the technology-specific level.

We also found a clear opportunity for the commercial sector: LP users can broadly benefit from space heating heat pumps. This is true in any climate of the four climate zones and only excludes larger boilers and institutional settings. As such, LP users may be an important group within the commercial sector to promote space heating with heat pumps. Their early adoptions may help improve cost-effectiveness and lead to adoptions by natural gas users.

Additional electrification opportunities exist in the commercial sector, though were not specifically modeled. These include forklift electrification, truck stop electrification, airport tug electrification, and other end-uses not associated with the major end-uses we modeled. To help illustrate potential beneficial electrification opportunities, GDS developed a technology snapshot to describe one case—truck-stop electrification.

4.5.5.1 Technology Snapshot – Truck Stop Electrification

Long haul trucks, commonly class 8 trucks, typically idle for several hours a day (up to 16 hours) at truck stops or rest areas to comply with federal regulations on the number of hours that can be driven in a single day. The impact of burning one to two gallons of diesel fuel per hour has negative effects on the operating and maintenance costs of the diesel engine, as well as leading to environmental emissions. Each gallon of avoided diesel fuel combustion avoids about 135g/hr of NOx emissions and approximately 33.8 lbs[53] of CO2e during idling each hour. With the advent of anti-idling technologies and legislation (in some states) to prohibit idling, the shore power industry has developed two different technologies that are being used and demonstrated across the country:

1 Off-board systems, sometimes called stationary systems, are permanently installed at truck stops. They can be designed so that no special equipment is needed on the truck. A driver

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[53] Assumes 0.0810 tons of CO2e per gallon of combusted diesel fuel, based on Climate Registry protocols and 1.5 gallons per hour consumed.

simply pulls into a designated parking spot, reaches out to an air hose and control module hanging from an overhead gantry, and inserts them into a special window template. An alternative off-board system design may require some equipment on the truck as well as on the ground. With off-board systems, the truck stop owner makes the capital investment and recoups its investment by selling services— electricity, Internet, entertainment—to the professional driver.

2 On-board systems, sometimes called mobile technologies, are installed on the truck. They generally comprise an inverter to convert 120-volt power, an electrical HVAC system, and the hardware to plug into "shore power" electrical outlets at truck stops. Some on-board systems use batteries that can either be charged by the main engine during driving, or plugged in during stops. With on-board systems, the truck owner makes the capital investment and maintains the equipment. The perceived advantage is that a driver can stop and use his or her system anywhere there is shore power.

Of the estimated 5,000+ truck stops in the United States, less than four percent are outfitted with the shore power electrification technology of either type. In Colorado, our research revealed only two truck stops that were registered as having shore power capability,[54] presenting a large technical potential for projects that would bridge the gap between reducing the idling of diesel vehicles today and preparing for the zero emission vehicles of the future. As the economics are the most common barrier for

FIGURE 4-10 EXAMPLE OF OFF-BOARD TRUCK STOP ELECTRIFICATION

Photo courtesy of US Department of Energy

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[54] Based on a personal communication with the owner of allstays.com

implementation, overcoming economic hurdles is the primary challenge to drive the shore power market forward.

To maximize investments in shore power, project planning and design should include sufficient power supply infrastructure to support electric vehicle charging equipment for medium and heavy-duty vehicle applications such as transformer upgrades, trenching and conduit runs. This future-proofing of projects will enable a more economical transition to charging infrastructure as the freight sector transitions to battery electric vehicles over the next decade.[55]

4.6 INDUSTRIAL SECTOR RESULTS

The industrial sector poses a challenge for electrification, but also some opportunities. LBNL[56] cites a study by EPRI indicating that by 2030, only 3.6 percent of the United States' industrial sector has technical potential for electrification, a stark contrast to residential and commercial buildings. LBNL found that "some processes have no existing or currently available replacement," as well a lack of data regarding current industry practices and on how well new technologies will work as replacements, and uncertainty regarding the status of existing equipment that has been amortized. Two fundamental challenges are 1) the diversity and industry-specific uses for natural gas, and 2) the low cost of natural gas. From an economic standpoint, the low cost of natural gas poses a hurdle that limits the economic viability and ultimate adoptions of electrification in the industrial sector.

Nevertheless, there are opportunities. The industrial sector in Colorado is diverse. Colorado hosts a wide range of industries with substantial aggregate energy consumption. From a recent CEO report,[57] these include (among many):

- Petroleum and Coal Products

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[55] The Alternative Fuels Data Center provides resources on electric vehicle charging: https://afdc.energy.gov/fuels/electricity.html.

[56] Lawrence Berkeley National Labs, "Electrification of Buildings and Industry in the United States." March 2018, p. 20 http://ipu.msu.edu/wp-content/uploads/2018/04/LBNL-Electrification-of-Buildings-2018.pdf

[57] CEO, "Industrial Energy Efficiency and Distributed Generation Opportunities in Colorado." June 2017.

- Food Processing
- Nonmetallic Mineral Products
- Chemicals
- Paper Products
- Primary Metals
- Wood Products
- Beverage Products
- Plastics and Rubber

Each of these industry types have their own specialized processes, some of which may have potential for electrification. We do expect that many of the same space heating and domestic water heating technologies from the commercial sector would apply to industrial buildings, but that their underlying share of natural gas or propane consumption is minor relative to their use of these fuels for processes.

In theory, the *technical potential* for the industrial sector is very high. LBNL (2018, p. 43) notes a number of electrification technology opportunities. These include:

- Electrolytic reduction in nonferrous metal (excluding aluminum)
- Induction heating (metal fabrication)
- Electric boilers (widespread opportunities)
- Resistance heating and melting (glass industry)
- Direct Arc Melting (iron and steel)
- Industrial process heat pumps (food, pulp and paper, and chemicals)

Other opportunities include:

- Replacing fossil fuel powered well pumps with electric pumps
- Oil and gas industry uses of methane for pumps and controls
- Ultra-violet sterilization
- Pasteurization

- Agricultural uses of power-take offs (from tractors and other on-farm equipment)

However, in 2018 EPRI concluded that "the heterogeneity of applications and individual processes makes comprehensive modeling of the industrial sector difficult."[58] As such, GDS approached the industrial sector potential for electrification from 2021-2030 with caution. Our general approach was to assume that the technical potential reflected 3.6 percent of 2030 industrial sector natural gas and propane energy consumption, referencing LBNL's 2018 estimate. LBNL further notes that approximately 2.3 percent of direct energy consumption (e.g. natural gas or propane) is a "realistic" potential. Our approach was to use the "realistic" potential as a metric for the economic potential, with the economic potential being approximately 63 percent of the technical potential.

In terms of adoption rates under the High or Moderate Electrification scenarios, we approximated a 2030 cumulative adoption. The High Electrification adoption rate was selected as half the economic potential, or 1.15 percent of natural gas and propane consumption in 2030. The Moderate Electrification scenario halved this amount again, arriving at 0.575 percent of the technical potential. For all scenarios, the annual savings percentages were extrapolated backwards in a linear fashion to 2021. For example, across the decade, we estimate that 0.36 percent of the cumulative technical potential each year (one-tenth of 3.6 percent).

This approach is conservative in modeling the potential for beneficial electrification in the industrial sector. Given the uncertainty of the availability and applicability of electrification technologies to Colorado's industrial sector, this conservative approach avoids overstating the potential of any scenario. That said, we acknowledge the conservative nature of the approach. It is possible that individual companies or industry groups may embrace electrification technologies. The result may be that higher levels of electrification are reached.

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[58] EPRI, "U.S. National Electrification Assessment," April 2018, p. 36.

A second uncertainty of the industrial sector electrification efforts is the nature of the technologies that may be adopted and their effect on electricity or carbon emissions. The use of industrial heat pumps with high COPs will have greater effects on reducing carbon emissions than technologies that use electric resistance heating. To model the carbon effects of the industrial sector, we reviewed the performance of technologies for the commercial sector, noting the relationship between reductions in natural gas or propane MMBtu relative to increases in electricity consumption. These ratios (e.g. natural gas MMBtu reduction per kWh increase) were applied to the reduction in MMBtu in the industrial sector to develop an estimate of increases in electricity sales and the subsequent impact on net carbon emissions.

The end results are shown in Table 4-11, below.

TABLE 4-11 INDUSTRIAL SECTOR ELECTRIFICATION IMPACTS

	NATURAL GAS		PROPANE	
Potential	2025 Percent Sales	2030 Percent Sales	2025 Percent Sales	2030 Percent Sales
Base Case Forecast	100%	100%	100%	100%
Technical Potential	1.8%	3.6%	1.8%	3.6%
Economic Potential	1.2%	2.3%	1.2%	2.3%
High Electrification	0.6%	1.2%	0.6%	1.2%
Moderate Electrification	0.3%	0.6%	0.3%	0.6%
Base Case MMBtu	101,494,500	101,418,513	2,836,562	2,836,562
High Electrification MMBtu reduction	599,904	1,198,933	16,310	32,620
Moderate Electrification MMBtu reduction	299,952	599,467	8,155	16,310

Table 4-12 illustrates the 2030 impact of the estimated industrial sector electrification adoptions under each adoption scenario. While expected to be modest relative to the residential or commercial sector, the adoptions show incremental progress in what may be a challenging sector to electrify in the near term.

TABLE 4-12 INDUSTRIAL SECTOR NET CO2E IMPACTS

Scenario	HIGH ELECTRIFICATION	MODERATE ELECTRIFICATION
Cumulative 2030 Total CO2e net reduction (short tons)	381,967	190,983
Measure Life Total CO2e net reduction (short tons)[59]	841,793	410,818

The resulting savings from electrification in the industrial sector are approximately one-third that of the commercial sector. The specific nature of what electrification technologies may be adopted are uncertain, but based on our literature review, it appears that there are many viable options. That said, some caution is warranted due to the low price of natural gas and potential that large capital investments may dampen enthusiasm. However, as with the commercial sector, the motivations and sources of savings may be dependent on individual decisions and technologies that are near a tipping point for cost-effectiveness. At the least, some of the heat pump technologies for space heating and water heating are applicable to the commercial sector and may prove to be relatively low-hanging-fruit that would drive industrial sector electrification over the next ten years.

GDS did not directly estimate the potential for the oil and gas segment to contribute to electrification and CO2e emissions reductions. The oil and gas segment provides a specific opportunity for CO2e emissions reductions unavailable to other industrial segments. Direct emissions of methane occur in some segment end-uses. Electrifying the end-uses will remove the direct emissions and a source of a potential greenhouse gas. To help illustrate potential beneficial

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[59] Measure life CO2e reductions are reductions associated with beneficial electrification measures installed through 2030, but with emissions effects counted for the life of the measures, which extend beyond 2030.

electrification opportunities in the oil and gas segment, GDS developed a technology snapshot to describe a specific opportunity with potentially large CO2e reduction impacts.

4.6.1.1 Technology Snapshot – Converting Gas Pneumatic Pumps to Electric Pumps

Natural gas facilities often use gas pneumatic pumps to circulate glycol as part of the dehydration process to prepare gas for pipeline transport. Pneumatic pumps -also called "energy exchange" or kimray pumps- operate by tapping into the energy in compressed natural gas, which is convenient and readily available at natural gas facilities. However, the technology results in the venting of methane into the atmosphere. It is possible to eliminate the methane emissions by converting to electric glycol pumps. For facilities located near accessible grid power, the conversion is relatively straightforward and most often economical with a payback period typically under two years and often much shorter.

According to an EPA report[60], electrifying a typical glycol pump in a dehydration system can result in a methane emission reduction of 18,000 MMBtu annually. At an approximate upfront cost of $9,000 and a value of $2.75/mcf vented methane, the payback period is slightly over two months to complete the electrification retrofit (not counting cost of bringing electricity to the location). The exact impact of replacing a given pump depends upon the size of the pump, how it's operated within the specific facility, and the cost of connecting to an electrical energy source. It is possible that methane emission regulations in Colorado may require all facilities with access to grid electricity to electrify all gas pneumatic pumps in the fall of 2020.

Direct methane emissions have a global warming potential (GWP) of 21, meaning that a ton of vented methane has 21 times the global warming effect as emitting a ton of carbon dioxide. With 18,000 MMBtu of methane being directly emitted from a typical glycol pump, the equivalent carbon dioxide emissions amounts to 22,113 tons of CO2e *per year*. In contrast, combusting that same amount of natural gas would emit 1,053 tons of CO2e *per year*. Converting to electrical pumps and generating the electricity directly from methane would result in a net reduction of

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[60] https://www.epa.gov/sites/production/files/2016-06/documents/ll_glycol_pumps3.pdf

21,060 tons of CO2e *per year*. In terms of electrification benefits, a single typical glycol pump could reduce CO2e emissions over ten years by over 220,000 tons. Due to the GWP of methane, the cost-effectiveness (using the mTRC) of such conversions could be very high, though without specific costs associated with locations and pump conditions, somewhat speculative. The major uncertainty is the cost of bringing electricity to the pumps, which may be in remote areas. Extending power lines, using natural gas-powered generators, or solar photovoltaic systems with battery back-up may be viable options, but would also increase the cost of the electrification.

5 Conclusions

This study finds that there are substantial opportunities for beneficial electrification to reduce greenhouse gas emissions in Colorado over the next decade and beyond. These opportunities exist due to Colorado electric utilities' commitments to invest in clean energy generation and reduce emissions of greenhouse gases substantially from historical levels by 2030 and beyond. Beneficial electrification aligns with the State's long-term greenhouse gas emission policy goals and utility plans to reduce the carbon intensity of electricity supplies.

The study modeling and results indicate that a long-term, market transformation approach is needed to shift end-uses from fossil fuel combustion (or direct methane emissions) to low-carbon electricity. Colorado has a high saturation of natural gas and propane heating systems in its buildings and industrial processes and replacing those technologies in existing building stock will take time.

Our modeling suggests that over the next decade, beneficial electrification in buildings can move from a market position punctuated by anecdotal experience to one that begins to capture substantial market share. By the end of the decade, we forecast that beneficial electrification can rise to meet or exceed the performance of established and mature natural gas demand side management programs in terms of natural gas savings. The actual results will depend on a blend of policies, programs, and market acceptance of beneficial electrification technologies.

Within Colorado's residential and commercial buildings, space heating and water heating have the highest potential to drive the benefits of beneficial electrification. Leveraging advances in cold climate heat pumps and heat pump water heaters will contribute to favorable market experiences. For propane users, the cost savings of shifting to electricity can be an early source of success that can further market development that will extend to natural gas users. New construction markets pose another substantial opportunity for early success. Avoiding the expense of installing fossil fuel equipment and infrastructure for new homes or businesses can also eliminate the need for future retrofits.

In closing, we reiterate the summary of our key findings and recommendations provided in the Executive Summary. These findings and recommendations help "set the table" for Colorado to move forward with beneficial electrification efforts, with an eye toward near-term market preparation and development in the first half of the decade, with ever greater shares of market deployment continuing through 2030.

TABLE 5-1 BENEFICIAL ELECTRIFICATION KEY FINDINGS AND RECOMMENDATIONS

Key Finding	Recommendation
Colorado has substantial market potential to develop beneficial electrification over the 2021-2030 decade and beyond.	Colorado should enact policies to encourage the adoption of beneficial electrification technologies, especially related to heat pumps for space heating and water heating.
Over the next ten years (2021 to 2030) Colorado has the potential to cumulatively reduce net carbon emissions by approximately 3.5 million tons of CO2e through beneficial electrification. For measures installed in this timeframe, the potential for net lifetime emissions reductions exceeds 16 million tons of CO2e.	To maximize emissions reductions, Colorado should adopt policies that ensure the decarbonization of the state's electricity grid while monitoring the pace of electrification to ensure that it is achieving a beneficial outcome for CO2e emissions.
Electrifying propane-fueled end uses is highly cost-effective.	Colorado should prioritize policies and efforts to electrify propane-fueled end-uses while creating general electrification opportunities and awareness.
Colorado can take advantage of the work that other regions in the U.S. have undertaken to improve heat pump technology and grow the market for electrification technologies. These efforts may allow Colorado to move from a fossil-fuel dominated energy market for space heating and water heating more quickly and with fewer challenges than others.	Colorado should leverage the program design and technology specifications already developed by other regions, states, and utilities. These include efforts in the Pacific Northwest and Northeastern United States.

CONCLUSION

Key Finding	Recommendation
There is limited market intelligence on fossil fuel end-uses and saturations that is publicly available. To-date, utility market saturation studies have not deeply investigated electrification opportunities.	Colorado should develop market intelligence and track the adoption of beneficial electrification over time to facilitate long-term market development efforts.
Capturing the full potential of beneficial electrification will require a fundamental transformation and long-term transition that will need to take place over multiple decades.	Colorado should take a coordinated market transformation approach toward beneficial electrification that includes electric utilities, local jurisdictions, the private sector, and the State in order to achieve the long-term decarbonization goal.

6 Technical Appendix

FORECAST DATA ASSUMPTIONS

GDS developed general assumptions for the State of Colorado by review of past Colorado utility potential studies and IRP filings. The Xcel 2016 DSM Potential Study provided values for discount rates, electric and fossil fuel adders, and line losses while the Xcel IRP filing was used to estimate statewide Reserve Margin Multiplier levels. Finally, the Social Cost of Carbon was determined from a 2016 EPA technical support document. The following tables show the values used for modeling discounts, adders, and losses and energy forecast baselines and sources for natural gas, propane and electricity.

Input	Value	Source
Inflation Rate (%):	2.30%	US Inflation Forecast
Electric Nominal Discount Rate (%):	6.78%	Xcel 2016 DSM Potential Study
Fuel Nominal Discount Rate (%):	6.59%	Xcel 2016 DSM Potential Study
Cost of Carbon Nominal Discount Rate (%)	5.37%	2016 EPA Social Cost of Carbon Tech. Support Doc.
Fossil Fuel NEI Adder:	1.20	Public Service of Colorado 2019-2020 DSM Plan
LI Benefits NEI Adder:	1.50	Public Service of Colorado 2019-2020 DSM Plan

Line Losses	Summer On Peak (%)	Summer Off Peak (%)	Winter On Peak (%)	Winter Off Peak (%)	Summer Demand	Winter Demand	T&D	Reserve Margin Multiplier
Residential	1.12	1.10	1.12	1.10	1.03	1.03	1.0769	1.163
Commercial	1.12	1.10	1.12	1.10	1.03	1.03	1.0650	1.163
Source	*Xcel Plan*	*Xcel Plan*	*Xcel Plan*	*Xcel Plan*	*Xcel Plan*	*Xcel Plan*	*Xcel Plan*	*Xcel IRP*

ADOPTION RATE ASSUMPTIONS

GDS developed four scenarios across the residential, commercial, and industrial sectors, covering the technical, economic, and two achievable potentials for beneficial electrification in Colorado. For the achievable potentials, a High Electrification Scenario was developed, with a residential adoption curve that resulted in a maximum of 14 percent market penetration by 2030 for an individual technology case. This curve is informed by historical adoptions of heat pumps in the Pacific Northwest and Northeastern United States, and electric vehicles in Colorado.

	Year 2021	Year 2022	Year 2023	Year 2024	Year 2025	Year 2026	Year 2027	Year 2028	Year 2029	Year 2030
Incremental Annual										
High-NG	0.55%	0.67%	0.81%	0.98%	1.17%	1.40%	1.66%	1.96%	2.30%	2.67%
High-LP	0.55%	0.67%	0.81%	0.98%	1.17%	1.40%	1.66%	1.96%	2.30%	2.67%
Mid-NG	0.52%	0.57%	0.62%	0.67%	0.73%	0.79%	0.85%	0.92%	0.99%	1.06%
Mid-LP	0.52%	0.57%	0.62%	0.67%	0.73%	0.79%	0.85%	0.92%	0.99%	1.06%
Cumulative Annual										
High-NG	0.55%	1.22%	2.03%	3.01%	4.18%	5.58%	7.24%	9.20%	11.50%	14.17%
High-LP	0.55%	1.22%	2.03%	3.01%	4.18%	5.58%	7.24%	9.20%	11.50%	14.17%
Mid-NG	0.52%	1.09%	1.71%	2.38%	3.10%	3.89%	4.74%	5.65%	6.64%	7.70%
Mid-LP	0.52%	1.09%	1.71%	2.38%	3.10%	3.89%	4.74%	5.65%	6.64%	7.70%

Forecasts

GDS worked with the CEO and Colorado utilities to gather information, data, and perspectives on the current state of electrification in Colorado. These state resources were combined with data from the Energy Information Administration (EIA) and the Propane Education & Research Council (PERC) to forecast a base case use of natural gas, propane, and electricity from 2021 through 2030. Historical Colorado energy use by sector for 2013-2018 were used to determine a baseline energy forecast. Growth indices taken from the U.S. Energy Information Administration 2020 Annual Energy Outlook[1] were used to forecast annual growth for each fuel type and sector.

The following tables list values for energy forecast sales and customers for electricity, natural gas, and propane.

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[1] https://www.eia.gov/outlooks/aeo/

ELECTRICITY BASE CASE

Retail sales (Mwh)	Year 2021	Year 2022	Year 2023	Year 2024	Year 2025	Year 2026	Year 2027	Year 2028	Year 2029	Year 2030
Residential	19,663,681	19,880,830	20,088,855	20,443,050	20,801,323	21,262,597	21,837,660	22,672,644	23,457,055	24,228,919
Commercial	21,089,770	20,986,231	20,879,031	20,922,724	21,020,690	21,142,410	21,277,220	21,573,950	21,615,293	21,706,789
Industrial	15,791,796	15,734,165	15,694,081	15,737,257	15,746,280	15,788,408	15,852,168	16,004,264	15,986,093	16,014,024
Total	56,545,247	56,601,227	56,661,967	57,103,030	57,568,293	58,193,415	58,967,048	60,250,857	61,058,442	61,949,732

Retail Electric sales (Consumers)	Year 2021	Year 2022	Year 2023	Year 2024	Year 2025	Year 2026	Year 2027	Year 2028	Year 2029	Year 2030
Residential	2,430,417	2,457,833	2,485,784	2,513,922	2,541,897	2,569,683	2,597,264	2,624,744	2,651,886	2,678,589
Commercial	288,176	290,027	291,904	293,779	295,629	297,452	299,245	301,021	302,762	304,467
Industrial	16,038	16,054	16,071	16,196	16,328	16,506	16,725	17,089	17,318	17,571
Total	2,734,631	2,763,914	2,793,759	2,823,898	2,853,854	2,883,641	2,913,234	2,942,855	2,971,967	3,000,627

NATURAL GAS BASE CASE

Retail sales (MMBtu)	Year 2021	Year 2022	Year 2023	Year 2024	Year 2025	Year 2026	Year 2027	Year 2028	Year 2029	Year 2030
Residential	146,529,498	147,137,743	147,093,603	147,551,682	147,211,627	147,489,466	148,165,873	149,306,111	149,097,087	149,470,376
Commercial	63,770,213	63,716,627	63,863,080	64,321,647	63,961,875	63,817,009	63,808,621	64,387,137	64,162,577	64,116,730
Industrial	97,805,866	99,265,434	99,998,829	100,218,194	101,494,500	100,660,706	97,492,635	100,706,436	101,323,615	101,418,513
Total	308,105,576	310,119,804	310,955,512	312,091,523	312,668,002	311,967,182	309,467,129	314,399,684	314,583,279	315,005,618

Retail Natural Gas sales (Consumers)	Year 2021	Year 2022	Year 2023	Year 2024	Year 2025	Year 2026	Year 2027	Year 2028	Year 2029	Year 2030
Residential	1,858,461	1,880,478	1,901,854	1,922,970	1,943,986	1,964,841	1,985,516	2,006,047	2,026,254	2,046,050
Commercial	153,595	153,617	153,721	153,887	154,031	154,161	154,272	154,361	154,430	154,476
Industrial	9,955	10,104	10,178	10,200	10,330	10,246	9,923	10,250	10,313	10,323
Total	2,022,011	2,044,199	2,065,753	2,087,058	2,108,347	2,129,248	2,149,712	2,170,658	2,190,997	2,210,848

Retail sales (MMBtu)	Year 2021	Year 2022	Year 2023	Year 2024	Year 2025	Year 2026	Year 2027	Year 2028	Year 2029	Year 2030
Commercial - Existing	63,749,204	63,676,856	63,764,598	64,132,970	63,694,028	63,476,909	63,406,018	63,932,090	63,665,077	63,588,139
Commercial – Cumulative New Construction	21,008	39,771	98,482	188,677	267,847	340,101	402,602	455,047	497,500	528,590
Commercial - Total	63,770,213	63,716,627	63,863,080	64,321,647	63,961,875	63,817,009	63,808,621	64,387,137	64,162,577	64,116,730

Propane

Retail sales (MMBtu)	Year 2021	Year 2022	Year 2023	Year 2024	Year 2025	Year 2026	Year 2027	Year 2028	Year 2029	Year 2030
Residential	9,790,714	9,790,714	9,790,714	9,790,714	9,790,714	9,790,714	9,790,714	9,790,714	9,790,714	9,790,714
Commercial	3,202,570	3,202,570	3,202,570	3,202,570	3,202,570	3,202,570	3,202,570	3,202,570	3,202,570	3,202,570
Agriculture	183,004	183,004	183,004	183,004	183,004	183,004	183,004	183,004	183,004	183,004
Industrial (Non-Forklift)	1,281,028	1,281,028	1,281,028	1,281,028	1,281,028	1,281,028	1,281,028	1,281,028	1,281,028	1,281,028
Cylinder Markets	640,514	640,514	640,514	640,514	640,514	640,514	640,514	640,514	640,514	640,514
Internal Combustion	732,016	732,016	732,016	732,016	732,016	732,016	732,016	732,016	732,016	732,016
Total	15,829,846	15,829,846	15,829,846	15,829,846	15,829,846	15,829,846	15,829,846	15,829,846	15,829,846	15,829,846

Retail Propane sales (Consumers)	Year 2021	Year 2022	Year 2023	Year 2024	Year 2025	Year 2026	Year 2027	Year 2028	Year 2029	Year 2030
Residential	171,763	171,763	171,763	171,763	171,763	171,763	171,763	171,763	171,763	171,763
Commercial	12,137	12,137	12,137	12,137	12,137	12,137	12,137	12,137	12,137	12,137
Agriculture	2,774	2,774	2,774	2,774	2,774	2,774	2,774	2,774	2,774	2,774

Industrial (Non-Forklift)	3,369	3,369	3,369	3,369	3,369	3,369	3,369	3,369	3,369	3,369
Cylinder Markets	8,746	8,746	8,746	8,746	8,746	8,746	8,746	8,746	8,746	8,746
Internal Combustion	3,568	3,568	3,568	3,568	3,568	3,568	3,568	3,568	3,568	3,568
Total	202,357	202,357	202,357	202,357	202,357	202,357	202,357	202,357	202,357	202,357

Source. Sales and Consumer forecasts from the Annual Retail Propane Sales Report U.S. Odorized Propane Sales by State and End-Use Sector Reporting Year 2017 via the Propane Education & Research Council Published Report February 2019

AVOIDED COSTS

GDS utilized a blend of utility reported data, EIA reported information, and utilization of professional subscription services that aggregate FERC data to develop the avoided costs of energy for the implementation of electrification technologies, replacing the liquid or gas fueled versions of the equipment by end use. These avoided costs do not attempt to account for self-generation of electricity by customers – solar PV, wind, combined heat and power, and other possible on-site electricity generation technologies. The following table presents the energy and capacity values used in the electrification model.

Electric Avoided Cost Type	Unit	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Summer On Peak Energy	($/kwh)	0.041	0.044	0.047	0.051	0.053	0.055	0.057	0.060	0.063	0.065
Summer Off-Peak Energy	($/kwh)	0.041	0.044	0.047	0.051	0.053	0.055	0.057	0.060	0.063	0.065
Winter On Peak Energy	($/kwh)	0.041	0.044	0.047	0.051	0.053	0.055	0.057	0.060	0.063	0.065
Winter Off-Peak Energy	($/kwh)	0.041	0.044	0.047	0.051	0.053	0.055	0.057	0.060	0.063	0.065
Summer Generation Capacity	($/kW-YR)	92.04	93.84	95.76	97.68	99.60	101.64	103.68	105.72	107.88	110.04
Winter Generation Capacity	($/kW-YR)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Avoided Transmission Capacity	($/kW-YR)	11.53	11.76	11.99	12.23	12.48	12.73	12.98	13.24	13.51	13.78
Avoided Distribution Capacity	($/kW-YR)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

MEASURE ASSUMPTIONS

Measure consumption and savings data were developed using a combination of standard algorithms, industry reports, primary research, utility provided information and reports, as appropriate. Measure cost estimates leverage data in regional technical reference manuals and other national or regional databases such as the NREL Residential Efficiency Measures Database.[2] Measure saturation estimates primarily leverage from the EIA Residential Energy Consumption Surveys (CBECS and RECS), but also include utility-provided saturation data.[3] End-use load share of natural gas and propane are included in the body of the report. The following tables provide measure assumptions for the residential, commercial, industrial, agricultural, and transportation sectors used in this study. For the industrial sector, the measure level assumptions were not used to directly forecast the industrial beneficial electrification scenarios or cost-effectiveness.

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[2] https://remdb.nrel.gov/

[3] https://www.eia.gov/consumption

RESIDENTIAL MEASURES

Measure #	End Use	Electrification Measure	Home Type	Income Type	Electrification Incremental Cost	Baseline MMBtu / Yr	Electrification kWh / Yr	mTRC + SCC Cost Effectiveness
1	Appliances	Heat Pump Dryer - NG Baseline - Early Replacement	SF	NLI	$56	2.4	274	0.98
2	Appliances	Heat Pump Dryer - NG Baseline - Market Opp	SF	NLI	($101)	2.4	274	1.44
3	Appliances	Heat Pump Dryer - NG Baseline - Early Replacement	MF	NLI	$56	2.4	274	0.98
4	Appliances	Heat Pump Dryer - NG Baseline - Market Opp	MF	NLI	($101)	2.4	274	1.44
5	Appliances	Heat Pump Dryer - LP Baseline - Early Replacement	SF	NLI	$56	0	274	3.00
6	Appliances	Heat Pump Dryer - LP Baseline - Market Opp	SF	NLI	($101)	0	274	3.77
7	Appliances	Electric Clothes Dryer - NG Baseline - Early Replacement	SF	NLI	($82)	2.4	474	0.75
8	Appliances	Electric Clothes Dryer - NG Baseline - Market Opp	SF	NLI	($240)	2.4	474	1.01
9	Appliances	Electric Clothes Dryer - NG Baseline - Early Replacement	MF	NLI	($82)	2.4	474	0.75
10	Appliances	Electric Clothes Dryer - NG Baseline - Market Opp	MF	NLI	($240)	2.4	474	1.01
11	Appliances	Electric Clothes Dryer - LP Baseline - Early Replacement	SF	NLI	($82)	0	474	2.02
12	Appliances	Electric Clothes Dryer - LP Baseline - Market Opp	SF	NLI	($240)	0	474	2.28
13	Appliances	Heat Pump Dryer - NG Baseline - Early Replacement	SF	LI	$56	2.4	274	1.06
14	Appliances	Heat Pump Dryer - NG Baseline - Market Opp	SF	LI	($101)	2.4	274	1.53
15	Appliances	Heat Pump Dryer - NG Baseline - Early Replacement	MF	LI	$56	2.4	274	1.06
16	Appliances	Heat Pump Dryer - NG Baseline - Market Opp	MF	LI	($101)	2.4	274	1.53
17	Appliances	Heat Pump Dryer - LP Baseline - Early Replacement	SF	LI	$56	0	274	3.57
18	Appliances	Heat Pump Dryer - LP Baseline - Market Opp	SF	LI	($101)	0	274	4.43
19	Appliances	Electric Clothes Dryer - NG Baseline - Early Replacement	SF	LI	($82)	2.4	474	0.80
20	Appliances	Electric Clothes Dryer - NG Baseline - Market Opp	SF	LI	($240)	2.4	474	1.05
21	Appliances	Electric Clothes Dryer - NG Baseline - Early Replacement	MF	LI	($82)	2.4	474	0.80
22	Appliances	Electric Clothes Dryer - NG Baseline - Market Opp	MF	LI	($240)	2.4	474	1.05

Measure #	End Use	Electrification Measure	Home Type	Income Type	Electrification Incremental Cost	Baseline MMBtu / Yr	Electrification kWh / Yr	mTRC + SCC Cost Effectiveness
23	Appliances	Electric Clothes Dryer - LP Baseline - Early Replacement	SF	LI	($82)	0	474	2.38
24	Appliances	Electric Clothes Dryer - LP Baseline - Market Opp	SF	LI	($240)	0	474	2.63
25	Cooking	Induction Cooktop - NG baseline	SF	NLI	($163)	4.1	126	1.09
26	Cooking	Induction Cooktop - NG baseline	SF	NLI	($402)	4.1	126	1.63
27	Cooking	Induction Cooktop - NG baseline	MF	NLI	($163)	4.1	123	1.08
28	Cooking	Induction Cooktop - NG baseline	MF	NLI	($402)	4.1	123	1.62
29	Cooking	Induction Cooktop - LP baseline	SF	NLI	($163)	0	126	4.60
30	Cooking	Induction Cooktop - LP baseline	SF	NLI	($402)	0	126	5.14
31	Cooking	Induction Cooktop - NG baseline	SF	LI	($163)	4.1	126	1.18
32	Cooking	Induction Cooktop - NG baseline	SF	LI	($402)	4.1	126	1.72
33	Cooking	Induction Cooktop - NG baseline	MF	LI	($163)	4.1	123	1.17
34	Cooking	Induction Cooktop - NG baseline	MF	LI	($402)	4.1	123	1.71
35	Cooking	Induction Cooktop - LP baseline	SF	LI	($163)	0	126	5.52
36	Cooking	Induction Cooktop - LP baseline	SF	LI	($402)	0	126	6.06
37	HVAC	16 SEER / 9.0 hspf ASHP - NG furnace/CAC baseline - Early Replacement	SF	NLI	$647	62.2	4,562	1.45
38	HVAC	16 SEER / 9.0 hspf ASHP - NG furnace/CAC baseline - Market Opp	SF	NLI	($507)	62.2	4,562	1.47
39	HVAC	16 SEER / 9.0 hspf ASHP - NG furnace/CAC baseline - Early Replacement	MF	NLI	$369	35.4	2,600	1.45
40	HVAC	16 SEER / 9.0 hspf ASHP - NG furnace/CAC baseline - Market Opp	MF	NLI	($289)	35.4	2,600	1.47
41	HVAC	16 SEER / 9.0 hspf ASHP - LP furnace/CAC baseline - Early Replacement	SF	NLI	$647	0	4,562	3.65
42	HVAC	16 SEER / 9.0 hspf ASHP - LP furnace/CAC baseline - Market Opp	SF	NLI	($507)	0	4,562	3.82

Measure #	End Use	Electrification Measure	Home Type	Income Type	Electrification Incremental Cost	Baseline MMBtu / Yr	Electrification kWh / Yr	mTRC + SCC Cost Effectiveness
43	HVAC	16 SEER / 9.0 hspf DFHP - NG furnace/CAC baseline - Early Replacement	SF	NLI	$3,026	62.2	2,941	1.11
44	HVAC	16 SEER / 9.0 hspf DFHP - NG furnace/CAC baseline - Market Opp	SF	NLI	$1,504	62.2	2,941	1.16
45	HVAC	16 SEER / 9.0 hspf DFHP - NG furnace/CAC baseline - Early Replacement	MF	NLI	$1,725	35.4	1,677	1.11
46	HVAC	16 SEER / 9.0 hspf DFHP - NG furnace/CAC baseline - Market Opp	MF	NLI	$857	35.4	1,677	1.16
47	HVAC	16 SEER / 9.0 hspf DFHP - LP furnace/CAC baseline - Early Replacement	SF	NLI	$647	0	2,941	3.15
48	HVAC	16 SEER / 9.0 hspf DFHP - LP furnace/CAC baseline - Market Opp	SF	NLI	$1,504	0	2,941	2.73
49	HVAC	Ductless HP - whole house - NG furnace/CAC baseline - Early Replacement	SF	NLI	$1,211	62.2	3,974	1.67
50	HVAC	Ductless HP - whole house - NG furnace/CAC baseline - Market Opp	SF	NLI	$57	62.2	3,974	1.76
51	HVAC	Ductless HP - whole house - NG furnace/CAC baseline - Early Replacement	MF	NLI	$690	35.4	2,265	1.67
52	HVAC	Ductless HP - whole house - NG furnace/CAC baseline - Market Opp	MF	NLI	$32	35.4	2,265	1.76
53	HVAC	Ductless HP - whole house - LP furnace/CAC baseline - Early Replacement	SF	NLI	$1,211	0	3,974	4.22
54	HVAC	Ductless HP - whole house - LP furnace/CAC baseline - Market Opp	SF	NLI	$57	0	3,974	4.68
55	HVAC	Ductless HP - supplemental - NG furnace/CAC baseline - Early Replacement	SF	NLI	$1,875	62.2	2,514	1.71
56	HVAC	Ductless HP - supplemental - NG furnace/CAC baseline - Market Opp	SF	NLI	$5,441	62.2	2,514	1.03
57	HVAC	Ductless HP - supplemental - NG furnace/CAC baseline - Early Replacement	MF	NLI	$1,069	35.4	1,433	1.71

Measure #	End Use	Electrification Measure	Home Type	Income Type	Electrification Incremental Cost	Baseline MMBtu / Yr	Electrification kWh / Yr	mTRC + SCC Cost Effectiveness
58	HVAC	Ductless HP - supplemental - NG furnace/CAC baseline - Market Opp	MF	NLI	$3,101	35.4	1,433	1.03
59	HVAC	Ductless HP - supplemental - LP furnace/CAC baseline - Early Replacement	SF	NLI	$1,875	0	2,514	3.81
60	HVAC	Ductless HP - supplemental - LP furnace/CAC baseline - Market Opp	SF	NLI	$5,441	0	2,514	2.43
61	HVAC	GSHP - NG furnace/CAC baseline - Early Replacement	SF	NLI	$7,937	62.2	3,421	0.91
62	HVAC	GSHP - NG furnace/CAC baseline - Market Opp	SF	NLI	$6,783	62.2	3,421	0.90
63	HVAC	GSHP - LP furnace/CAC baseline - Early Replacement	SF	NLI	$7,937	0	3,421	2.30
64	HVAC	GSHP - LP furnace/CAC baseline - Market Opp	SF	NLI	$6,783	0	3,421	2.39
65	HVAC	16 SEER / 9.0 hspf ASHP - NG boiler/AC baseline - Early Replacement	SF	NLI	($538)	62.2	4,562	1.74
66	HVAC	16 SEER / 9.0 hspf ASHP - NG boiler/AC baseline - Market Opp	SF	NLI	($2,039)	62.2	4,562	1.77
67	HVAC	16 SEER / 9.0 hspf ASHP - NG boiler/AC baseline - Early Replacement	MF	NLI	($307)	35.4	2,600	1.74
68	HVAC	16 SEER / 9.0 hspf ASHP - NG boiler/AC baseline - Market Opp	MF	NLI	($1,162)	35.4	2,600	1.77
69	HVAC	16 SEER / 9.0 hspf ASHP - LP boiler/AC baseline - Early Replacement	SF	NLI	($538)	0	4,562	4.30
70	HVAC	16 SEER / 9.0 hspf ASHP - LP boiler/AC baseline - Market Opp	SF	NLI	($2,039)	0	4,562	4.32
71	HVAC	16 SEER / 9.0 hspf ASHP - NG furnace/No AC baseline - Early Replacement	SF	NLI	$3,026	62.2	5,644	0.60
72	HVAC	16 SEER / 9.0 hspf ASHP - NG furnace/No AC baseline - Market Opp	SF	NLI	$2,570	62.2	5,644	0.62
73	HVAC	16 SEER / 9.0 hspf ASHP - NG furnace/No AC baseline - Early Replacement	MF	NLI	$1,725	35.4	3,217	0.60

Measure #	End Use	Electrification Measure	Home Type	Income Type	Electrification Incremental Cost	Baseline MMBtu / Yr	Electrification kWh / Yr	mTRC + SCC Cost Effectiveness
74	HVAC	16 SEER / 9.0 hspf ASHP - NG furnace/No AC baseline - Market Opp	MF	NLI	$1,465	35.4	3,217	0.62
75	HVAC	16 SEER / 9.0 hspf ASHP - LP furnace/No AC baseline - Early Replacement	SF	NLI	$3,026	0	5,644	2.39
76	HVAC	16 SEER / 9.0 hspf ASHP - LP furnace/No AC baseline - Market Opp	SF	NLI	$2,570	0	5,644	2.48
77	HVAC	16 SEER / 9.0 hspf DFHP - NG furnace/No AC baseline - Early Replacement	SF	NLI	$3,026	62.2	4,024	0.46
78	HVAC	16 SEER / 9.0 hspf DFHP - NG furnace/No AC baseline - Market Opp	SF	NLI	$4,581	62.2	4,024	0.40
79	HVAC	16 SEER / 9.0 hspf DFHP - NG furnace/No AC baseline - Early Replacement	MF	NLI	$1,725	35.4	2,293	0.46
80	HVAC	16 SEER / 9.0 hspf DFHP - NG furnace/No AC baseline - Market Opp	MF	NLI	$2,611	35.4	2,293	0.40
81	HVAC	16 SEER / 9.0 hspf DFHP - LP furnace/No AC baseline - Early Replacement	SF	NLI	$3,026	0	4,024	1.82
82	HVAC	16 SEER / 9.0 hspf DFHP - LP furnace/No AC baseline - Market Opp	SF	NLI	$4,581	0	4,024	1.59
83	HVAC	Ductless HP - whole house - NG furnace/No AC baseline - Early Replacement	SF	NLI	$3,590	62.2	5,056	0.67
84	HVAC	Ductless HP - whole house - NG furnace/No AC baseline - Market Opp	SF	NLI	$3,134	62.2	5,056	0.70
85	HVAC	Ductless HP - whole house - NG furnace/No AC baseline - Early Replacement	MF	NLI	$2,046	35.4	2,882	0.67
86	HVAC	Ductless HP - whole house - NG furnace/No AC baseline - Market Opp	MF	NLI	$1,786	35.4	2,882	0.70
87	HVAC	Ductless HP - whole house - LP furnace/No AC baseline - Early Replacement	SF	NLI	$3,590	0	5,056	2.68
88	HVAC	Ductless HP - whole house - LP furnace/No AC baseline - Market Opp	SF	NLI	$3,134	0	5,056	2.80

Measure #	End Use	Electrification Measure	Home Type	Income Type	Electrification Incremental Cost	Baseline MMBtu / Yr	Electrification kWh / Yr	mTRC + SCC Cost Effectiveness
89	HVAC	Ductless HP - supplemental - NG furnace/No AC baseline - Early Replacement	SF	NLI	$1,875	62.2	3,596	0.70
90	HVAC	Ductless HP - supplemental - NG furnace/No AC baseline - Market Opp	SF	NLI	$5,441	62.2	3,596	0.47
91	HVAC	Ductless HP - supplemental - NG furnace/No AC baseline - Early Replacement	MF	NLI	$1,069	35.4	2,050	0.70
92	HVAC	Ductless HP - supplemental - NG furnace/No AC baseline - Market Opp	MF	NLI	$3,101	35.4	2,050	0.47
93	HVAC	Ductless HP - supplemental - LP furnace/No AC baseline - Early Replacement	SF	NLI	$1,875	0	3,596	2.79
94	HVAC	Ductless HP - supplemental - LP furnace/No AC baseline - Market Opp	SF	NLI	$5,441	0	3,596	1.87
95	HVAC	GSHP - NG furnace/No AC baseline - Early Replacement	SF	NLI	$10,316	62.2	4,503	0.41
96	HVAC	GSHP - NG furnace/No AC baseline - Market Opp	SF	NLI	$9,860	62.2	4,503	0.42
97	HVAC	GSHP - LP furnace/No AC baseline - Early Replacement	SF	NLI	$10,316	0	4,503	1.62
98	HVAC	GSHP - LP furnace/No AC baseline - Market Opp	SF	NLI	$9,860	0	4,503	1.66
99	HVAC	16 SEER / 9.0 hspf ASHP - NG boiler/No AC baseline - Early Replacement	SF	NLI	$1,841	62.2	5,644	0.73
100	HVAC	16 SEER / 9.0 hspf ASHP - NG boiler/No AC baseline - Market Opp	SF	NLI	$1,038	62.2	5,644	0.79
101	HVAC	16 SEER / 9.0 hspf ASHP - NG boiler/No AC baseline - Early Replacement	MF	NLI	$1,050	35.4	3,217	0.73
102	HVAC	16 SEER / 9.0 hspf ASHP - NG boiler/No AC baseline - Market Opp	MF	NLI	$592	35.4	3,217	0.79
103	HVAC	16 SEER / 9.0 hspf ASHP - LP boiler/No AC baseline - Early Replacement	SF	NLI	$1,841	0	5,644	2.88
104	HVAC	16 SEER / 9.0 hspf ASHP - LP boiler/No AC baseline - Market Opp	SF	NLI	$1,038	0	5,644	3.10

Measure #	End Use	Electrification Measure	Home Type	Income Type	Electrification Incremental Cost	Baseline MMBtu / Yr	Electrification kWh / Yr	mTRC + SCC Cost Effectiveness
105	**HVAC**	16 SEER / 9.0 hspf ASHP - NG furnace/CAC baseline - Early Replacement	SF	LI	($2,039)	62.2	4,562	1.87
106	**HVAC**	16 SEER / 9.0 hspf ASHP - NG furnace/CAC baseline - Market Opp	SF	LI	($507)	62.2	4,562	1.56
107	**HVAC**	16 SEER / 9.0 hspf ASHP - NG furnace/CAC baseline - Early Replacement	MF	LI	$369	35.4	2,600	1.54
108	**HVAC**	16 SEER / 9.0 hspf ASHP - NG furnace/CAC baseline - Market Opp	MF	LI	($289)	35.4	2,600	1.56
109	**HVAC**	16 SEER / 9.0 hspf ASHP - LP furnace/CAC baseline - Early Replacement	SF	LI	$647	0	4,562	4.28
110	**HVAC**	16 SEER / 9.0 hspf ASHP - LP furnace/CAC baseline - Market Opp	SF	LI	($507)	0	4,562	4.49
111	**HVAC**	16 SEER / 9.0 hspf DFHP - NG furnace/CAC baseline - Early Replacement	SF	LI	$3,026	62.2	2,941	1.17
112	**HVAC**	16 SEER / 9.0 hspf DFHP - NG furnace/CAC baseline - Market Opp	SF	LI	$1,504	62.2	2,941	1.22
113	**HVAC**	16 SEER / 9.0 hspf DFHP - NG furnace/CAC baseline - Early Replacement	MF	LI	$1,725	35.4	1,677	1.17
114	**HVAC**	16 SEER / 9.0 hspf DFHP - NG furnace/CAC baseline - Market Opp	MF	LI	$857	35.4	1,677	1.22
115	**HVAC**	16 SEER / 9.0 hspf DFHP - LP furnace/CAC baseline - Early Replacement	SF	LI	$647	0	2,941	3.65
116	**HVAC**	16 SEER / 9.0 hspf DFHP - LP furnace/CAC baseline - Market Opp	SF	LI	$1,504	0	2,941	3.19
117	**HVAC**	Ductless HP - whole house - NG furnace/CAC baseline - Early Replacement	SF	LI	$1,211	62.2	3,974	1.78
118	**HVAC**	Ductless HP - whole house - NG furnace/CAC baseline - Market Opp	SF	LI	$57	62.2	3,974	1.88
119	**HVAC**	Ductless HP - whole house - NG furnace/CAC baseline - Early Replacement	MF	LI	$690	35.4	2,265	1.78

Measure #	End Use	Electrification Measure	Home Type	Income Type	Electrification Incremental Cost	Baseline MMBtu / Yr	Electrification kWh / Yr	mTRC + SCC Cost Effectiveness
120	**HVAC**	Ductless HP - whole house - NG furnace/CAC baseline - Market Opp	MF	LI	$32	35.4	2,265	1.88
121	**HVAC**	Ductless HP - whole house - LP furnace/CAC baseline - Early Replacement	SF	LI	$1,211	0	3,974	4.95
122	**HVAC**	Ductless HP - whole house - LP furnace/CAC baseline - Market Opp	SF	LI	$57	0	3,974	5.52
123	**HVAC**	Ductless HP - supplemental - NG furnace/CAC baseline - Early Replacement	SF	LI	$1,875	62.2	2,514	1.80
124	**HVAC**	Ductless HP - supplemental - NG furnace/CAC baseline - Market Opp	SF	LI	$5,441	62.2	2,514	1.08
125	**HVAC**	Ductless HP - supplemental - NG furnace/CAC baseline - Early Replacement	MF	LI	$1,069	35.4	1,433	1.80
126	**HVAC**	Ductless HP - supplemental - NG furnace/CAC baseline - Market Opp	MF	LI	$3,101	35.4	1,433	1.08
127	**HVAC**	Ductless HP - supplemental - LP furnace/CAC baseline - Early Replacement	SF	LI	$1,875	0	2,514	4.40
128	**HVAC**	Ductless HP - supplemental - LP furnace/CAC baseline - Market Opp	SF	LI	$5,441	0	2,514	2.83
129	**HVAC**	GSHP - NG furnace/CAC baseline - Early Replacement	SF	LI	$7,937	62.2	3,421	0.97
130	**HVAC**	GSHP - NG furnace/CAC baseline - Market Opp	SF	LI	$6,783	62.2	3,421	0.96
131	**HVAC**	GSHP - LP furnace/CAC baseline - Early Replacement	SF	LI	$7,937	0	3,421	2.70
132	**HVAC**	GSHP - LP furnace/CAC baseline - Market Opp	SF	LI	$6,783	0	3,421	2.82
133	**HVAC**	16 SEER / 9.0 hspf ASHP - NG boiler/AC baseline - Early Replacement	SF	LI	($538)	62.2	4,562	1.85
134	**HVAC**	16 SEER / 9.0 hspf ASHP - NG boiler/AC baseline - Market Opp	SF	LI	($2,039)	62.2	4,562	1.87
135	**HVAC**	16 SEER / 9.0 hspf ASHP - NG boiler/AC baseline - Early Replacement	MF	LI	($307)	35.4	2,600	1.85

Measure #	End Use	Electrification Measure	Home Type	Income Type	Electrification Incremental Cost	Baseline MMBtu / Yr	Electrification kWh / Yr	mTRC + SCC Cost Effectiveness
136	HVAC	16 SEER / 9.0 hspf ASHP - NG boiler/AC baseline - Market Opp	MF	LI	($1,162)	35.4	2,600	1.87
137	HVAC	16 SEER / 9.0 hspf ASHP - LP boiler/AC baseline - Early Replacement	SF	LI	($538)	0	4,562	5.03
138	HVAC	16 SEER / 9.0 hspf ASHP - LP boiler/AC baseline - Market Opp	SF	LI	($2,039)	0	4,562	5.05
139	HVAC	16 SEER / 9.0 hspf ASHP - NG furnace/No AC baseline - Early Replacement	SF	LI	$3,026	62.2	5,644	0.67
140	HVAC	16 SEER / 9.0 hspf ASHP - NG furnace/No AC baseline - Market Opp	SF	LI	$2,570	62.2	5,644	0.70
141	HVAC	16 SEER / 9.0 hspf ASHP - NG furnace/No AC baseline - Early Replacement	MF	LI	$1,725	35.4	3,217	0.67
142	HVAC	16 SEER / 9.0 hspf ASHP - NG furnace/No AC baseline - Market Opp	MF	LI	$1,465	35.4	3,217	0.70
143	HVAC	16 SEER / 9.0 hspf ASHP - LP furnace/No AC baseline - Early Replacement	SF	LI	$3,026	0	5,644	2.90
144	HVAC	16 SEER / 9.0 hspf ASHP - LP furnace/No AC baseline - Market Opp	SF	LI	$2,570	0	5,644	3.01
145	HVAC	16 SEER / 9.0 hspf DFHP - NG furnace/No AC baseline - Early Replacement	SF	LI	$3,026	62.2	4,024	0.51
146	HVAC	16 SEER / 9.0 hspf DFHP - NG furnace/No AC baseline - Market Opp	SF	LI	$4,581	62.2	4,024	0.45
147	HVAC	16 SEER / 9.0 hspf DFHP - NG furnace/No AC baseline - Early Replacement	MF	LI	$1,725	35.4	2,293	0.51
148	HVAC	16 SEER / 9.0 hspf DFHP - NG furnace/No AC baseline - Market Opp	MF	LI	$2,611	35.4	2,293	0.45
149	HVAC	16 SEER / 9.0 hspf DFHP - LP furnace/No AC baseline - Early Replacement	SF	LI	$3,026	0	4,024	2.21
150	HVAC	16 SEER / 9.0 hspf DFHP - LP furnace/No AC baseline - Market Opp	SF	LI	$4,581	0	4,024	1.94

Measure #	End Use	Electrification Measure	Home Type	Income Type	Electrification Incremental Cost	Baseline MMBtu / Yr	Electrification kWh / Yr	mTRC + SCC Cost Effectiveness
151	HVAC	Ductless HP - whole house - NG furnace/No AC baseline - Early Replacement	SF	LI	$3,590	62.2	5,056	0.75
152	HVAC	Ductless HP - whole house - NG furnace/No AC baseline - Market Opp	SF	LI	$3,134	62.2	5,056	0.79
153	HVAC	Ductless HP - whole house - NG furnace/No AC baseline - Early Replacement	MF	LI	$2,046	35.4	2,882	0.75
154	HVAC	Ductless HP - whole house - NG furnace/No AC baseline - Market Opp	MF	LI	$1,786	35.4	2,882	0.79
155	HVAC	Ductless HP - whole house - LP furnace/No AC baseline - Early Replacement	SF	LI	$3,590	0	5,056	3.26
156	HVAC	Ductless HP - whole house - LP furnace/No AC baseline - Market Opp	SF	LI	$3,134	0	5,056	3.39
157	HVAC	Ductless HP - supplemental - NG furnace/No AC baseline - Early Replacement	SF	LI	$1,875	62.2	3,596	0.79
158	HVAC	Ductless HP - supplemental - NG furnace/No AC baseline - Market Opp	SF	LI	$5,441	62.2	3,596	0.53
159	HVAC	Ductless HP - supplemental - NG furnace/No AC baseline - Early Replacement	MF	LI	$1,069	35.4	2,050	0.79
160	HVAC	Ductless HP - supplemental - NG furnace/No AC baseline - Market Opp	MF	LI	$3,101	35.4	2,050	0.53
161	HVAC	Ductless HP - supplemental - LP furnace/No AC baseline - Early Replacement	SF	LI	$1,875	0	3,596	3.39
162	HVAC	Ductless HP - supplemental - LP furnace/No AC baseline - Market Opp	SF	LI	$5,441	0	3,596	2.27
163	HVAC	GSHP - NG furnace/No AC baseline - Early Replacement	SF	LI	$10,316	62.2	4,503	0.46
164	HVAC	GSHP - NG furnace/No AC baseline - Market Opp	SF	LI	$9,860	62.2	4,503	0.47
165	HVAC	GSHP - LP furnace/No AC baseline - Early Replacement	SF	LI	$10,316	0	4,503	1.96
166	HVAC	GSHP - LP furnace/No AC baseline - Market Opp	SF	LI	$9,860	0	4,503	2.01

Measure #	End Use	Electrification Measure	Home Type	Income Type	Electrification Incremental Cost	Baseline MMBtu / Yr	Electrification kWh / Yr	mTRC + SCC Cost Effectiveness
167	HVAC	16 SEER / 9.0 hspf ASHP - NG boiler/No AC baseline - Early Replacement	SF	LI	$1,841	62.2	5,644	0.82
168	HVAC	16 SEER / 9.0 hspf ASHP - NG boiler/No AC baseline - Market Opp	SF	LI	$1,038	62.2	5,644	0.88
169	HVAC	16 SEER / 9.0 hspf ASHP - NG boiler/No AC baseline - Early Replacement	MF	LI	$1,050	35.4	3,217	0.82
170	HVAC	16 SEER / 9.0 hspf ASHP - NG boiler/No AC baseline - Market Opp	MF	LI	$592	35.4	3,217	0.88
171	HVAC	16 SEER / 9.0 hspf ASHP - LP boiler/No AC baseline - Early Replacement	SF	LI	$1,841	0	5,644	3.49
172	HVAC	16 SEER / 9.0 hspf ASHP - LP boiler/No AC baseline - Market Opp	SF	LI	$1,038	0	5,644	3.75
173	Pools	Heat Pump Pool Heater - NG Baseline - Early Replacement	SF	NLI	$1,841	17.6	318	0.48
174	Pools	Heat Pump Pool Heater - NG Baseline - Market Opp	SF	NLI	$1,250	17.6	318	0.68
175	Water Heating	Heat Pump Water Heater - NG Tank Baseline - Early Replacement	SF	NLI	$968	28.6	1,641	0.93
176	Water Heating	Heat Pump Water Heater - NG Tank Baseline - Market Opp	SF	NLI	$793	28.6	1,641	1.00
177	Water Heating	Heat Pump Water Heater - NG Tank Baseline - Early Replacement	MF	NLI	$968	26.6	1,526	0.91
178	Water Heating	Heat Pump Water Heater - NG Tank Baseline - Market Opp	MF	NLI	$793	26.6	1,526	0.97
179	Water Heating	Heat Pump Water Heater - LP Tank Baseline - Early Replacement	SF	NLI	$968	0	1,641	4.01
180	Water Heating	Heat Pump Water Heater - LP Tank Baseline - Market Opp	SF	NLI	$793	0	1,641	4.29
181	Water Heating	Heat Pump Water Heater - NG Instantaneous Baseline - Early Replacement	SF	NLI	$667	19.9	1,641	1.12
182	Water Heating	Heat Pump Water Heater - NG Instantaneous Baseline - Market Opp	SF	NLI	$499	19.9	1,641	1.20
183	Water Heating	Heat Pump Water Heater - NG Instantaneous Baseline - Early Replacement	MF	NLI	$667	18.5	1,526	1.09

Measure #	End Use	Electrification Measure	Home Type	Income Type	Electrification Incremental Cost	Baseline MMBtu / Yr	Electrification kWh / Yr	mTRC + SCC Cost Effectiveness
184	**Water Heating**	Heat Pump Water Heater - NG Instantaneous Baseline - Market Opp	MF	NLI	$499	18.5	1,526	1.18
185	**Water Heating**	Heat Pump Water Heater - LP Instantaneous Baseline - Early Replacement	SF	NLI	$667	0	1,641	4.56
186	**Water Heating**	Heat Pump Water Heater - LP Instantaneous Baseline - Market Opp	SF	NLI	$499	0	1,641	4.90
187	**Water Heating**	Electric Water Heater - NG Tank Baseline - Early Replacement	SF	NLI	$357	28.6	5,197	0.51
188	**Water Heating**	Electric Water Heater - NG Tank Baseline - Market Opp	SF	NLI	$245	28.6	5,197	0.52
189	**Water Heating**	Electric Water Heater - NG Tank Baseline - Early Replacement	MF	NLI	$357	26.6	4,833	0.50
190	**Water Heating**	Electric Water Heater - NG Tank Baseline - Market Opp	MF	NLI	$245	26.6	4,833	0.51
191	**Water Heating**	Electric Water Heater - LP Tank Baseline - Early Replacement	SF	NLI	$357	0	5,197	2.17
192	**Water Heating**	Electric Water Heater - LP Tank Baseline - Market Opp	SF	NLI	$245	0	5,197	2.22
193	**Water Heating**	Electric Water Heater - NG Instantaneous Baseline - Early Replacement	SF	NLI	$56	19.9	5,197	0.57
194	**Water Heating**	Electric Water Heater - NG Instantaneous Baseline - Market Opp	SF	NLI	($113)	19.9	5,197	0.60
195	**Water Heating**	Electric Water Heater - NG Instantaneous Baseline - Early Replacement	MF	NLI	$56	18.5	4,833	0.57
196	**Water Heating**	Electric Water Heater - NG Instantaneous Baseline - Market Opp	MF	NLI	($113)	18.5	4,833	0.61
197	**Water Heating**	Electric Water Heater - LP Instantaneous Baseline - Early Replacement	SF	NLI	$56	0	5,197	2.33
198	**Water Heating**	Electric Water Heater - LP Instantaneous Baseline - Market Opp	SF	NLI	($113)	0	5,197	2.39
199	**Water Heating**	Heat Pump Water Heater - NG Tank Baseline - Early Replacement	SF	LI	$968	28.6	1,641	1.05

Measure #	End Use	Electrification Measure	Home Type	Income Type	Electrification Incremental Cost	Baseline MMBtu / Yr	Electrification kWh / Yr	mTRC + SCC Cost Effectiveness
200	Water Heating	Heat Pump Water Heater - NG Tank Baseline - Market Opp	SF	LI	$793	28.6	1,641	1.13
201	Water Heating	Heat Pump Water Heater - NG Tank Baseline - Early Replacement	MF	LI	$968	26.6	1,526	1.03
202	Water Heating	Heat Pump Water Heater - NG Tank Baseline - Market Opp	MF	LI	$793	26.6	1,526	1.10
203	Water Heating	Heat Pump Water Heater - LP Tank Baseline - Early Replacement	SF	LI	$968	0	1,641	4.88
204	Water Heating	Heat Pump Water Heater - LP Tank Baseline - Market Opp	SF	LI	$793	0	1,641	5.22
205	Water Heating	Heat Pump Water Heater - NG Instantaneous Baseline - Early Replacement	SF	LI	$667	19.9	1,641	1.25
206	Water Heating	Heat Pump Water Heater - NG Instantaneous Baseline - Market Opp	SF	LI	$499	19.9	1,641	1.34
207	Water Heating	Heat Pump Water Heater - NG Instantaneous Baseline - Early Replacement	MF	LI	$667	18.5	1,526	1.22
208	Water Heating	Heat Pump Water Heater - NG Instantaneous Baseline - Market Opp	MF	LI	$499	18.5	1,526	1.32
209	Water Heating	Heat Pump Water Heater - LP Instantaneous Baseline - Early Replacement	SF	LI	$667	0	1,641	5.53
210	Water Heating	Heat Pump Water Heater - LP Instantaneous Baseline - Market Opp	SF	LI	$499	0	1,641	5.94
211	Water Heating	Electric Water Heater - NG Tank Baseline - Early Replacement	SF	LI	$357	28.6	5,197	0.57
212	Water Heating	Electric Water Heater - NG Tank Baseline - Market Opp	SF	LI	$245	28.6	5,197	0.58
213	Water Heating	Electric Water Heater - NG Tank Baseline - Early Replacement	MF	LI	$357	26.6	4,833	0.57
214	Water Heating	Electric Water Heater - NG Tank Baseline - Market Opp	MF	LI	$245	26.6	4,833	0.58
215	Water Heating	Electric Water Heater - LP Tank Baseline - Early Replacement	SF	LI	$357	0	5,197	2.64
216	Water Heating	Electric Water Heater - LP Tank Baseline - Market Opp	SF	LI	$245	0	5,197	2.70

Measure #	End Use	Electrification Measure	Home Type	Income Type	Electrification Incremental Cost	Baseline MMBtu / Yr	Electrification kWh / Yr	mTRC + SCC Cost Effectiveness
217	Water Heating	Electric Water Heater - NG Instantaneous Baseline - Early Replacement	SF	LI	$56	19.9	5,197	0.64
218	Water Heating	Electric Water Heater - NG Instantaneous Baseline - Market Opp	SF	LI	($113)	19.9	5,197	0.67
219	Water Heating	Electric Water Heater - NG Instantaneous Baseline - Early Replacement	MF	LI	$56	18.5	4,833	0.64
220	Water Heating	Electric Water Heater - NG Instantaneous Baseline - Market Opp	MF	LI	($113)	18.5	4,833	0.67
221	Water Heating	Electric Water Heater - LP Instantaneous Baseline - Early Replacement	SF	LI	$56	0.0	5,197	2.83
222	Water Heating	Electric Water Heater - LP Instantaneous Baseline - Market Opp	SF	LI	($113)	0	5,197	2.89
223	New Construction	New Electric Home - NG/CAC Baseline	SF	All	($3,034)	95.6	9,923	1.36
224	New Construction	New Electric Home - LP/CAC Baseline	SF	All	($3,063)	0	9,913	3.61
225	New Construction	New Electric Home - NG/CAC Baseline	MF	All	($2,839)	90.5	7,568	1.56
226	New Construction	New Electric Home - NG/No AC Baseline	SF	All	$43	95.6	11,005	0.69
227	New Construction	New Electric Home - LP/ No AC Baseline	SF	All	$14	0	10,995	2.93
228	New Construction	New Electric Home - NG/No AC Baseline	MF	All	($1,085)	90.5	8,185	1.02

COMMERCIAL MEASURES

Measure #	End Use	Baseline Measure	Electrification Measure	Electrification Measure Details	Replacement Type	Electrification Incremental Cost	Baseline MMBtu / Yr	Electrification kWh / Yr	mTRC + SCC Cost Effectiveness
1	**Appliances - NG**	NG Clothes Dryer	Electric Resistance Dryer	4.0 CEF	EOL	$0	32.1	5,025	0.72
2	**Appliances - NG**	NG Clothes Dryer	Heat Pump Dryer	6.0 CEF	EOL	$2,109	32.1	2,513	0.68
3	**Appliances - LP**	LP Clothes Dryer	Electric Resistance Dryer	4.0 CEF	EOL	$0	32.1	5,025	2.30
4	**Appliances - LP**	LP Clothes Dryer	Heat Pump Dryer	6.0 CEF	EOL	$2,109	32.1	2,513	2.17
5	**Water Heating - NG**	Tank-style	Electric Resistance	92% UEF	EOL	($355)	27.0	5,066	0.67
6	**Water Heating - NG**	Tank-style	Electric Resistance	92% UEF	ER	($413)	24.0	5,066	0.62
7	**Water Heating - NG**	Instantaneous	Electric Resistance	92% UEF	EOL	($1,405)	27.5	5,066	1.16
8	**Water Heating - NG**	Instantaneous	Electric Resistance	92% UEF	ER	($1,836)	17.5	5,066	0.97
9	**Water Heating - NG**	Tank-style	Heat Pump Water Heater	High Efficiency Heat Pump Water Heater	EOL	$649	27.0	1,578	1.28
10	**Water Heating - NG**	Tank-style	Heat Pump Water Heater	High Efficiency Heat Pump Water Heater	ER	$577	24.0	1,578	1.18
11	**Water Heating - NG**	Instantaneous	Heat Pump Water Heater	High Efficiency Heat Pump Water Heater	EOL	($401)	27.5	1,607	3.03
12	**Water Heating - NG**	Instantaneous	Heat Pump Water Heater	High Efficiency Heat Pump Water Heater	ER	($867)	17.5	1,151	3.29
13	**Water Heating - LP**	Tank-style	Electric Resistance	92% UEF	EOL	($355)	27.0	5,066	2.09
14	**Water Heating - LP**	Tank-style	Electric Resistance	92% UEF	ER	($413)	24.0	5,066	1.88
15	**Water Heating - LP**	Instantaneous	Electric Resistance	92% UEF	EOL	($1,405)	27.5	5,066	3.04
16	**Water Heating - LP**	Instantaneous	Electric Resistance	92% UEF	ER	($1,836)	17.5	5,066	2.16
17	**Water Heating - LP**	Tank-style	Heat Pump Water Heater	High Efficiency Heat Pump Water Heater	EOL	$649	27.0	1,578	4.37
18	**Water Heating - LP**	Tank-style	Heat Pump Water Heater	High Efficiency Heat Pump Water Heater	ER	$577	24.0	1,578	4.04
19	**Water Heating - LP**	Instantaneous	Heat Pump Water Heater	High Efficiency Heat Pump Water Heater	EOL	($401)	27.5	1,578	9.35

Measure #	End Use	Baseline Measure	Electrification Measure	Electrification Measure Details	Replacement Type	Electrification Incremental Cost	Baseline MMBtu / Yr	Electrification kWh / Yr	mTRC + SCC Cost Effectiveness
20	**Water Heating - LP**	Instantaneous	Heat Pump Water Heater	High Efficiency Heat Pump Water Heater	ER	($867)	17.5	1,578	6.45
21	**Pools - NG**	Pool Heater	Heat Pump Pool Heater	COP = 3; assume demand controlled to avoid peak	ER	$1,486	29.4	2,586	0.81
22	**Pools - LP**	Pool Heater	Heat Pump Pool Heater	COP = 3; assume demand controlled to avoid peak	ER	$1,486	29.4	2,586	2.73
23	**CZ5 Space Heating - NG**	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	Central ASHP Heat Pump - 100% displacement	Cold Climate ASHP with at least 50 kBtu/h capacity at 5F. 2.5 weighted average heating COP. 18 SEER for cooling	ER	$8,678	67.1	11,298	0.63
24	**CZ5 Space Heating - NG**	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	Central ASHP Heat Pump - 100% displacement	Cold Climate ASHP with at least 50 kBtu/h capacity at 5F. 2.5 weighted average heating COP. 18 SEER for cooling	EOL	$9,329	72.6	11,298	0.66
25	**CZ5 Space Heating - NG**	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	Central ASHP Heat Pump - partial displacement	5 Ton Cold Climate ASHP with at least 60 kBtu/h capacity at 47F. 2.5 weighted average COP. 18 SEER.	ER	$4,016	53.7	7,957	0.73
26	**CZ5 Space Heating - NG**	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	Central ASHP Heat Pump - partial displacement	5 Ton Cold Climate ASHP with at least 60 kBtu/h capacity at 47F. 2.5 weighted average COP. 12.8 IEER	EOL	$3,244	58.1	7,957	0.83
27	**CZ5 Space Heating - NG**	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	Ductless Heat Pump - partial displacement	Mini-Split Heat Pump 3 tons cooling, 18 SEER and 9 HSPF	ER	$1,788	40.3	5,284	0.94
28	**CZ5 Space Heating - NG**	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	Ductless Heat Pump - partial displacement	Mini-Split Heat Pump 3 tons cooling, 18 SEER and 9 HSPF	EOL	$1,016	43.6	5,284	1.09
29	**CZ5 Space Heating - NG**	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	GSHP - Full Displacement	GSHP <135,000 19EER	ER	$34,917	67.1	6,844	0.31

Measure #	End Use	Baseline Measure	Electrification Measure	Electrification Measure Details	Replacement Type	Electrification Incremental Cost	Baseline MMBtu / Yr	Electrification kWh / Yr	mTRC + SCC Cost Effectiveness
30	CZ5 Space Heating - NG	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	GSHP - Full Displacement	GSHP <135,000 19EER	EOL	$35,568	72.6	6,844	0.32
31	CZ5 Space Heating - NG	Commercial Forced Air (RTU) with Dx cooling and gas heating (average 10 ton cooling, 200 MBH heating)	Heat pump RTU (Average 10 ton cooling, 60 MBH heat pump, 150 MBH gas-fired) Partial displacement	11.5 EER cooling, 2.92 average COP heating	EOL	$6,000	71.3	13,704	0.92
32	CZ5 Space Heating - NG	200 ton central water-cooled chiller/ 3,500 MBH boiler, 4-pipe terminal units	200 ton combined WHSPs, and 2,800 MBH condensing boiler	23.2 EER cooling, 4.7 COP heating WSHPs	EOL	$422,200	2,424.5	230,324	0.62
33	CZ5 Space Heating - NG	1750 MBH Central boiler - hot water radiation, no cooling	Ductless Heat Pump - partial displacement	Cold Climate ASHP with at least 24 MBH capacity at 5F. 3.1 average COP. 13 IEER	EOL	$475,791	1,385.4	173,351	0.27
34	CZ5 Space Heating - NG	3,500 MBH central hot water boiler, 20 ton RTUs, hot water heat, DX cooling	20 ton GSHP RTUs, vertical well field	Ground loop, 21.3 EER, 3.8 COP	EOL	$595,325	3,463.5	353,330	0.86
35	CZ5 Space Heating - LP	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	Central ASHP Heat Pump - 100% displacement	Cold Climate ASHP with at least 50 kBtu/h capacity at 5F. 2.5 weighted average heating COP. 18 SEER for cooling	ER	$8,678	67.1	11,298	1.50
36	CZ5 Space Heating - LP	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	Central ASHP Heat Pump - 100% displacement	Cold Climate ASHP with at least 50 kBtu/h capacity at 5F. 2.5 weighted average heating COP. 18 SEER for cooling	EOL	$9,329	72.6	11,298	1.57
37	CZ5 Space Heating - LP	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	Central ASHP Heat Pump - partial displacement	5 Ton Cold Climate ASHP with at least 60 kBtu/h capacity at 47F. 2.5 weighted average COP. 18 SEER.	ER	$4,016	53.7	7,957	1.66
38	CZ5 Space Heating - LP	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	Central ASHP Heat Pump - partial displacement	5 Ton Cold Climate ASHP with at least 60 kBtu/h capacity at 47F. 2.5 weighted average COP. 12.8 IEER	EOL	$3,244	58.1	7,957	1.90

Measure #	End Use	Baseline Measure	Electrification Measure	Electrification Measure Details	Replacement Type	Electrification Incremental Cost	Baseline MMBtu / Yr	Electrification kWh / Yr	mTRC + SCC Cost Effectiveness
39	**CZ5 Space Heating - LP**	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	Ductless Heat Pump - partial displacement	Mini-Split Heat Pump 3 tons cooling, 18 SEER and 9 HSPF	ER	$1,788	40.3	5,284	1.97
40	**CZ5 Space Heating - LP**	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	Ductless Heat Pump - partial displacement	Mini-Split Heat Pump 3 tons cooling, 18 SEER and 9 HSPF	EOL	$1,016	43.6	5,284	2.32
41	**CZ5 Space Heating - LP**	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	GSHP - Full Displacement	GSHP <135,000 19EER	ER	$34,917	67.1	6,844	0.73
42	**CZ5 Space Heating - LP**	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	GSHP - Full Displacement	GSHP <135,000 19EER	EOL	$35,568	72.6	6,844	0.78
43	**CZ5 Space Heating - LP**	Commercial Forced Air (RTU) with Dx cooling and gas heating (average 10 ton cooling, 200 MBH heating)	Heat pump RTU (Average 10 ton cooling, 60 MBH heat pump, 150 MBH gas-fired) Partial displacement	11.5 EER cooling, 2.92 average COP heating	EOL	$6,000	71.3	13,704	1.48
44	**CZ5 Space Heating - LP**	200 ton central water-cooled chiller/ 3,500 MBH boiler, 4-pipe terminal units	200 ton combined WHSPs, and 2,800 MBH condensing boiler	23.2 EER cooling, 4.7 COP heating WSHPs	EOL	$422,200	2,424.5	230,324	1.60
45	**CZ5 Space Heating - LP**	1750 MBH Central boiler - hot water radiation, no cooling	Ductless Heat Pump - partial displacement	Cold Climate ASHP with at least 24 MBH capacity at 5F. 3.1 average COP. 13 IEER	EOL	$475,791	1,385.4	173,351	0.88
46	**CZ5 Space Heating - LP**	3,500 MBH central hot water boiler, 20 ton RTUs, hot water heat, DX cooling	20 ton GSHP RTUs, vertical well field	Ground loop, 21.3 EER, 3.8 COP	EOL	$595,325	3,463.5	353,330	1.79
119	**Cooking - NG**	Convection Oven	ENERGY STAR Commercial electric convection (retrofit)	Energy Star Electric Convection Oven	ER	$383	80.2	10,122	0.63
120	**Cooking - NG**	Convection Oven	ENERGY STAR Commercial electric convection (EOL)	Energy Star Electric Convection Oven	EOL	($595)	67.3	10,122	0.61
121	**Cooking - NG**	Combination Oven	ENERGY STAR Commercial electric combination (retrofit)	Energy Star Combination Electric Oven	ER	$17,110	103.5	11,914	0.29
122	**Cooking - NG**	Combination Oven	ENERGY STAR Commercial electric combination (EOL)	Energy Star Combination Electric Oven	EOL	($8,537)	70.0	11,914	1.22

Measure #	End Use	Baseline Measure	Electrification Measure	Electrification Measure Details	Replacement Type	Electrification Incremental Cost	Baseline MMBtu / Yr	Electrification kWh / Yr	mTRC + SCC Cost Effectiveness
123	Cooking - NG	Steam Cooker	ENERGY STAR Commercial electric steam cooker (retrofit)	Energy Star Electric Steam Cooker	ER	($5,490)	200.1	7,632	2.91
124	Cooking - NG	Steam Cooker	ENERGY STAR Commercial electric steam cooker (EOL)	Energy Star Electric Steam Cooker	EOL	($14,997)	94.7	7,632	3.03
125	Cooking - NG	Griddle	ENERGY STAR Commercial electric griddle (retrofit)	Energy Star Electric Griddle	ER	$2,175	115.5	13,905	0.70
126	Cooking - NG	Griddle	ENERGY STAR Commercial electric griddle (EOL)	Energy Star Electric Griddle	EOL	$293	102.4	13,905	0.72
127	Cooking - NG	Fryer	ENERGY STAR Commercial electric fryer (retrofit)	Energy Star Electric Fryer	ER	$10,171	158.1	15,063	0.58
128	Cooking - NG	Fryer	ENERGY STAR Commercial electric fryer (EOL)	Energy Star Electric Fryer	EOL	$8,289	107.4	15,063	0.43
129	Cooking - LP	Convection Oven	ENERGY STAR Commercial electric convection (retrofit)	Energy Star Electric Convection Oven	ER	$383	80.2	10,122	2.18
130	Cooking - LP	Convection Oven	ENERGY STAR Commercial electric convection (EOL)	Energy Star Electric Convection Oven	EOL	($595)	67.3	10,122	1.96
131	Cooking - LP	Combination Oven	ENERGY STAR Commercial electric combination (retrofit)	Energy Star Combination Electric Oven	ER	$17,110	103.5	11,914	1.01
132	Cooking - LP	Combination Oven	ENERGY STAR Commercial electric combination (EOL)	Energy Star Combination Electric Oven	EOL	($8,537)	70.0	11,914	2.41
133	Cooking - LP	Steam Cooker	ENERGY STAR Commercial electric steam cooker (retrofit)	Energy Star Electric Steam Cooker	ER	($5,490)	200.1	7,632	8.23
134	Cooking - LP	Steam Cooker	ENERGY STAR Commercial electric steam cooker (EOL)	Energy Star Electric Steam Cooker	EOL	($14,997)	94.7	7,632	5.55
135	Cooking - LP	Griddle	ENERGY STAR Commercial electric griddle (retrofit)	Energy Star Electric Griddle	ER	$2,175	115.5	13,905	2.42
136	Cooking - LP	Griddle	ENERGY STAR Commercial electric griddle (EOL)	Energy Star Electric Griddle	EOL	$293	102.4	13,905	2.49
137	Cooking - LP	Fryer	ENERGY STAR Commercial electric fryer (retrofit)	Energy Star Electric Fryer	ER	$10,171	158.1	15,063	1.99

Measure #	End Use	Baseline Measure	Electrification Measure	Electrification Measure Details	Replacement Type	Electrification Incremental Cost	Baseline MMBtu / Yr	Electrification kWh / Yr	mTRC + SCC Cost Effectiveness
138	**Cooking - LP**	Fryer	ENERGY STAR Commercial electric fryer (EOL)	Energy Star Electric Fryer	EOL	$8,289	107.4	15,063	1.48
139	**NC Appliances - NG**	ES Electric Clothes Dryer 4.0 CEF replacing NG Clothes Dryer	Electric Resistance Dryer	4.0 CEF	NC	$0	32.1	5,025	0.72
140	**NC Appliances - NG**	ES Heat PumpClothes Dryer 6.0 CEF replacing NG Clothes Dryer	Heat Pump Dryer	6.0 CEF	NC	$2,109	32.1	2,513	0.68
141	**NC Appliances - LP**	ES Electric Clothes Dryer 4.0 CEF replacing LP Clothes Dryer	Electric Resistance Dryer	4.0 CEF	NC	$0	32.1	5,025	2.30
142	**NC Appliances - LP**	ES Heat PumpClothes Dryer 6.0 CEF replacing LP Clothes Dryer	Heat Pump Dryer	6.0 CEF	NC	$2,109	32.1	2,513	2.17
143	**NC Water Heating - NG**	Tank-style	Electric Resistance	92% UEF	NC	($355)	24.0	5,066	0.61
144	**NC Water Heating - NG**	Instantaneous	Electric Resistance	92% UEF	NC	($1,405)	17.5	5,066	0.87
145	**NC Water Heating - NG**	Tank-style	Heat Pump Water Heater	High Efficiency Heat Pump Water Heater	NC	$649	24.0	1,578	1.14
146	**NC Water Heating - NG**	Instantaneous	Heat Pump Water Heater	High Efficiency Heat Pump Water Heater	NC	($401)	17.5	1,578	2.08
147	**NC Water Heating - LP**	Tank-style	Electric Resistance	92% UEF	NC	($355)	24.0	5,066	1.86
148	**NC Water Heating - LP**	Instantaneous	Electric Resistance	92% UEF	NC	($1,405)	17.5	5,066	2.06
149	**NC Water Heating - LP**	Tank-style	Heat Pump Water Heater	High Efficiency Heat Pump Water Heater	NC	$649	24.0	1,578	3.89
150	**NC Water Heating - LP**	Instantaneous	Heat Pump Water Heater	High Efficiency Heat Pump Water Heater	NC	($401)	17.5	1,578	6.07
151	**NC CZ5 Space Heating - NG**	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	Central ASHP Heat Pump - 100% displacement	Cold Climate ASHP with at least 50 kBtu/h capacity at 5F. 2.5 weighted average heating COP. 18 SEER for cooling	NC	$9,329	72.6	11,298	0.66
152	**NC CZ5 Space Heating - NG**	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	Central ASHP Heat Pump - partial displacement	5 Ton Cold Climate ASHP with at least 60 kBtu/h capacity at 47F. 2.5 weighted average COP. 12.8 IEER	NC	$3,244	58.1	7,957	0.83

Measure #	End Use	Baseline Measure	Electrification Measure	Electrification Measure Details	Replacement Type	Electrification Incremental Cost	Baseline MMBtu / Yr	Electrification kWh / Yr	mTRC + SCC Cost Effectiveness
153	NC CZ5 Space Heating - NG	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	Ductless Heat Pump - partial displacement	Mini-Split Heat Pump 3 tons cooling, 18 SEER and 9 HSPF	NC	$1,016	43.6	5,284	1.09
154	NC CZ5 Space Heating - NG	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	GSHP - Full Displacement	GSHP <135,000 19EER	NC	$35,568	72.6	6,844	0.32
155	NC CZ5 Space Heating - NG	Commercial Forced Air (RTU) with Dx cooling and gas heating (average 10 ton cooling, 200 MBH heating)	Heat pump RTU (Average 10 ton cooling, 60 MBH heat pump, 150 MBH gas-fired) Partial displacement	11.5 EER cooling, 2.92 average COP heating	NC	$6,000	71.3	13,704	0.92
156	NC CZ5 Space Heating - NG	200 ton central water-cooled chiller/ 3,500 MBH boiler, 4-pipe terminal units	200 ton combined WHSPs, and 2,800 MBH condensing boiler	23.2 EER cooling, 4.7 COP heating WSHPs	NC	$422,200	2,424.5	230,324	0.62
157	NC CZ5 Space Heating - NG	1750 MBH Central boiler - hot water radiation, no cooling	Ductless Heat Pump - partial displacement	Cold Climate ASHP with at least 24 MBH capacity at 5F. 3.1 average COP. 13 IEER	NC	$475,791	1,385.4	173,351	0.27
158	NC CZ5 Space Heating - NG	3,500 MBH central hot water boiler, 20 ton RTUs, hot water heat, DX cooling	20 ton GSHP RTUs, vertical well field	Ground loop, 21.3 EER, 3.8 COP	NC	$595,325	3,463.5	353,330	0.86
159	NC CZ5 Space Heating LP	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	Central ASHP Heat Pump - 100% displacement	Cold Climate ASHP with at least 50 kBtu/h capacity at 5F. 2.5 weighted average heating COP. 18 SEER for cooling	NC	$9,329	72.6	11,298	1.57
160	NC CZ5 Space Heating LP	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	Central ASHP Heat Pump - partial displacement	5 Ton Cold Climate ASHP with at least 60 kBtu/h capacity at 47F. 2.5 weighted average COP. 12.8 IEER	NC	$3,244	58.1	7,957	1.90
161	NC CZ5 Space Heating LP	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	Ductless Heat Pump - partial displacement	Mini-Split Heat Pump 3 tons cooling, 18 SEER and 9 HSPF	NC	$1,016	43.6	5,284	2.32
162	NC CZ5 Space Heating LP	Central Forced Air Furnace with DX cooling (Average 65 kBtu/h)	GSHP - Full Displacement	GSHP <135,000 19EER	NC	$35,568	72.6	6,844	0.78

Measure #	End Use	Baseline Measure	Electrification Measure	Electrification Measure Details	Replacement Type	Electrification Incremental Cost	Baseline MMBtu / Yr	Electrification kWh / Yr	mTRC + SCC Cost Effectiveness
163	NC CZ5 Space Heating LP	Commercial Forced Air (RTU) with Dx cooling and gas heating (average 10 ton cooling, 200 MBH heating)	Heat pump RTU (Average 10 ton cooling, 60 MBH heat pump, 150 MBH gas-fired) Partial displacement	11.5 EER cooling, 2.92 average COP heating	NC	$6,000	71.3	13,704	1.48
164	NC CZ5 Space Heating LP	200 ton central water-cooled chiller/ 3,500 MBH boiler, 4-pipe terminal units	200 ton combined WHSPs, and 2,800 MBH condensing boiler	23.2 EER cooling, 4.7 COP heating WSHPs	NC	$422,200	2,424.5	230,324	1.60
165	NC CZ5 Space Heating LP	1750 MBH Central boiler - hot water radiation, no cooling	Ductless Heat Pump - partial displacement	Cold Climate ASHP with at least 24 MBH capacity at 5F. 3.1 average COP. 13 IEER	NC	$475,791	1,385.4	173,351	0.88
166	NC CZ5 Space Heating LP	3,500 MBH central hot water boiler, 20 ton RTUs, hot water heat, DX cooling	20 ton GSHP RTUs, vertical well field	Ground loop, 21.3 EER, 3.8 COP	NC	$595,325	3,463.5	353,330	1.79
215	NC Cooking - NG	Convection Oven	ENERGY STAR Commercial electric convection (EOL)	Energy Star Electric Convection Oven	NC	($595)	67.3	10,122	0.61
216	NC Cooking - NG	Combination Oven	ENERGY STAR Commercial electric combination (EOL)	Energy Star Combination Electric Oven	NC	($8,537)	70.0	11,914	1.22
217	NC Cooking - NG	Steam Cooker	ENERGY STAR Commercial electric steam cooker (EOL)	Energy Star Electric Steam Cooker	NC	($14,997)	94.7	7,632	3.03
218	NC Cooking - NG	Griddle	ENERGY STAR Commercial electric griddle (EOL)	Energy Star Electric Griddle	NC	$293	102.4	13,905	0.72
219	NC Cooking - NG	Fryer	ENERGY STAR Commercial electric fryer (EOL)	Energy Star Electric Fryer	NC	$8,289	107.4	15,063	0.43
220	NC Cooking - LP	Convection Oven	ENERGY STAR Commercial electric convection (EOL)	Energy Star Electric Convection Oven	NC	($595)	67.3	10,122	1.96
221	NC Cooking - LP	Combination Oven	ENERGY STAR Commercial electric combination (EOL)	Energy Star Combination Electric Oven	NC	($8,537)	70.0	11,914	2.41
222	NC Cooking - LP	Steam Cooker	ENERGY STAR Commercial electric steam cooker (EOL)	Energy Star Electric Steam Cooker	NC	($14,997)	94.7	7,632	5.55
223	NC Cooking - LP	Griddle	ENERGY STAR Commercial electric griddle (EOL)	Energy Star Electric Griddle	NC	$293	102.4	13,905	2.49

Measure #	End Use	Baseline Measure	Electrification Measure	Electrification Measure Details	Replacement Type	Electrification Incremental Cost	Baseline MMBtu / Yr	Electrification kWh / Yr	mTRC + SCC Cost Effectiveness
224	NC Cooking - LP	Fryer	ENERGY STAR Commercial electric fryer (EOL)	Energy Star Electric Fryer	NC	$8,289	107.4	15,063	1.48
225	NC Pools - NG	Pool Heater	Heat Pump Pool Heater	COP = 3; assume demand controlled to avoid peak	ER	$1,486	29.4	2,586	0.81
226	NC Pools - LP	Pool Heater	Heat Pump Pool Heater	COP = 3; assume demand controlled to avoid peak	ER	$1,486	29.4	2,586	2.73

INDUSTRIAL, AGRICULTURAL, TRANSPORTATION

Measure #	End Use	Measure	Efficiency	Replacement Type	Electrification Incremental Cost	Baseline Usage MMBtu / Yr	Efficient Baseline Usage kWh / Yr
1	NRE	Electric Forklift	Conventional charge electric forklift replacing class 5 ICE forklift	ER	$10,200	190.3	31,468
2	NRE	Transport/Truck Refrigeration Unit (TRU)	Electric TRU (eTRU) - Replace diesel powered TRU with eTRU	ER	$4,000	240.0	14,991
3	NRE	Truckstop Electrification (TSE) Plug-in/Shore Power Connection	One shorepower connection (50A) (Onboard equipment)	ER	$6,500	528.3	22,213
4	O&G	Convert gas pneumatic controls to instrument air	Compressed air pneumatic instruments	ER	$60,000	20,000.0	175,200
5	O&G	Replace gas-fired pipeline compressors with electric	Electric pipeline compressors - replacement	ER	$6,000,000	302,000.0	20,000,000
6	O&G	New pipeline electric compressors instead of gas-fired	Electric pipeline compressors - new	EOL	$500,000	302,000.0	20,000,000
7	O&G	New dual drive compressors instead of gas-fired only	Dual-fuel pipeline compressors	EOL	$1,500,000	302,000.0	10,000,000
8	O&G	Gas pneumatic kimray pump to electric (impacts per pump)	Electric Kimray Pump	ER	$10,000	5,000.0	20,000
9	O&G	Replace gas-assisted glycol pump with electric (impacts per pump)	Electric glycol pump	ER	$9,000	18,000.0	41,600
10	Irrigation	HE electric irrigation pumping plant	Electric Irrigation	ER	-$10,000	1,395.0	59,978

Measure #	End Use	Measure	Efficiency	Replacement Type	Electrification Incremental Cost	Baseline Usage MMBtu / Yr	Efficient Baseline Usage kWh / Yr
11	**Irrigation**	HE electric irrigation pumping plant	Electric Irrigation	ER	-$10,000	1,668.0	59,978
12	**Manure Handling**	Electric manure pumping	Electric Manure Handling	ER	$25,000	278.0	5,475
13	**Manure Handling**	Electric alley scrapers	Electric Manure Handling	ER	$20,000	695.0	19,710
14	**Livestock Feeding**	Electric feed mixer	Electric Feed Mixing	ER	$175,000	139.0	216,810
15	**Livestock Feeding**	Electric feed pusher	Electric Feed Pushing	ER	$50,000	139.0	964
16	**Steel Melting**	Electric Arc Furnace (475 kWh/ton)	Electric Steel Furnace	EOL	$0	1,736,000.0	294,500,000
17	**Steel Melting**	Electric Induction Furnace (567 kWh/ton)	Electric Steel Furnace	EOL	$200,000	868,000.0	175,770,000

CARBON MODELING ASSUMPTIONS

Carbon model assumptions were based on four sources of data and information:

- Climate Registry Protocols
- EIA data regarding electric utility carbon emissions to set the 2005 and 2018 Colorado baseline emissions factors
- CO2e emissions factors for the electricity sector with percentage reductions from the 2005 baseline were calculated for each of the three scenarios, all of which resulted in 100% emissions reductions by 2050. Reductions were linear from the 2018 baseline to 2030 and then linear from 2030 to 2050
    - 50% reduction in emissions by 2030
    - The Base Case of 80% emissions reductions by 2030
    - 100% reduction in emissions by 2030
- The valuation of CO2e emissions utilized the SB-236 value of $46 per short ton in 2020, escalating at rates based on the 2016 EPA Technical Guidance document referenced in the report. These values were converted to nominal values using the EPA’s 3 percent central case and general inflation rate noted above.

CARBON MODELING FACTORS

Emissions Factor	2005	2018	2020	2025	2030	2035	2040	2045	2050
Electricity (tons per MWh)									
100 percent in 2030	0.9602218	0.6737547	0.5591039	0.2748268	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
80 percent in 2030 - base case	0.9602218	0.6737547	0.5871733	0.3714093	0.1538599	0.1100277	0.0694625	0.0326852	0.0000000
50 percent in 2030	0.9602218	0.6737547	0.6292775	0.5162830	0.3846498	0.2750694	0.1736563	0.0817130	0.0000000
NG Emissions Factor (CO2 tons/MMBTU)	0.058488	0.058488	0.058488	0.058488	0.058488	0.058488	0.058488	0.058488	0.058488
Propane Emissions Factor (CO2 tons/MMBTU)	0.067747	0.067747	0.067747	0.067747	0.067747	0.067747	0.067747	0.067747	0.067747
Distillate Fuel Oil #2 (CO2e tons/MMBTU)	0.081039	0.081039	0.081039	0.081039	0.081039	0.081039	0.081039	0.081039	0.081039
Motor Gasoline (CO2 tons/MMBTU)	0.078121	0.078121	0.078121	0.078121	0.078121	0.078121	0.078121	0.078121	0.078121
Annual Cost of Carbon ($ per Ton) - nominal	N/A	N/A	$ 46.00	$ 66.29	$ 95.53	$ 136.33	$ 194.54	$ 273.56	$ 384.66

BENEFICIAL ELECTRIFICATIO IN COLORADO

Market Potential 2021-2030

Prepared for

COLORADO ENERGY OFFICE

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