REPORT

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Ground source heat pumps: Opportunities and challenges

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February 2024

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About the authors

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David Petroy is the Founder of NTS Energy, bringing over 20 years of expertise in renewable energy and sustainability. As the former Founder/President of Blue Valley Energy, a ground source heat pump engineering design and installation company, he oversaw nearly 100 installations throughout Colorado. Petroy's early experience includes leading technical sales of solar and energy power systems for residential and commercial businesses at RMS Electric. More recently, he served as Sustainability Manager at Golden Aluminum, one of the largest single-site industrial power users in Colorado. Currently, Petroy focuses on his role at NTS Energy, a consulting company dedicated to HVAC and energy solutions for residential, commercial, and industrial clients.

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Executive summary

Both air-source heat pumps (ASHPs) and ground-source heat pumps (GSHPs) offer improved efficiencies and greatly reduced greenhouse gas (GHG) emissions for heating of residential and commercial buildings compared to gas or propane heating systems. Increasing the installations of these heat pump technologies is an important pathway for Colorado to achieve its climate goals for residential and commercial buildings.

GSHPs offer improved efficiencies compared to ASHPs, but at significantly greater upfront costs. Therefore, GSHPs will be most cost-effective and will achieve the greatest benefits for larger buildings or for networks of buildings, including these applications:

- Schools (K-12) and college/university buildings
- Medium-size and larger commercial buildings
- Geothermal networks for new home developments or a mix of residential and commercial buildings

Colorado has many examples of these types of applications, and we highlight several in this report. With a focused effort among GSHP businesses, building owners, real estate professionals, and policymakers, there is great potential for expanding GSHP use in these types of building scenarios.

GSHP market development

The greatest bottleneck to expanding the number of GSHP projects in the state for the larger applications above is the number and capacity of installers. Currently only a handful of drillers or “looping contractors'' are doing GSHP projects in Colorado, and many of these projects are single-family residential.

Growing the commercial drilling/looping industry and GSHP installation supply chain in Colorado will take sustained leadership from the Colorado Energy Office (CEO), in collaboration with the Colorado Geothermal Advisory Group, utilities, and the investment community. We recommend that CEO explore the following strategies:

1) Hold discussions on how to improve the geothermal drilling market for commercial and housing development applications with the four large successful GSHP installation companies currently serving Colorado.

2) Collaborate with utilities/investors to develop a sustainable business model for large-scale commercial looping operations.
3) Work with the Colorado Water Well Contractors Association (CWWCA) association to expand the number of geothermal looping contractors.

GSHP grant funds and other state support

There is already an abundance of federal and state tax credits and utility rebates for GSHP projects. There is also a state Geothermal Energy Grant Program, which we recommend focusing its GSHP funding towards:

- Public schools, community colleges, and state universities
- Government buildings and complexes
- Nonprofit medical facilities
- Networks of new residential and/or commercial buildings

For large GSHP demonstration projects, we recommend the following process to ensure system performance as proposed:

- Independent design review prior to installation approval
- Post-installation performance testing validation

In addition, the state Public Utility Commission (PUC) should encourage gas and electric utilities to perform demonstration projects and cost analyses of geothermal networks for new developments. If shown to be cost-effective, this could provide a new revenue stream for gas utilities, while contributing to the state's climate goals for the buildings sector.

Residential GSHP market

In general, ASHPs are a more competitive solution for smaller buildings and single-family homes. However, our analysis shows that for homes in Denver or the Front Range larger than about 3,500 square feet or with a heating load of five tons or more, GSHPs have about the same life-cycle costs as ASHPs (including tax credits and rebates). For the high country, which has more challenging geology, this equality of costs would be true for slightly larger homes, such as 4,000 square feet or more, because of the higher drilling costs.

We anticipate that the residential GSHP market will remain a niche market for large single-family homes on the Front Range and in the high country throughout the next decade. This market is already well-supported by the currently available federal, state, and utility financial support and will continue to grow organically via small GSHP businesses, so it does not require any additional state focus or resources.

Heating and cooling of buildings with heat pumps

In order to address the climate challenge and reduce carbon emissions from buildings, there is growing interest in electric heat pump technology to replace the use of gas or propane for space and water heating. In Colorado, about 10% of total direct (Scope 1) GHG emissions are from residential and commercial buildings, with about two-thirds of this from residential buildings.[1] Further, most of the GHG emissions from buildings are from space heating, with water heating, cooking, and clothes drying accounting for a much smaller percentage of total fuel use and carbon emissions.

There are two main types of heat pumps for space heating of residential and commercial buildings - "ground-source" and "air-source" heat pumps. Both significantly reduce carbon and other pollutant emissions and are much more efficient compared to heating with gas or propane. Below, we discuss the advantages and disadvantages of these two types of heat pumps and highlight the best applications for each. Since there is already a lot of information available on ASHPs, the focus of this report is on "geothermal" or GSHPs.

We mainly focus on Colorado's market and its drillers and installers, tax credits, and grants -- although much of the information also applies to other states. Also, the focus of this report is on heat pump systems for new buildings. Retrofits of existing buildings with GSHPs are possible but are generally significantly more expensive. We highlight some successful Colorado examples and make some recommendations for how to increase the adoption of this technology for the most cost-effective applications.

Comparison of ground- and air-source heat pumps

GSHPs use sealed underground water pipe loops to pull energy from the ground to heat buildings in winter and push heat from the buildings back into the ground in the summer to cool them. The boreholes to circulate the water underground and back to the surface can either be vertical or horizontal.[2]

In this report we focus on operating costs and first costs for vertical loop fields because the vast majority of homes and commercial buildings in Colorado do not have the land area necessary for horizontal loop fields. If a homeowner or building owner has land available for a horizontal loop and low-cost access to equipment or contractors to excavate and fill trenches, then the savings for a GSHP installation can be significant. However, for a residential horizontal loop, you typically need 1+ acres of land; this can vary due to the lower thermal conductivity of unconsolidated soils.

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[1] "Colorado GHG Emissions Inventory," CO Dept. of Public Health and Environment, https://cdphe.colorado.gov/environment/air-pollution/climate-change/GHG-inventory. In addition to the direct GHG emissions from fuel use, commercial and residential buildings consume 73% percent of electricity generated, and electricity generation accounts for 24% of the total direct GHG emissions.

[2] There is also growing interest in geothermal electricity generation, which relies on high-temperature fluids found beneath the earth's surface in some locations. See the U.S. Department of Energy's Geothermal Electricity Generation website.

Vertical Loop Field[3]

Horizontal Loop Field[4]

There are two other possible GSHP loop types: 1) surface water pond or lake loops; and 2) open well water loops. Since it is very rare in Colorado to have the conditions needed for these, our paper does not discuss them.

ASHPs, on the other hand, pull energy from the outside air to heat buildings in the winter and push heat back outside in the summer to cool them. There are numerous studies of the benefits of ASHPs.[5] All the major utilities in Colorado offer significant rebates for ASHPs, and they are becoming increasingly accepted as replacements for home central air-conditioning (AC) systems, while offering the benefit of both heating and cooling.

There are also increasing applications of ASHPs in commercial buildings. The following table highlights the common types of heating/cooling systems in buildings (new proposed buildings or existing building retrofits) and the electrification/heat pump alternatives.[6]

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[3] https://www.hydro.mb.ca/your_home/geothermal_heat_pumps/components/

[4] https://www.hydro.mb.ca/your_home/geothermal_heat_pumps/components/.

[5] For example, "Benefits of Heat Pumps for Colorado Homes," SWEEP, February 2022, https://www.swenergy.org/directory/co-heat-pump-study-feb-2022/; and "Benefits of Heat Pumps for Southwest Homes, SWEEP, May 2022, https://www.swenergy.org/directory/sw-heat-pump-study-may-2022/.

[6] Decarbonizing HVAC and Water Heating in Commercial Buildings, U.S. Department of Energy, November 2021; VRF Heat Pump Systems Vs. Mini-Split Vs. Multi-Split – Explained - BlocPower, BlocPower, August 2022; Variable Refrigerant Flow (VRF) Systems and Technology, Mitsubishi, August 2023.

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ASHP options for commercial buildings

Standard heating/cooling System	ASHP options
Gas-fired packaged rooftop units (RTUs)	1. **Heat pump RTU**: Most major manufacturers offer ASHP RTUs in capacities of 3-25 tons, with optional auxiliary heating provided by electric resistance coils. 2. **Dual-fuel heat pump RTU**: A few manufacturers offer dual-fuel heat pump RTUs which operate the heat pump to around 17°F and then switch over to an integrated gas furnace for colder temperatures.
Split-system ACs and gas furnaces	1. **Ducted split system heat pump**: Similar to residential systems, the AC and gas furnace heating can be replaced with a ducted "split system" ASHP. The furnace may continue to be utilized for back-up heating. Ducted split system ASHPs are available for small commercial applications from 6-20 ton capacities. 2. **Ductless mini-split heat pump**: The AC and gas furnace can be replaced with a non-ducted ASHP (ductless mini-split). Typically, each outdoor unit can provide heating or cooling to three or more indoor units within the same zone. 3. **Variable Refrigerant Flow (VRF) heat pump system**: VRF systems are a more complex type of mini-split system. Mini-split systems can only provide heating or cooling to all the indoor units within the same zone, but VRF systems continually adjust the flow of the refrigerant to each indoor unit to provide heating *or* cooling, as needed. If the building has varying heating and cooling needs, these systems are very efficient, but also more expensive. The indoor units can be ductless or have short ducts (mini-ducts).

For buildings with low or medium temperature boilers and hydronic heating systems, there are more limited options for ASHPs. For example, air-to-water heat pumps can be used, but they have limitations on the water temperature achievable. Or mini-splits could be used in place of the hydronic system, but this would require an expensive retrofit for an existing building.

Below we discuss some advantages and disadvantages of ground-source versus air-source heat pumps.

Energy efficiency

GSHPs draw heat energy out of the earth during the winter to heat buildings. On the Colorado Front Range and Western Slope, the earth temperature around the subsurface loops is 50-55°F, and in the high country the earth temperature is lower, such as 35-45°F. Over the course of the winter, as the home or building continues to pull heat from the earth, the earth in the vicinity of the borehole cools and its temperature decreases, resulting in lower fluid temperatures in the ground loop. Through proper sizing and design of the looping system, the objective for a closed loop GSHP system is to maintain an entering water temperature to the heat pump in a range that is acceptable for reliable operation and sufficient capacity to meet the building's heating (and cooling) loads.[7]

Because they rely on the higher and more consistent earth temperatures throughout the winter (as opposed to the air temperatures), GSHPs are more energy efficient than ASHPs. Coefficient of performance (COP) is a measure of energy efficiency (higher COPs are more efficient). In the Colorado Front Range, the COP of a GSHP over a winter typically ranges from 3.5-4.5, whereas the COP of an efficient ASHP system typically ranges from 1.5-3.5 over the course of a winter.[8] However, for ASHP systems, choosing a properly sized, efficient cold-climate rated heat pump system is critical in order to minimize the size and use of backup electric resistance heating (or backup gas or propane) for the coldest weather. Backup heating is less of an issue with GSHPs, as discussed below.

However, GSHPs require more energy to pump the water through the loops, which partially offsets their higher efficiencies. The pumping energy as a proportion of the total energy use for an individual installation can add anywhere from 5% to 20% to the total energy consumption (with the lower percentages in this range mainly applying to heating, and the higher percentages to cooling).[9] For commercial buildings, ASHP systems with VRF (ASHP-VRF) are more efficient than standard ASHP systems, and depending upon building load diversity, they can approach GSHP efficiencies.

Life of equipment

There is not a lot of actual data on how long heat pumps last. However, based on ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) and manufacturers' estimates and some data for central AC systems in hot climates, which are very similar to ASHPs, we expect residential ASHPs to last about 15 years on average (with a range of 13-17 years). We expect residential hybrid ASHP/furnace systems to last 18-20 years and commercial ASHP systems to last 15-20 years. Because GSHPs can be located inside buildings, we estimate them to have a longer life-span, such as 20-25 years.[10]

Grid impacts

In addition to being more efficient, GSHPs offer the potential added benefit of adding less electricity demand than ASHPs in the coldest weather. For example, for a home with a whole house ASHP and no backup furnace, there will be some additional electricity load during the coldest days. Even if the heat

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7 Terry Proffer, Major Heating, personal communication, January 2, 2024, tproffer@gomajornow.com.

8 GSHP values are based on efficiency ratings from manufacturers based on typical entering water temperature (EWT) for Colorado loop designs. For ASHP values, see: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwj8kfjlrMKDAxVoD0QIHUHNDZUQFnoECCEQAw&url=https%3A%2F%2Fwww.nrel.gov%2Fdocs%2Ffy23osti%2F85081.pdf&usg=AOvVaw0deL3YwHAf_b1-ceJGq9dK&opi=89978449.

9 https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiqhf6rl7qCAxXkHjQIHcVhACUQFnoECEIQAQ&url=https%3A%2F%2Fwww.aceee.org%2Ffiles%2Fproceedings%2F2000%2Fdata%2Fpapers%2FSS00_Panel10_Paper10.pdf&usg=AOvVaw3PsCyh30G1TFAK4onevnNF&opi=89978449.

10 For example, commercial water-air GSHP units are projected to have a service life of 24+ years. See Chapter 37, 2015 ASHRAE Handbook, Table 4, Comparison of Service Life Estimates (for various types of mechanical equipment).

pump is a cold-climate heat pump, properly designed to handle the full heating load of the building at the design temperature, there will be a few days of the year during which the heating load exceeds the heat pump's capacity. On these days, the backup electric resistance heating may add an additional ~8 kilowatts (kW) of load to the home's heating power needs (for an average size home). However, cold-climate ductless "mini-split" ASHP systems are able to heat to lower outdoor temperatures than whole house ducted systems and generally require less backup heating. In Appendix B, we provide more details on backup heating needs. Our estimates for backup electric heating needs are summarized in the table below.

Backup electric heating needs

Heat pump system	3-4 ton home	5 ton home
ASHP – ducted	3-8 kW	6-10 kW
ASHP – ductless	3-6 kW	6-9 kW
GSHP	3-5 kW	5-7 kW

Because of the relatively steady and warmer temperatures of the earth and underground fluids in the loops, a GSHP system will be able to efficiently provide the home's heating needs down to very cold outdoor temperatures with very little electric resistance backup, and its electricity use will be less than ASHPs at cold temperatures.

In addition to energy demand on the grid, heat pump systems can have an impact on the distribution infrastructure at the building (electrical panel size) and transformer levels. Therefore, GSHPs offer additional value, for both the building owner and the utility, from less additional winter peak demand relative to ASHP systems.

Initial costs

On the other hand, geothermal heat pump systems cost significantly more than ASHPs. For a new single-family home of about 2,500 square feet, we estimate a cold-climate ASHP system with electric strip backup would cost about $25,000. For a GSHP system for the same home, the cost of the heat pump equipment and pumps would be slightly less than the cost of the ASHP system – about $20,000. However, the cost of installing the underground piping system for the geothermal system is about $45,000 on average, so the GSHP system would cost about $40,000 more than the ASHP system initially, which is a steep cost to overcome. We analyze the life-cycle costs for single-family homes in more detail in a later section of this report.

Summary

For small commercial stand-alone buildings ("small" meaning with six tons or less of heating capacity), ASHPs will tend to be more cost-effective in "mild" climates such as Climate Zones 5 and lower. For medium and large commercial buildings, ASHP-VRF systems, mentioned in the previous section, are an excellent, cost effective technology to be considered in addition to GSHPs. For medium-size and larger commercial buildings in Climate Zones 5 or higher, GSHPs may generally be cost-competitive compared to ASHP or ASHP-VRF systems, and GSHPs will have the potential advantages of slightly lower energy consumption, GHG emissions, and grid impacts.[11] [12]

Commercial buildings GSHP applications

We estimate that in the past five years, there have been about 5-10 non-residential GSHP projects installed annually in Colorado, covering a variety of commercial building types. This is based on a compilation of projects from one of the larger GSHP designers in Colorado, summarized in the Table below.[13]

Colorado commercial GSHP projects

Type of building	No. of projects (2019-23)	
	High Country	**Front Range**
Housing development	3	1
Government buildings	5	4
Medical facilities	1	1
Education facilities, K-12 through university		7
Commercial	1	2
Community Service	1	
Total	**11**	**15**
Total heating capacity (tons)	**1357**	**3772**

Below we present a few examples of successful GSHP projects (and one new project under construction) involving larger commercial buildings and networks of buildings.[14]

[11] These are our general recommendations, partially based on our analysis in the Residential Applications section. Further research is needed to clarify which are the most cost-effective GSHP applications compared to ASHP or ASHP-VRF technologies.

[12] As stated above, we are mainly focusing in this report on new buildings and homes; but GSHPs would also make sense for existing commercial buildings with radiant heating, because ASHPs don't perform as well in air-water applications.

[13] Terry Proffer, Major Heating, personal communication, December 8, 2023, tproffer@gomajornow.com.

[14] More examples of Colorado geothermal projects can be found here: https://www.cogeothermal.com/gallery/.

Colorado Mesa University

Colorado Mesa University (CMU) in Grand Junction established a goal to be the first American university to be fully heated and cooled by a geothermal heat pump system. The initial geothermal system was installed at CMU in 2007, with a central loop serving four new buildings and one existing building. The system was paid for using funds from the university's annual budgets. Since then, there have been many additions, and currently, the geothermal loop system includes 3.5 miles of piping and serves 17 buildings (just over half of the university's buildings) in an area occupying about half of a square mile. More additions are being planned for 2024 and will leverage grants from the State of Colorado and Inflation Reduction Act tax credits.[15] The current system includes seven well fields, which circulate water and ethylene glycol at a constant 54°F year-round. Heat pumps and other equipment provide the heating and cooling needs of individual campus buildings. The CMU geothermal exchange system has been well-documented and is an example for college campuses nation-wide.[16]

One feature of the campus system, which is an advantage compared to a geothermal system serving a group of homes, is that some buildings have excess heat that can be efficiently transferred to other buildings that need heat, making the overall system much more efficient than one in which all buildings need to provide heating or cooling at the same time. For example, the initial system was designed to use about 200 feet of piping per ton of heating (or cooling), and now the system only requires 89 feet of piping per ton.[17] The CMU geothermal system also achieves high levels of efficiency for both heating and cooling, with coefficients of performance ranging from 3.1-6.1.[18] (The system achieves higher efficiencies (higher COPs) for heating or cooling during milder weather, and lower COPs during very hot or very cold weather.)

Gunnison County

Over the last seven years, Gunnison County on Colorado's West Slope has constructed two new buildings with geothermal heat pump systems and retrofitted three existing buildings using geothermal systems, using a variety of funding sources.

Existing buildings:

- Health and Human Services building – 11,600 square feet (SF)
- Blackstock government building – 26,200 SF
- Airport terminal – 48,000 SF

New buildings:

- County courthouse – 45,900 SF
- Library – 15,000 SF

[15] Cary Smith, Sound Geothermal, personal communication, November 30, 2023, dcsmith@soundgt.com.
[16] "Geo-Grid System," Colorado Mesa University, https://www.coloradomesa.edu/sustainability/initiatives/geo-grid.html.
[17] Cary Smith, Sound Geothermal, personal communication, November 30, 2023, dcsmith@soundgt.com.
[18] Hyunjun Oh and Koenraad Beckers, "Cost and Performance Analysis for Five Existing Geothermal Heat Pump-Based District Energy Systems in the United States," National Renewable Energy Laboratory, https://www.nrel.gov/docs/fy23osti/86678.pdf.

The Health and Human Services building and the Blackstock government building are connected to the same geothermal system; all the others have a separate geothermal system for each building. To pay for the geothermal systems and other building improvements, the County assembled an impressive package of funding, taking advantage of a combination of sources:[19]

- *Local taxpayer-approved funding and annual budgets.* Gunnison County residents voted in 2019 on how their tax dollars would be spent for a new library building on donated acres of land, and the results came back with strong public support to make the building all-electric. That tax funding, combined with a $1 million endowment from the rancher who donated the land, became the main source of funding for the library project. In addition, the County Commissioners approved using some of the County's annual budget for building improvements.
- *Energy performance contracts.* The Blackstock building renovation was funded through an energy performance contract, which uses the project's ongoing savings to gradually pay for the upfront costs.
- *Lease-purchase agreements.* Lease purchase agreements or Certificates of Participation are a finance mechanism available to local governments. This mechanism was used to finance improvements at Blackstock and the Courthouse.
- *State grant funding. Colorado's* Department of Local Affairs (DOLA) has a grant program for local government and community projects, funded with sales taxes from energy extraction companies. The DOLA grant cycle is typically twice a year and can help cover the gap between internal cash flow and funding from energy performance contracts.

Town of Carbondale

With the help of a $700,000 grant from the U.S. Department of Energy (DOE), the Town of Carbondale is exploring the design and costs for a geothermal heat pump loop system to serve a group of buildings in downtown Carbondale. The loop could potentially serve several new and existing buildings, including the community center, a town administration building, the high school, the library, and multiple townhouses and condominiums. The project is being coordinated by Clean Energy Economy for the Region (CLEER), a nonprofit organization based in Carbondale, with input from the Town of Carbondale. The project is being designed by Grey Edge Group, a geothermal system design company with an office in Montrose, Colorado. CLEER is also applying for a second DOE grant, which could pay for up to 80% of the project costs.[20]

Best commercial applications

Given the current GSHP looping supply constraints, discussed in more detail in the section on market development, we recommend that GSHP programs focus on non-residential market applications of the types shown below. This will help establish an annual GSHP installation demand in a set of larger

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[19] "Gunnison Does Away with Gas," SWEEP, May 2023, https://www.swenergy.org/gunnison-does-away-with-gas/.
[20] "A Colorado town wants to use geothermal energy to heat and cool a section of its downtown core," Mark Jaffe, Colorado Sun, December 5, 2023, https://coloradosun.com/2023/12/05/geothermal-heat-cooling-carbondale-colorado-grant/.

applications, which will support the growth of GSHP looping businesses. Specifically, we recommend focusing programs and support on these applications:

- Schools (K-12)[21] and college/university buildings[22]
- Local and state government buildings (medium-size or larger)
- New home developments or mixed-use developments

The first two types of applications above are well established within the industry.[23] The third one, geothermal networks for new home developments or mixed use developments,[24] is an area with a lot of potential and growing interest nationally. Networks of this type could be explored by local governments, with the help of grants from the state or federal government, as in the Carbondale example above.

Another exciting possibility is for gas or electric utilities to obtain authorization through legislation or state PUC rules to provide the financing for these types of geothermal networks. The utilities could be allowed to earn a return on their investment through monthly fees to the building owners, such as over a 20-year period. If shown to be cost-effective,[25] geothermal networks could provide a new revenue source for gas utilities, while avoiding new gas piping infrastructure for new developments and contributing to state climate goals for the buildings sector.[26] In Colorado, gas utilities are required by law to implement "Clean Heat Plans," and geothermal networks are an excellent option for meeting a portion of their emission reduction requirements.

Residential geothermal heat pump applications and modeling

The residential GSHP market was first established in Colorado in the late 1990s and has been a mix of new and retrofit projects for early technology adopters, with annual installations of a few hundred per year.[27] With increased awareness and financial support in the past few years, the residential industry is slowly growing in the new home market, with the customer base branching out beyond early adopters. However, a parallel and competing trend is that over the past 15 years, ASHP efficiencies have improved

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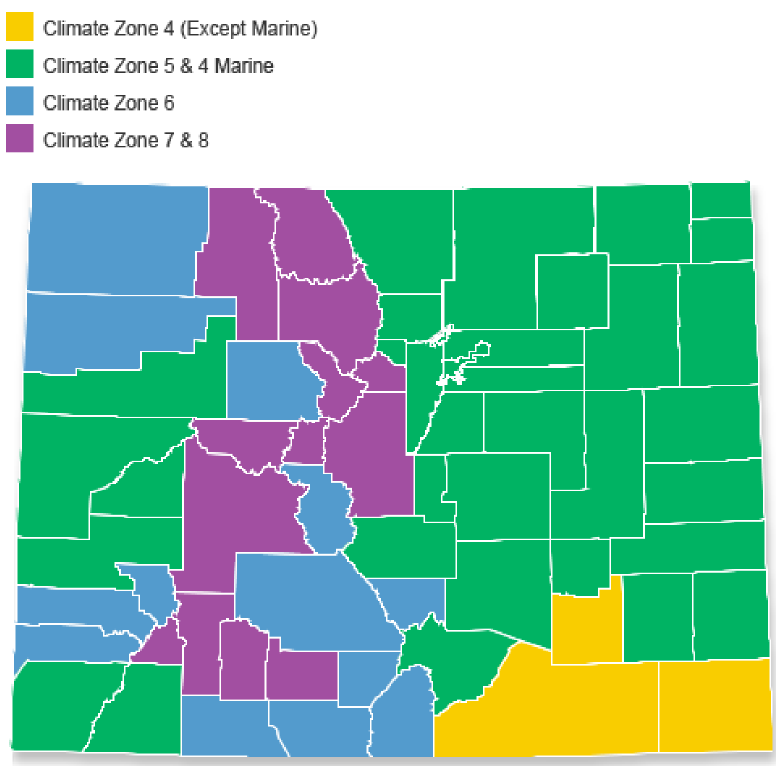
[21] Geothermal Heat Pumps Score High Marks in Schools, Office of Geothermal Technologies, September 1998.
[22] "To Slash Carbon Emissions, Colleges are Digging Really Deep," New York Times, January 23, 2024.
[23] However, as mentioned above, further research would be useful to clarify which are the most cost-effective commercial building GSHP applications.
[24] Note that networks of new homes would not have the advantage of load diversity, which a mixture of building types might offer, improving the overall efficiency of the system. On the other hand, if each home has its own separate GSHP, the system controls would be much simpler than for a more robust system, such as the Colorado Mesa University example above.
[25] The life-cycle cost analyses should include the social cost of carbon emissions, and include all rebates and tax credits available for GSHP systems.
[26] For more information on this topic, see "Networked Geothermal: A Warm Solution for a Cooler Planet," University of Colorado, Masters of the Environment Graduate Program Capstone project, February 2024, forthcoming.
[27] Dan Rau, Colorado Geothermal, personal communication, December 8, 2023, dan@cogeothermal.com.

by more than 30%,[28] significantly reducing the efficiency gap between ASHPs and GSHPs. ASHP heating capacities in cold temperatures have also improved, widening their geographic viability.

To clarify the question of whether GSHPs make sense for single-family homes in Colorado, and if so, at what size of home, we conducted some modeling and analysis. We compared the total costs for GSHPs versus ASHPs for two sizes of residential single-family homes, in several Colorado climate zones and near-surface geological conditions. Below we describe the main assumptions, highlight the results, and provide a summary of the main findings at the end of the section. We also provide more details on the modeling parameters in Appendix A.

Annual heating and cooling cost modeling

For the heating and cooling costs, we modeled several different scenarios and climate zones in Colorado. The map below shows the heating/cooling climate zones for Colorado.



We present modeling results here for the following climate zones:

- Climate Zone 5 – Denver and eastern Colorado
- Climate Zone 6 – Eagle County

[28] "Evolution of the Heat Pump," Amana, https://www.amana-hac.com/resources/hvac-learning-center/hvac-101/heat-pump-history-and-generations-evolution.

Note that Climate Zone 5 in western Colorado is very similar to Denver and eastern Colorado. Grand Junction has a slightly milder climate than Denver. The energy use and cost for Grand Junction would be ~3% less than the Denver modeled results.[29]

The following climate zones were not specifically modeled but results would be similar to the modeled zones:

- Climate Zone 4 in the southeast corner of the state: both the climate and ground temperature conditions in that corner of the state are more favorable than Climate Zone 5, so they can anticipate 10-20% lower operating costs for either GSHPs or ASHPs.
- Climate Zones 7 and 8 present several challenges for both GSHP and ASHP systems that drive up the costs, including a) higher elevations that reduce the capacity of both GSHP and ASHP systems, b) harsh climate conditions requiring more operating hours below 0°F, and c) lower earth subsurface temperatures that contribute to larger loop field requirements. Because of these challenges, for these zones we recommend ASHP systems with gas or propane supplemental heating. Assuming continued evolution of ASHP technology, the need for gas or propane supplemental heating will probably be unnecessary when homeowners are ready to replace their ASHP systems in 15 years.

The table below shows the assumed efficiencies of the three types of HVAC systems we modeled. We chose these efficiencies because they represent a similar level of efficiency for the three types of HVAC systems – above-average but representative of several brands that are readily available.

Efficiencies of HVAC equipment modeled

Type of HVAC system	Efficiency of heating and cooling
Gas furnace and AC	95% AFUE, 18 SEER
Cold-climate ASHP – ductless	10.5 HSPF, 18 SEER[30]
GSHP	3.7 COP, 18.2 EER

[29] Climate Zone 5 also includes a sub-zone, "5a," which includes the Front Range foothills in the 6,500 - 8,500' elevation range (e.g., Estes Park, Nederland, Evergreen, Aspen Park, Woodland Park). This sub-zone is not identified on official climate zone maps, but its elevation and climate requires systems with higher capacities than Climate Zone 5 (but not quite as high as Climate Zone 6). The operating and installation costs are between Climate Zone 5 and Climate Zone 6.

[30] For this system, we assume it is properly sized and will need very modest backup electric strip heating, as described in more detail in Appendix B.

Detailed modeling parameters are provided in Appendix C. The models consider any backup heating required for the various systems. Note that energy costs do not vary with soil conditions, only with location and climate zone. The annual heating and cooling costs below are based on homes with four- or five-ton heating loads. Four-ton was selected because that is the maximum house load that can be heated with the largest single unit residential ASHPs currently on the market. A new home with a four-ton heating load would be about 2,800 square feet in size, slightly larger than the average new home.

Residential energy prices

Energy Prices[31]	Price ($)	Date
Winter gas ($/therm)	$1.277	Average winter 2022-23
Winter electricity ($/kWh)	$0.1402	January 2023
Summer electricity ($/kWh)	$0.1443	August 2023

Summary of energy modeling for four- and five-ton Homes

	Annual Energy Costs ($)					
	Gas furnace and AC		ASHP		GSHP	
Location and size of home	Heating	Cooling	Heating	Cooling	Heating	Cooling
Denver 4-ton	$1,553	$174	$1,356	$171	$1,182	$173
Denver 5-ton	$1,884	$210	$1,658	$222	$1,419	$214
Eagle 4-ton (4.2)	$2,122	$107	$1,862	$99	$1,579	$94
Eagle 5-ton (5.3)	$2,638	$124	$2,270	$134	$1,985	$124

Key highlights from our analysis are:

[31] Residential energy prices are taken from the Energy Information Administration (EIA), https://www.eia.gov/electricity/data.php and https://www.eia.gov/naturalgas/data.php.

- Heating costs for the cold-climate ASHP are about 12-14% less than for the gas furnace for both Denver and Eagle, for both sizes of homes.
- Heating costs for the GSHP are about 10-15% less than for the ASHP, for both Denver and Eagle, for both sizes of homes.

It is important to note that the differences in annual heating costs between an ASHP system and a GSHP system can have a larger range than above, depending upon the selection and design of HVAC systems, especially the ASHP systems. For example, a GSHP system will reduce the annual heating bill by as little as 5-10% over an ASHP system with an HSPF of 12, and by as much as 20-25% over an ASHP with an HSPF of 9.5.

The total annual cooling costs in Denver during a normal year are less than 15% of the annual heating costs, and only about 6% of annual heating costs in Eagle. The annual cooling costs for the AC, ASHP, and GSHP are almost the same, varying only by a few percent. The expectation that GSHPs should have a much lower cooling cost is offset by two factors: 1) in Colorado much of the cooling is at outdoor air temperatures below 85F where ASHP cooling is very efficient, and 2) the loop pumping energy for GSHP systems offsets much of the cooling efficiency advantage. For outdoor temperatures above the mid-80s, the GSHP cooling advantage offsets the pumping energy, and the GSHP cooling costs will be slightly less than for the ASHP.

System first cost comparisons

In this section, we present estimates of the range of drilling and HVAC system costs, focusing on new homes. (Geothermal heat pump retrofits of existing homes are much more challenging, for numerous reasons.)

Drilling costs

For GSHPs, there are several key drivers of the wide variation of drilling and installation costs across Colorado. These key drivers are:

- Effect of near-surface site geology on the loop field size
- Effect of near-surface site geology on drilling risks
- Loop field and indoor unit location
- Mobilization costs

The loop field is designed and sized so that the fluid coming into the GSHP unit never goes below a certain temperature in the coldest portion of the winter. The colder the accepted design temperature, the smaller the loop field, but the lower the efficiency and capacity of the heat pump system. Considering this tradeoff, for Colorado a good loop design temperature is in the mid-30s°F (~35°F).

The other factor contributing to determining the loop field size is the average ground temperature in the range of the loop field depth (200-400 feet). The colder the average annual temperature, which is reflected in a colder average subsurface ground temperature, the larger the loop that is required. The average annual sub-surface temperature in Denver is ~6°F higher than in Eagle, which accounts for the loop field depth differences between Eagle and Denver shown in the table below.

The table below is a specific example of the impact of the geology and location on the loop sizes for our models for three of the common ASHRAE geologic classifications for design.[32] As shown, depending upon the geology, the loop field size (number and depth of boreholes) can vary by a factor of two. The table reflects the same hours of heating for a home located in Denver or Eagle. The home heating design load is slightly different for each because of the design temperatures shown.

Geology and loop field size

Location (design temperature)	ASHRAE subsurface geology classification	Home heating load (tons)	Number of boreholes	Depth of boreholes (ft)
Denver (-1°F)	**Average rock**	**4**	**3**	**250**
Denver (-1°F)	**Heavy damp**	**4**	**4**	**277**
Denver (-1°F)	**Light damp**	**4**	**5**	**300**
Eagle (-5°F)	**Average rock**	**4.2**	**5**	**263**
Eagle (-5°F)	**Heavy damp**	**4.2**	**6**	**341**
Eagle (-5°F)	**Light damp**	**4.2**	**8**	**354**

Even with detailed geology maps, drillers never know the exact conditions they will encounter until they start the loop field. Here are a few examples of the risk and variability that can drive up drilling costs:

- Low risk: consolidated shales from top to bottom of the borehole, with lower thermal conductivity values.
- Low risk: granite and other metamorphic rocks in the high country, with higher thermal conductivity values.
- High risk/high cost: foothills transition zones throughout the state. Varying unconsolidated soils with boulders intermixed with rock layers. Thermal conductivity values can range from poor to good.

[32] These three ASHRAE geologic classifications are: 1) Average/Sedimentary Rocks: shale, sandstone etc.; 2) Heavy, Damp Soils: clay-rich soils with some moisture but not below the water table; and 3) Light Damp Soils: clay/sand mixed soils with some moisture but not below the water table.

Because of the factors noted above, the GSHP loop field installation cost has a wide range. The cost estimates below are prior to any tax credits or rebates. Note that the loop and equipment costs can vary by +/- 10% from the estimate in the table depending upon the local HVAC market. On the Front Range the loop prices will tend to be in the middle to low end of the range, while in the high country they will tend to be in the middle to high end of the range.

Range of loop costs for new homes

New home size (SF)	Heating load (tons)	Loop cost - low	Loop cost - high
2,800	4	$35,000	$56,000
3,500	5	$43,750	$70,000
4,200	6	$52,500	$84,000
4,800	7	$61,250	$98,000
5,500	8	$70,000	$112,000

HVAC system costs

As mentioned above, for the ASHP system, we chose an efficient cold-climate mini-split system. The largest available residential ASHP pumps have a standard rating of 4.5 tons (54,000 British thermal units (Btu)/hour (hr)), but for applications in Colorado these heat pumps have an effective capacity about 20% less than this rating, or about 43,000 Btu/hr or 3.5 tons. We estimate the initial cost of this system to be as shown in the table below. Homes with a heating load of five tons will require two ASHP systems, which makes the initial costs for the five-ton ASHP system significantly higher. The five-ton home only requires one GSHP system, because higher capacities of GSHP systems are available.[33]

[33] The largest available residential GSHP pumps have a standard rating of 6 tons (72,000 Btu/hr). For applications in Colorado, these heat pumps have an effective capacity in the 5-6 ton range. For homes with loads of six tons or greater, you will generally need two or more systems for both the ASHP and GSHP options. However, for these larger homes, the price range is wide, and it is very difficult to make generalized pricing assumptions.

Total life-cycle costs

In the tables below, we summarize the life-cycle costs for GSHPs versus ASHPs.[34]

Life-cycle costs of GSHPs vs. ASHPs for Denver/Front Range

Type of cost	4-ton home		5-ton home	
	ASHP	GSHP	ASHP	GSHP
Initial cost				
- Equipment	$28,000	$20,000	$40,000	$22,000
- Drilling (weighted avg. of low and high)[35]	0	$42,000	0	$52,500
Total initial cost	$28,000	$62,000	$40,000	$74,500
Total initial cost (after tax credits and rebates)	**$22,100**	**$41,000**	**$33,600**	**$49,400**
Net Present Value (NPV) of equipment replacement costs (after 15 years for ASHPs, 22 years for GSHPs)[36]	**$13,470**	**$6,840**	**$19,240**	**$7,520**
Energy costs				
- Annual Energy Costs (heating and cooling)	$1,527	$1,355	$1,880	$1,633
- NPV of energy costs (25 years)[37]	**$21,520**	**$19,100**	**$26,500**	**$23,010**
NPV of total costs (25 years)	**$57,090**	**$66,930**	**$79,340**	**$79,930**

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[34] We did not include the "standard HVAC" system in this comparison. But we have compared the initial costs of the standard system versus ASHPs for single-family homes and found the costs to be nearly the same. See https://loveelectric.org/for-builders-developers/.

[35] These are based on the range of drilling costs shown in the previous table. For Denver/Front Range, we calculated the weighted average, giving the lower end of the range twice as much weight as the high end, and for Eagle, we weighted the high end twice as much as the lower end.

[36] For ASHP systems, we assume the equipment needs to be replaced after 15 years, while we expect the GSHP equipment to last about 22 years. We used a discount rate of 5%. The GSHP equipment lasts somewhat longer because it is housed inside the building, facing less extreme temperatures.

[37] Again, using a 5% discount rate and no energy price escalation beyond inflation.

Life-cycle costs of GSHPs vs. ASHPs for Eagle

Type of Cost	4-ton Home		5-ton Home	
	ASHP	GSHP	ASHP	GSHP
Initial cost				
- Equipment	$28,000	$20,000	$40,000	$22,000
- Drilling (weighted average of low and high)	0	$49,000	0	$61,250
Total initial cost	$28,000	$69,000	$40,000	$83,250
Total initial cost (after tax credits and rebates)	**$22,100**	**$45,900**	**$33,600**	**$55,525**
NPV of equipment replacement costs (after 15 yrs for ASHPs, 22 years for GSHPs)	**$13,470**	**$6,840**	**$19,240**	**$7,520**
Energy costs				
- Annual energy costs (heating and cooling)	1,961	1,673	2,404	2,109
- NPV of energy costs (25 years)	**$27,640**	**$23,580**	**$33,880**	**$29,720**
NPV of total costs (25 years)	**$63,210**	**$76,320**	**$86,720**	**$92,770**

For Denver/the Front Range, as shown above, for the four-ton home, the total life-cycle costs for the ASHP system are lower than the costs for the GSHP system (by ~16%); while for the five-ton home, the total life-cycle costs of the GSHP system are about the same (within 1%). (Note that all our cost estimates are only accurate within about 5-10%.) Also note that the rebates and tax credits for GSHPs are much more generous, which helps make the total costs for the homeowner closer to those for ASHPs.

For a home in Eagle, even for the five-ton home, the GSHP system has higher life-cycle costs than the ASHP system (by ~6%), because of the higher drilling costs in the high country. It would take a slightly larger home, perhaps with at least six tons of heating demand, for the GSHP system to be cost-effective in the high country.

GHG emission reduction benefits of GSHPs

In the table below, we provide the calculated GHG emissions for the gas furnace and AC, ASHP, and GSHP systems, for both four- and five-ton homes, for Denver/Front Range. Largely because of the transition of Colorado's power generation to renewable resources over the next 16-20 years,[38] the GHG emission reductions for both ASHPs and GSHPs are 69-73% compared to emissions for the gas furnace home.[39] The additional GHG emission reductions for GSHPs compared to ASHPs (3-4%) are not very significant, especially compared with the total life-cycle costs. As shown, from a societal point of view, the cost of the GHG emissions reduced from GSHPs compared to ASHPs is very expensive, $2,300-$4,200 per metric ton of carbon dioxide equivalent.[40]

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[38] Colorado has set a goal to achieve 100% renewable electricity by 2040. In practice, this may take slightly longer, but all of Colorado's major utilities, which account for over 90% of the state's electricity generation, have plans to achieve at least 80% GHG emission reductions by 2030.

[39] We used projected electricity emission factors for Colorado from NREL, found here: https://scenarioviewer.nrel.gov/?project=a3e2f719-dd5a-4c3e-9bbf-f24fef563f45&mode=download&layout=Default. NREL offers several scenarios for projected emission factors, from which we chose the average of two scenarios; the "mid-case 95 by 2035" and the "mid-case 95 by 2050." In addition, we chose the long-term marginal emission factors for these scenarios. We discuss these choices further and provide these emission factors in Appendix D.

[40] Note that the federal social cost of carbon, one indicator of the societal costs of GHG emissions, is currently only about $83/metric ton of CO2e. See https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html. However, there are proposals to increase this to $190/metric ton of CO2e. See https://www.nytimes.com/2023/12/02/climate/biden-social-cost-carbon-climate-change.html.

GHG emission reductions from GSHPs vs. ASHPs for Denver/Front Range

GHG emissions	4-ton home			5-ton home		
	Furnace and AC	ASHP	GSHP	Furnace and AC	ASHP	GSHP
Heating therms	1,128			1,409		
Annual heating and cooling electricity consumption (kWh)	2,012	10,858	9,621	2,063	13,370	11,601
Total GHG emissions (metric tons CO2e, 25 years)	**158.9**	**49.6**	**43.9**	**196.5**	**61.1**	**53.0**
Percentage reduction compared to furnace		**68.8%**	**72.4%**		**68.9%**	**73.0%**
Emissions benefits for GSHP vs. ASHP (metric tons CO2e, 25 years)			**5.6**			**8.1**
NPV of 25-year costs (with rebates and credits)		$57,090	$66,000		$79,340	$78,910
NPV of 25-year costs (full costs with no rebates)		**$62,990**	**$87,000**		**$85,740**	**$104,010**
Increased NPV costs for GSHP			**$24,010**			**$18,270**
Cost of emissions saved ($/metric ton CO2e, full costs with no rebates and credits)			**$4,250**			**$2,260**

Summary for single-family homes

For average-size single-family homes, those with heating loads of four tons or less, our analysis shows that ASHPs have much lower initial costs, which more than offset the slightly higher heating and cooling costs compared to GSHPs, resulting in a lower NPV cost over 25 years. For homes with heating loads of five tons, approximately 3,500 square feet in size for Denver/Front Range (or slightly greater than five tons for larger homes in the high country),[41] homeowners that can afford the additional upfront costs of

[41] The estimate of 3,500 square feet is based on a home that meets the 2021 IECC, which will be required in more and more Colorado cities and counties as they update their building codes.

the GSHP system should consider obtaining designs and contractor bids for both ASHP and GSHP systems.

The GHG emissions for single-family homes with GSHPs are only slightly smaller than for homes with ASHPs, especially compared to the large reduction in emissions for both heat pump technologies versus homes heated with a gas furnace. Because of the small GHG emissions benefits of GSHPs compared to ASHPs, in our opinion there is much less of a need for further state assistance regarding the residential GSHP market, particularly given that there is already an abundance of tax credits and utility rebates for GSHPs (see Appendix A).

GSHP market development challenges

GSHP drilling and installation businesses have had a niche presence in Colordao since the mid-1990s. The annual demand for projects has mainly involved residential installations with a few larger commercial projects. The GSHP loop supply chain and the market demand have been stable and in balance with little overall annual growth. However, over the past five years, there has been an increasing desire for growth in the industry, driven by greater awareness of GSHP technology, and by the desire to achieve reduced GHG emissions from buildings.

The major challenge to developing a more impactful GSHP market in Colorado will be the need to significantly expand the supply of vertical loop field installation contractors. Currently the backlog for vertical loop installation is several months.[42] At present, there are only six geothermal contractors who are licensed by the Colorado Department of Water Resources to drill and install geothermal piping loops as of April 2023:

1) Bertram, Dilling, Inc.
2) Can-America Drilling, Inc.
3) Colorado Geothermal Drilling
4) Just Geo Loops, Inc.
5) Panterra Energy
6) Standard Geothermal Solutions, LLC

The commercial GSHP market in Colorado is mainly served by Can-America Drilling, Colorado Geothermal Solutions, and Panterra Energy, which are located on the eastern plains and Front Range. In addition, there are only four vertical loop drilling operations outside of Colorado but within 500-1,000 miles, with the resources and experience to travel to Colorado for large commercial jobs.[43] What's more, large mobilization and demobilization fees negatively impact the economics for these operators to undertake projects in Colorado.

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[42] Dan Rau, Colorado Geothermal Drilling, personal communication, December 8, 2023, dan@cogeothermal.com; Brian Fowler, GeoSource Distributors, personal communication, December 15, 2023, brian.fowler@geosourcedistributors.com.

[43] Dan Rau, Colorado Geothermal Drilling, personal communication, December 8, 2023, dan@cogeothermal.com; Brian Fowler, GeoSource Distributors, personal communication, December 15, 2023, brian.fowler@geosourcedistributors.com.

Currently, a significant portion of GSHP activities in Colorado are focused on single-family homes on the Front Range.[44] Three of the above looping companies, Colorado Geothermal Drilling, Can-America Drilling, and Standard Geothermal Solutions, work on residential GSHP systems.[45] The first two mainly focus on commercial GSHP projects and do residential projects as their schedules allow.[46]

Building an expanded workforce of GSHP drilling and looping specialists is the biggest challenge to expanding the looping industry. Because of the complexities of the subsurface, the skills needed to operate a GSHP drill rig can only be learned on the job. In addition to finding workers willing to do this work, the costs and challenges of training and retraining workers can be significant.

The scope and complexity of a GSHP drilling operation is similar to water well operation, so there is some potential for re-training of water well drillers. GSHP drilling is very different from oil and gas drilling operations, so retraining those workers would be a bigger challenge.

In addition to the market and workforce challenges, there are financial and capital issues. We estimate that the drill rigs and associated pumping and looping equipment needed to handle the wide variety of geologic conditions in Colorado requires a minimum of $500,000 - $750,000 in capital for a residential operation. For commercial operations, the capital requirements would be several times this amount.

While this might not seem like a large investment to start a business, the financing requires a minimum consistent level of GSHP business throughout the year and over a several year period to ensure business survival. The challenge that GSHP drilling and looping contractors have faced since 2000 is the overall limited and sporadic nature of the GSHP market in Colorado. One factor in this weak demand has been the historically low natural gas prices. However, with the growing interest in building electrification and decarbonization and the influx of funding from the state and federal government, there are opportunities to sustainably grow the GSHP market for commercial applications.

Conclusions and recommendations

Both ASHPs and GSHPs significantly reduce carbon emissions from the heating of residential and commercial buildings compared to gas or propane heating. ASHPs have lower initial costs than GSHPs and make sense for most single-family homes and many small- or medium-size commercial buildings. GSHPs offer slightly better energy efficiency than ASHPs as well as slightly reduced GHG emissions, but have higher initial costs because of the significant costs of drilling and installing the underground pipes. Therefore, GSHPs will be more cost-effective and offer the greatest benefits for the following applications:

- Schools (K-12) and college/university buildings
- Medium-size and larger commercial buildings

[44] For example, in 2023 there were 108 GSHP loops constructed in Colorado, and more than half of these were residential installations. See Colorado Division of Water Resources, Decision Support Systems Database, (provide link)

[45] Dan Rau, Colorado Geothermal Drilling, personal communication, December 8, 2023, dan@cogeothermal.com; Brian Fowler, GeoSource Distributors, personal communication, December 15, 2023, brian.fowler@geosourcedistributors.com.

[46] Terry Proffer, Major Heating, personal communication, January 2, 2024, tproffer@gomajornow.com.

- Geothermal networks for new home developments or a mix of residential and commercial buildings

GSHP market development

Since there are currently only a few contractors that are completing these types of larger projects, stakeholders will need to work together to support the required investment in equipment and workers needed to increase the capacity of the GSHP drilling industry. Growing the commercial drilling and looping industry and equipment installation supply chain in Colorado, focusing on the priority applications listed above, will take sustained leadership from the CEO, in collaboration with the Colorado Geothermal Energy Advisory Group, utilities, and the investment community. We recommend that the CEO and the Geothermal Advisory Group explore the following strategies:

Front Range/Eastern Plains. For commercial projects on the Front Range or eastern plains, we suggest exploring three approaches to expand GSHP industry capacity:

1) Hold discussions with Can-America, Panterra, and Bertram Drilling to understand and determine the required annual revenue from GSHP commercial projects that will be required for them to expand their presence in Colorado.

2) Collaborate with utilities and investors to develop a sustainable business model for large scale commercial looping operations, either as utility-owned subsidiaries or new businesses with adequate financial and focused market support.

3) Work with the CWWCA and the ~30 water well contractors on the Front Range and eastern plains to present the opportunity and encourage a few members to grow into the GSHP loop business with capabilities to take on medium to large commercial projects.

High Country. In the high country, the challenge is complicated by the additional geologic risks associated with drilling and the shortened looping season (6-7 months versus 10-11 months on the Front Range). We suggest working with the CWWCA to develop a plan and investment strategy to encourage and support a few members to grow their operations into the GSHP looping business focused on medium-sized commercial jobs in some of the markets described below. There are currently ~15 water well drilling companies in the high country. The equipment, cost, expertise, and complexity of water well drilling and GSHP loop installation are in many ways similar and are complementary business endeavors. CanAmerica drilling is a Colorado company that has been operating under this dual business strategy for at least 20 years. This is the most likely avenue to expand GSHP capacity in the high country.

State grant programs

As described above, there is already a generous amount of state funding and utility rebates for geothermal heat pump systems for all types of applications. Because of limited capacity, we feel that the limited state Geothermal Energy Grant Program funds should be focused on the following types of GSHP projects:

- Public schools, community colleges, and state universities
- Government buildings and complexes
- Nonprofit medical facilities
- Networks of new residential and commercial buildings

For large GSHP demonstration projects, we recommend the following process to ensure adequate system performance:

- Independent design review prior to installation approval
- Post-installation performance testing validation

Other state support

The state PUC should encourage Colorado's gas and electric utilities to complete demonstration projects of geothermal networks for new home development (or other new building developments), and to compare the life-cycle costs of the GSHP networks versus gas heating technology and gas piping infrastructure for the buildings. If shown to be cost-effective, this would provide a new revenue stream for gas utilities, while contributing to the state's climate goals for the buildings sector.

Other GSHP applications, such as private colleges, medical facilities, or commercial buildings, do not require additional funding other than the tax credits and utility rebates already available for developers. However, we do encourage the CEO to provide ongoing non-financial support and to encourage developers to undertake limited-risk projects to demonstrate the market potential. The goal of these projects should be to identify which market applications will provide steady and adequate financial opportunities over the next two decades to support the capital influx required to establish a strong commercial looping industry capacity in Colorado.

As discussed above, we anticipate that the residential GSHP market will remain a niche market for large single-family homes on the Front Range and in the high country. This market will continue to grow organically via small GSHP businesses and therefore does not require additional state resources.

By focusing its resources on the most promising, cost-effective applications, Colorado can demonstrate GSHPs' contribution to the path toward more sustainable and lower carbon buildings. In doing so, we can also set an example for other states.

Appendices

Appendix A - Rebates, tax credits, and grants

There are a variety of utility, state, and federal rebates and incentives for geothermal heat pump systems, for both commercial and residential buildings, which we summarize below.

Utility rebates

Many Colorado utilities provide rebates for new geothermal heat pump systems. For example, Xcel Energy provides rebates of $600/ton for residential or commercial ground source heat pumps that meet its minimum efficiency criteria.

State tax credits

The State of Colorado offers the following state tax credits for geothermal heat pump systems in 2024-26 (with the rebate amounts decreasing gradually in subsequent years):[47]

State tax credits

Type of building	GSHP rebate amount
Residential - single-family	$3,000 per home, of which $1,000 goes to the homeowner, and $2,000 to the installer[48]
Residential - multi-family	$3,000 per unit
Commercial	$3,000 for each 4 tons of heating capacity (e.g., $6,000 for an 8-ton system)

State geothermal energy grant program

In addition to the state tax credits, the CEO is administering a state GSHP grant program based on legislation passed in 2022.[49] Building owners, developers of new buildings and others are eligible to apply for grants for GSHP systems or geothermal networks for groups of buildings. The grants for GSHPs are limited to the following amounts:

[47] C.R.S. 39-22-554, https://leg.colorado.gov/sites/default/files/documents/2023A/bills/2023a_1272_rer.pdf.
[48] Bryce Carter, personal communication, Colorado Energy Office, December 18, 2023, bryce.carter@state.co.us.
[49] C.R.S. 24-38.5-118, https://leg.colorado.gov/sites/default/files/documents/2023A/bills/2023a_1252_rer.pdf.

Colorado geothermal heat pump grants

Type of building	GSHP grant limit
Single-family home	$2,000 per ton, up to $10,000 (5 tons)
Commercial or nonprofit organization	$3,000 per ton, up to $300,000 (100 tons)
Commercial and business	$2,000 per ton, up to $200,000 (100 tons)
Geothermal network for multiple buildings	See section 4.b. of the legislation

Note that a homeowner or building owner could potentially take advantage of the state tax credit and also apply for and obtain a state grant for a GSHP system.

Federal tax credit

Owners of new or existing homes or commercial buildings that install a geothermal heat pump system can receive a federal tax credit for 30% of the cost of the GSHP, under Sections 25D (Residential) or 48.a. (Commercial) of the Inflation Reduction Act.

Appendix B - Understanding heat pump capacities, sizing, and supplemental electric heating

Heat pump capacities and ratings

The standard capacity labels for equipment are somewhat misleading for Colorado, which can lead to inadequate design and sizing in many cases.

The standard term for communicating the size of a specific heat pump unit is tons (e.g., 1 ton = 12,000 Btu/hr, 3 tons = 36,000 Btu/hr, etc.). The tons are reflected in the serial number of the unit:

- Model 4TTZ0036A1000AA is a 3 ton unit
- Model 4TTZ0048A1000AA is a 4 ton unit

There are standard heating and cooling capacity ratings, certified by the American Heating and Refrigeration Institute (AHRI), and additional standard capacity ratings provided by the manufactures of GSHP and ASHP equipment.

GSHP capacity ratings

- AHRI capacity ratings: Provided for two entering water temperatures (EWTs) from the loop into the heating unit:
    - 50°F
    - 32°F
- Additional capacity ratings are provided by most manufacturers, including for EWT of 40 F.

ASHP capacity ratings

- AHRI capacity ratings: Provided for two outdoor air temperatures:
  - 47°F
  - 17°F
- Additional capacity ratings provided by most manufacturers of cold-climate ASHPs, for outdoor air temperatures of:
  - 5°F
  - -13°F

Elevation effects on GSHP and ASPH capacities

Both ASHP and GSHP heat pump system capacities are rated at sea level. At higher elevations, because thinner air has less capacity to hold heat, the capacities of ASHP and GSHP water-to air systems must be adjusted down to reflect the capacity at the specific elevation of the home or building. In Colorado this adjustment can range from 5% to 25%. For GSHPs and ASHPs that use radiant/hydronic systems, there is also an adjustment but it is near zero for GSHP and less than 15% for ASPH systems. In the sizing discussion below the elevation corrections to system capacities must be taken into account during system design.

GSHP sizing for new homes

When sizing a GSHP system for a Colorado home or commercial building, designers and contractors must:

1) Choose a GSHP unit with enough capacity (when the ground loop is sized to a minimum EWT of ~35F) to heat the home in the winter to at least -1°F in the front range and at least -5°F in the high country.
2) Size the ground loop based on the building needs, geology and climate. In Colorado, ground loops are designed to ensure the EWT into the unit is ~35°F in the winter, not 50°F (loops designed for 50°F would be so large as to be economically impractical).
3) For the relatively few hours per year (less than 50) that the outdoor temperature goes below -1°F or -5°F, decide whether to upsize the GSHP unit and loop or add some supplemental auxiliary electrical heat. Normally it is more cost effective to add some supplemental auxiliary heat.

ASHP sizing for new homes

1) Choose a cold-climate ASHP (inverter-driven unit) which has enough capacity to heat the home in the winter to at least 0F in the front range and the high country.
2) For the relatively few hours per year (<100) that the outdoor temperature goes below 0°F, the ASHP and supplemental electric, gas or propane heating will share the heating load. The designer will need to determine the most cost-effective and operationally efficient balance between how much to upsize the ASHP unit and how much supplemental heating capacity to add.
3) Compensate for altitude.

GSPH and ASPH sizing for existing homes

The process for existing homes is generally the same as for new homes (above), with two key points that normally will change the sizing strategies.

1) Homes/buildings with existing duct systems were designed to heat the home with furnace heating. Furnace air (130-140°F) is much warmer than heat pump system air (95-100°F). Duct systems that were designed for furnaces are large enough to provide full house heating down to an outdoor temperature typically in the range of 15-20°F when used with a heat pump system. Below that temperature range, the duct system is normally inadequate for full heating with a heat pump system. If upgrading the duct system is not feasible, the ASHP or GSHP can be sized to heat the home to 10-20°F outdoor temperature, and the supplemental backup system will take more of the heating burden below that temperature range (this is still a relatively small portion of the annual heating load; see Appendix E).
2) The existing home might have a limit on electric capacity such that it cannot support both a heat pump system and electrical supplemental backup. In this case, a hybrid ASPH and furnace system is a cost-effective solution.

Supplemental electric heat for ASHP and GSHP systems in new homes

When considering the need for electrical supplemental heating with GSHP or ASHP systems for new homes, there are two common misconceptions:

1) GSHP systems don't need any electrical supplemental heating.
2) ASHP systems need excessive amounts of electrical supplemental heating that is burdensome to the electrical system.

Heat pump systems are sized to fully meet the home heating needs at a design outdoor temperature, as established by ASHRAE and the Air Conditioning Contractors Association (ACCA) for most cities and towns in the U.S. For example, in Denver, that design temperature is -1°F (ASHRAE, 2017, 99.6%). A well-designed heat pump system will fully heat the home to this temperature, -1°F, without any supplemental heating.

However, there are several reasons why supplemental electrical heat is still needed for both ASHP and GSHP systems. First, some electrical backup heat is required in the event there is a problem with the heat pump compressor. The electrical backup provides some heat to the home to keep the home livable (i.e. above freezing) should the compressor system ever break down and need repair.

The table below shows the electric strip heating requirements to keep the home above freezing when the outdoor temperature is 12°F.

	3 ton home	4 ton home	5 ton home
Electric heat required (12°F outdoor, 33°F indoor)	3.5kW	4.5 kW	5.5kW

For an ASHP system, in additional to the above, there is also a need for electrical strip for the following reasons:

1) The heating requirement of the home at design temperature may require slightly more heat than the closest heat pump system size can produce.
2) When the outdoor temperature drops below the design temperature, more heat is needed to fully heat the home.
3) When ASHPs operate below the outdoor design temperature, they will lose some heating capacity.

Heat pumps come in specific heating capacities (sizes), with increments of ½ ton:

- 3 ton - 36,000 btu/hr (fits homes with design needs of 36,000 - 39,000 btu/hr)
- 3.5 ton - 42,000 btu/hr (fits homes with design needs of 40,000 - 45,000 btu/hr)
- 4 ton - 48,000 btu/hr (fits homes with design needs of 46,000 - 51,000 btu/hr)
- 4.5 ton - 54,000 btu/hr (fits homes with design needs of 52,000 - 57,000 btu/hr)
  - Note that currently 4.5 ton is the largest ccASHP readily available on the market)
- 6 ton - 60,000 btu/hr (fits homes with design needs of 58,000 - 63,000 btu/hr)

Example. For an ASHP system for a home in the Denver area, here is an example illustrating the sizing of supplemental electrical heat.

The heating load for this example home at -1°F is **44,000 Btu/hr.**

The perfect match is a heat pump that will produce 44,000 Btu/hr at -1°F. It is rare to find a perfect match. The goal is to find the closest match that is slightly under or slightly over the need. In this case, it would be a 3.5 ton system that produces 42,000 Btu/hr at -1°F. Typically, if a designer can find a system within 3000 btu/hr (¼ ton) of the design heating needs that is the best sizing, otherwise it's best to jump up one half ton.

Heating Design Load Shortage to meet with supplemental: 44,000 - 42,000 = 2,000 Btu/hr

In an average year the outdoor temperature in Denver will go below -1°F down to -13°F, for about 30-50 hours. The heating need of this home at -13°F will be 17% more than the heating need at -1°F. Thus at -13°F the heating need will be:

44,000 btu/hr * 1.17 = 51,480 Btu/hr

Extra heat required at -13°F to meet with supplemental: 51,480 - 44,000 = 7,480 Btu/hr

At an outdoor temperature of -13°F, ASHP systems have a lower heating capacity than at -1°F, even cold climate units. This drop off will vary by equipment, but 25% is a typical number to use.

ASHP Extra heat required at -13°F from capacity shortage: 42,000 * .25 = 10,500 Btu/hr

For GSHPs, there is also a need for supplemental heating for the following reasons:

1) The heating requirement of the home at the design temperature may be slightly more than the closest heat pump system size can produce.

2) When the outdoor temperature goes below the design temperature, this requires additional heat to fully heat the home.

For GSHPs, the loop can be enlarged beyond the normal design (i.e. to meet the home heating needs at the standard outdoor design temperature) to meet the needs at the coldest outdoor temperature. However, the additional loop added can be quite expensive to ensure heating for <50 hours per year when a small additional amount of supplemental electrical heating (very inexpensive to add) can provide the additional heating necessary.

The three types of shortages for the Denver example above are summarized in the table below.

Summary of calculation of supplemental heating needed (4-ton home)

	ASHP	GSHP
Design shortage (Btu/hr)	**2,000**	**2,000**
Extra heat needed at -13°F	**7,480**	**7,480**
Capacity decrease at -13°F	**10,500**	**0**
Total (Btu/hr)	**19,980**	**9,480**
Btu/hr per kW conversion	**3,412**	**3,412**
Total strip heat needed (kW)	**5.9**	**2.8**
Rounded up to available size (kW)	**6**	**3**

The table below was generated working through similar calculations for different sizes of homes, and it also includes the backup electrical heating needs to keep the house livable when there is a compressor problem.

Summary of backup heating needs

Heat pump system	3-4 ton home	5-ton home
ASHP – ducted	3-8 kW	6-10kW
ASHP – ductless	3-6 kW	6-9 kW
GSHP	3-5 kW	5-7 kW

Note that indoor units of ductless ASHP systems can be oversized slightly and can shift heating between different parts of the home when it is cold. Essentially resulting in the systems having slightly more capacity than ducted ASHP systems, thus reducing the supplemental heating needs somewhat.

While not a need, an additional benefit of the electrical supplemental heating is much faster home warm-up capacity, such as when returning from vacation.

Colorado climate heating requirements - *not as cold as you think*

When considering heat pump systems for buildings in Colorado there is a strong focus on heating when the outdoor temperature is below zero. While the systems must keep buildings warm at the coldest temperatures, the majority of heating in Colorado is during milder temperatures.

For an average year:

In the Front Range (Denver):

- Above 0°F outdoor temperature: >95% of the annual heating energy use. Over 2,000 hours of heating.
- Below 0°F outdoor temperature: <5% of the annual heating energy use. Less than 100 hours of heating.

In the High Country (Eagle):

- Above 0°F outdoor temperature: >90% of the annual heating energy use. Over 3,500 hours of heating.
- Below 0°F outdoor temperature: <10% of the annual heating energy use. Less than 200 hours of heating.

Appendix C - modeling parameters

Heating load - Same house model

- Denver: -1°F (99.6 percentile) - 48,200 (4.0 tons)
- Eagle: -5°F (99.6 percentile) - 50,600 btu/hr (4.2 tons)

Equipment

- Furnace AFUE .95, AC SEER 18
- ASHP 10.5 HSPF, SEER 18
- GSHP Waterfurnace 500 series. Up to 19.1 EER, 6.4 COP.

Bin data

- Denver Stapleton - ASHRAE 2017
- Eagle County Regional - ASHRAE 2017

Mean Earth temperature for loop

- Denver: 52°F
- Eagle: 46°F

Altitude system air density deratings (ASHP ductless indoor or GSHP indoor air handler unit, 72°F)

- Denver: 18%
- Eagle: 23%

GSHP loop common parameters used in the modeling

- Borehole pipe: 1” (Note: .75” pipe is also used as an alternative to 1” in many installations)
- Manifold pipe: 1.25”
- Loop fluid: 15% methanol (Note: Propylene glycol is also used in many loop installations)
- Borehole spacing: 15’ (Note: borehole spacing for residential ranges from 15 to 20’ in actual installations)
- Borehole depth range: 250’ - 350’

GSHP loop sized to meet minimum loop fluid temperature during winter heating season: 35°F

Change over temperature from all heat pump heating to heat pump/supplemental combo.

Denver - GSHP: -13°F (3kW), ASHP 12°F (7kW)

Eagle - GSHP - 0°F (5kW), ASHP 12°F (9kW)

Cost and energy use of the supplemental heating is fully accounted for and a very small percentage of the total energy used for heating (GSHP <1%, ASHP <7%)

Cooling efficiency of GSHPs versus ASHPs

Why does the modeling show such a small percentage difference between GSHPs and ASHPs?

There are two main reasons that the difference is rather small.

1) There have been dramatic improvements in ASHP cooling efficiency over the past 10-15 years.
    a. ASPHs have had a dramatic increase in cooling efficiency. A SEER 18 system is nearly 30% more efficient than an old SEER 14 system. The top ASHP units now have a SEER ratings in the 20-25 range.
    b. At lower speeds, inverter-driven ASHPs have SEER’s that are in the range of SEER 23-25.
    c. At temperatures below the mid-80s°F, ASHPs operate at low speeds and can be equal to or more efficient at cooling than a GSHP; in the mid-80s the systems are generally comparable. It is only when the outdoor temperatures get above the mid-80s that GSHP are more efficient.
2) Colorado’s cooling needs are considerably less than many parts of the country.
    a. In any given year, only 20-25% of Colorado’s annual cooling occurs when the outdoor temperatures are above the mid 80s.
    b. In any given year, only 20-30% of the annual cooling is when the outdoor temperatures are in the mid 80s.

c. In any given year, the majority of cooling (50-55%) occurs when the outdoor temperatures are below the mid 80s.
d. The above statistics are for the Front Range and Western Slope (climate zone 5). In the high country, even less of the cooling requirements are at high outdoor temperatures.

Appendix D - GHG emission factors

We used projected electricity emission factors for the State of Colorado from the National Renewable Energy Laboratory (NREL).[50] NREL offers several scenarios, of which we chose the average of the "Mid-Case 95 by 2035" and "Mid-Case 95 by 2050" scenarios, which are the closest to Colorado's goal of achieving 100% (or nearly 100%) renewable electricity generation by 2040. NREL also offers several choices for GHG emission factors, and we chose the "long-range marginal emission rate." The marginal emission rates (as opposed to the annual average emission rates) are appropriate for analyzing questions like, "what will be the effect on the grid of policies and programs that encourage more electrification of buildings?" which seems appropriate for this study. In addition, we chose the marginal emission factors for SWEEP's previous heat pump studies,[51] and we wanted to be consistent with those. These emission factors are shown in the table below.

[50] "Cambium," NREL, 2021, https://scenarioviewer.nrel.gov/?project=a3e2f719-dd5a-4c3e-9bbf-f24fef563f45&mode=download&layout=Default.
[51] "Benefits of Heat Pumps for Colorado Homes," SWEEP, February 2022, https://www.swenergy.org/directory/co-heat-pump-study-feb-2022/; and "Benefits for Heat Pumps for Southwest Homes," SWEEP, June 2022, https://www.swenergy.org/directory/sw-heat-pump-study-may-2022/.

Projected electricity GHG emission factors for Colorado

Projected Marginal GHG Emission Rate (kg CO2e/MWh)			
Year	**Mid-Case 95 by 2035**	**Mid-Case 95 by 2050**	**Average of two scenarios**
2024	398.6	415.8	**407.2**
2026	339.7	380.7	**360.2**
2028	277	356.2	**316.6**
2030	210.5	325.4	**268.0**
2032	143.2	301.6	**222.4**
2034	80.5	275.3	**177.9**
2036	41.1	248.3	**144.7**
2038	21.1	221.1	**121.1**
2040	19.4	190.1	**104.8**
2042	20.4	155.2	**87.8**
2044	22.1	120	**71.1**
2046	16.8	90.3	**53.6**
2048	15	64.8	**39.9**
	25-year average		**182.7**

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