WCU/CU PARTNERSHIP PROGRAM

Building Electrification Implementation Plan

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WCU/CU Partnership Program's Building Electrification Implementation Plan

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Abstract

The Western Colorado University/University of Colorado at Boulder partnership program (the Program) has a select group of students who are working closely with the Gunnison Valley Home Energy Advancement Team (GV-HEAT) to create a beneficial building electrification plan for three pilot homes. The homes have all gone through the Colorado Affordable Residential Energy (CARE) program. While the primary goal of electrification is to reduce greenhouse gas (GHG) emissions, the primary goal for GV-HEAT is to increase the quality of life for the end users. As a next step to help achieve this primary goal, GV-HEAT would like to install beneficial electrification in income-qualified homes. The three chosen homes include a small single-family home that relies on space heaters and gas heating, a slightly larger single-family home with electric baseboard heaters and a propane fireplace, and a mobile home with propane heating. The double-wide mobile home seems to be the best candidate for electrification, because it has existing ductwork but just needs to be sealed to reduce air leakage.

Keywords: GV-HEAT, income-qualified, electrification, emissions, greenhouse gas, Gunnison, heat pump

1. Background

In the Gunnison Valley of Colorado, the Gunnison Valley Home Energy Advancement Team (GV-HEAT) administers the Colorado Affordable Residential Energy (CARE) program, a weatherization program in which income-qualified Colorado residents are provided with free energy-efficiency upgrades, whether the resident is a homeowner or renter[1]. The increased efficiency of these homes will not only positively impact the environment by reducing the total fossil fuels consumed, it will also improve comfort, resiliency, and safety of these homes.

Since the inception of GV-HEAT, approximately 30 households are served through CARE each year. To date, 14 households are on the waiting list. Forty-five percent of GV-HEAT's CARE clients are seniors living on a fixed income, 25% are Hispanic, and the remaining 30% are a mix of non-Hispanic families, individuals, and students. Nearly half of the served homes are mobile homes, and the remaining half are single-family or multi-family homes. Program metrics, including energy and greenhouse gas (GHG) emission reductions, are modeled using Energy Outreach Colorado and Energy Smart Colorado software.

GV-HEAT has been successful in administering weatherization services and wants to continue to improve home safety, quality of life and reduce emissions and energy use as a result of increasing efficiency. Additionally, as the electric grid continues to add renewable energy generation, converting all fossil fuel combustion appliances to electric appliances will even further reduce emissions.

The Western Colorado University/University of Colorado at Boulder partnership program's Design for Community course provides juniors and seniors in the mechanical engineering program with the opportunity to learn basic consulting practices and the logistics behind preparing a project proposal for industry. GV-HEAT was chosen as the industry partner since they actively work with the local community, as well as their high need for support in an exponentially growing industry.

Having limited in-house resources to implement electrification to income-qualified households, GV-HEAT seeks the assistance of the program's mechanical engineering students to develop a building electrification implementation plan.

2. Objectives

This document serves to discuss the following:

- **How** home electrification could be **implemented** in three pilot homes
- **What** the step-by-step **framework** for this implementation looks like including the homeowners' points of view
- **How** this project can **educate** homeowners, build **trust** and ensure successful and **future implementation** of electric homes
- General **guidelines** for electrifying homes, including:
    - **Costs** and opportunities for funding
    - Available **contractors**
    - Key criteria for **successful candidates**

3. What is Building Electrification?

Building electrification describes the use of all-electric appliances within a building. For the case of this document, the phrase *building* can be interchanged with *homes*, i.e., this program does not focus on commercial or industrial buildings. We will focus on "beneficial electrification," being defined as replacing direct fossil fuel use in seek of reducing GHG emissions, reducing energy costs, improving grid management, and increasing overall quality of life. This excludes relying on electric-resistance heating as the primary heating source, for instance, because it does not decrease energy use.

In most buildings, the biggest consumers of fossil fuels are space heating, cooling, water heating, cooktops and ovens, and clothes dryers. Traditionally, gas and propane appliances have been favored, and because of this, these appliances contribute to 11% of total Gunnison County emissions, as shown on the next page.[2] Beneficial electrification is necessary because we can remove a large amount of GHG emissions from Gunnison County's emission profile.

[1] Colorado's Affordable Residential Energy Program. Energy Outreach Colorado; 2023. Available from: energyoutreach.org/care.

[2] Gunnison County 2020 GHG Emissions Footprint. Gunnison County; 2020.

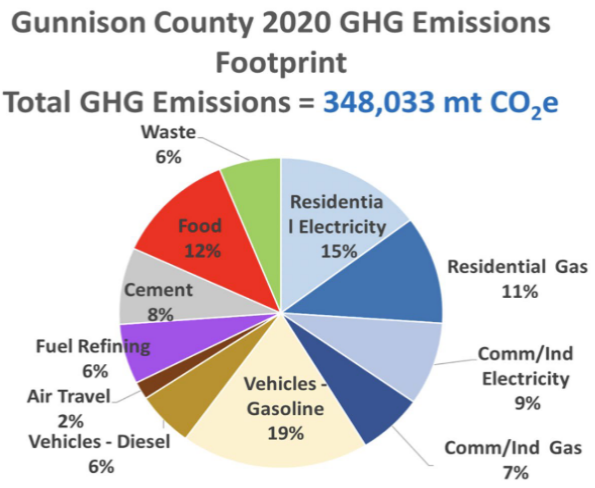

Figure 1: Gunnison County's Emissions Footprint, Courtesy of Gunnison County

According to Harvard Medical School[26], children living in houses with gas appliances are 42% more likely to develop asthma than children who do not live in houses with gas appliances.

The most efficient way to convert gas reliant HVAC appliances to electric is through the use of air source heat pumps (ASHPs). Air source heat pumps are electrically driven appliances, very similar to a conventional air conditioning unit, used for heating and cooling homes. This appliance works on the refrigeration cycle, removing heat from the air and placing it in a desired space. This process is reversible, working to either heat or cool a home depending on the season.

Heat pumps are favorable because not only are they fully electric, but since they move heat rather than burn a fuel to heat a space, they can be more than 100% efficient. This means that for every unit of energy the heat pump requires to run, more than one unit of energy of heat is either added or removed from the space. This is referred to as the coefficient of performance (COP). A COP of 4, typical of a heat pump in ideal conditions, means that 4 units of energy are moved to heat or cool a space for every 1 unit of energy input to the system[3].

There are many types of air source heat pumps available to consumers, but because of the extreme cold climates Gunnison County faces in the winter, contractors should install a cold climate air source heat pump (ccASHP). These heat pumps perform at temperatures as low as -5 ℉ while maintaining a COP greater than 1.75[4]. These ASHPs heat most efficiently at or above 47 ℉[5]. At these temperatures, homeowners will see the greatest savings and will receive the highest return on investment. The ASHPs will still work at temperatures below -5 ℉, but homeowners will see losses in efficiency . Under -5 ℉, which happens most nights around January and February in Gunnison, homeowners may require supplemental heating in the form of baseboard heaters or fossil fuel appliances. Local contractors noted that existing electric baseboard heaters are a great source of supplemental heating and work best in smaller rooms for homes that utilize a mini split system, which is a non-central method of space conditioning. Baseboard heaters operate using electric resistance heating but are less efficient than ASHPs. This additional heating element will help reduce the load on the ASHPs and also helps reduce cost by reducing the amount of electricity the ASHP consumes at an inefficient rate.

Like ASHPs, electric heat pump water heaters (HPWHs) move heat from one place to another. They too pull heat from the surrounding air, and then transfer it into the water storage tank at elevated temperatures. Since the unit does not generate heat directly, they can be two to three times as efficient as a standard electric resistance water heater, depending on installation and location. In a cold area of the house, HPWH efficiency is decreased due to the fact the units themselves tend to cool the surrounding area[6]. HPWHs cost between $1,500 and $3,000 on average, and installation can

[3] Maritime Geothermal Ltd. How to Calculate Coefficient of Performance. Maritime Geothermal; 2015. Available from: nordicghp.com/2015/08/how-to-calculate-coefficient-of-performance.

[4] Cold Climate Air Source Heat Pump Specification, Version 4.0. Northeast Energy Efficiency Partnerships; 2023. Available from neep.org/sites/default/files/media-files/cold_climate_air_source_heat_pump_specification_-_version_4.0_final_1.pdf.

[5] Schoenbauer B, Bohac D, Kushler M. Field assessment of Cold Climate Air Source Heat Pumps - ACEEE. ACEEE; 2016. Available from: aceee.org/files/proceedings/2016/data/papers/1_700.pdf.

[6] How They Work. Energy.gov. Available from: energy.gov/energysaver/heat-pump-water-heaters.

range between $1,200 to $3,500[7]. However, they tend to reduce energy costs by up to $330 per year and $3,400 in the unit's lifetime.

Replacing gas cooking systems and clothes dryers all make substantial improvements to indoor air quality and also reduces the amount of gas a household consumes. To replace gas burners for cooking, high performance induction stoves would be the alternative. Electric dryers would operate purely from electricity with a higher COP.

4. Why Gunnison?

Gunnison Valley is a cold community. During the winter months, Gunnison averages a high of 29℉ and gets down to an average low of 1℉. In the summer months, Gunnison Valley warms up, reaching an average high of 78°F and average lows of 46℉[8]. On average, the Gunnison Valley receives upwards of 48 inches of snow annually. The Gunnison Valley, according to the Crested Butte News, produces more emissions than other similarly cold counties per square foot of livable space[9].

Additionally, the Gunnison Valley is a good pilot county to implement these changes. By implementing changes on a smaller scale before rolling it out to a whole community, those in charge have a better chance of catching mistakes and design/implementation errors before they extend to a much larger community. With building electrification still in its infancy, this focus on a smaller community will assist in getting more people educated and in favor of this movement.

5. Why Now?

The strategy for electrification follows a simple logic: Depending on the makeup of the electric grid, it can make sense to burn gas for home use. Once the grid achieves a certain level of cleanliness, it makes more sense to switch to electric appliances. Cleanliness is defined using the grid's *carbon intensity,* or how much carbon dioxide, or equivalent, gets emitted as a result of producing electricity or heat energy. By considering the grid of the Gunnison Valley and its suppliers, Tri-State Generation and Transmission and the Municipal Energy Agency for Nebraska, we can mathematically compare emissions and determine the carbon intensity of the grid. According to industry professionals, the intensity should be in between 1,500 and 1,300 lbs/MWh to justify the use of ASHPs[10]. The local grid currently sits at less than 1,500 lbs/MWh and by 2025 the carbon intensity will likely reach 1,000 lbs/MWh for residents served by Gunnison County Electric Association (GCEA), as mentioned in a correspondence with GCEA. Additionally, by analyzing Tri-State's renewable energy commitments of 50% by 2024 and 70% by 2030, we can calculate the carbon intensity savings using a linear regression[11]. Because energy utilities' renewable commitments are decreasing the carbon intensity, now marks a good time to start the transition to beneficial electrification. However, it must be noted that MEAN provides electricity to all residents within the City of Gunnison and Tri-State provides electricity to GCEA who then serves everyone outside the City of Gunnison.

With the increased demand for electricity due to electrification, some residents are concerned with the effect on our grid and the possibility of overloading the current configuration. Gunnison County Electric Association provides electricity for one-third of the Gunnison Valley. Currently, GCEA's power grid only uses 25% of its maximum load on average. This gives plenty of space for higher electricity consumption caused by the shift from gas to electricity in buildings. GCEA will not consider upgrading the grid until around 70% of the maximum load is being used, which is not a high concern in the current system or in the foreseeable future, per discussions with Mike McBride, GCEA's CEO. We reached out to the City of Gunnison electric utility, but we were not able to collect similar information.

[7] Crail, Chauncey. Heat Pump Water Heaters: Complete Guide, Pros and Cons and More. Forbes; 2022. Available from: forbes.com/home-improvement/plumbing/heat-pump-water-heaters.

[8] Climate Gunnison. Available from: usclimatedata.com.

[9] Nettles, Katherine. County Considering Climate Action Plan Updates to Building Code; 2023. Available from: crestedbuttenews.com/2023/01/county-considering climate-action-plan-updates-to-building-code.

[10] Artale, Emily. Industry experience; 2023.

[11] Boughey L, Stutz M. Tri-State reflects on third anniversary of its transformative Responsible Energy Plan. Tri-State Generation and Transmission; 2023. Available from: tristate.coop/tri-state-reflects-third-anniversary-its-transformative-responsible-energy-plan.

It is important to note that until a few years ago, it still made sense to heat homes with gas compared to electric energy from an emissions standpoint in the Gunnison Valley, but this is no longer the case. If proper energy management practices are put into place, along with the increased efficiency of insulation of homes, the same level of comfort will become cheaper when houses are made fully electric. It is rather difficult to time this intercept, however, so a common practice has been to start earlier than later. By doing so, it allows ample time to educate the population and begin rolling out these changes.

Additionally, funding is available to help cover equipment and labor costs for both ccASHP's and electrical panel upgrades including:

- A $1,500 to $2,300 rebate from Gunnison County Electric Association[12] when a qualified ASHP is used*.
- MEAN offers rebates to households located in the City of Gunnison[13], ranging between $400 and $1,200 for mini-splits and ducted ccASHPs**.
- Energy Star offers rebates up to 30% of the project cost for ASHP installation, not exceeding $2,000[14].
- The federal Inflation Reduction Act (IRA) provides up to $4,000 for electrical panel updates and an additional $2,500 for wiring improvements to support adding heat pumps. https://news.energysage.com/colorado-heat-pump-rebates-and-incentives/#:~:text=As%20long%20as%20your%20air,percent%20of%20your%20equipment%20costs
- The IRA also has proposed a tax credit to cover up to 30% of the costs for beneficial home electrification, but our target communities may not qualify[15]. Income qualified households can receive up to an $8,000 rebate for heat pump purchase and installation.

* Not exceeding 50% of the equipment costs. Must be a resident of Gunnison County but does not apply to residents within the City of Gunnison.
** For more information, refer to MEAN's rebate description: nmppenergy .org/about-nmpp.

As shown above, many of these rebates available on the federal, state, and local levels can greatly reduce the cost of electrification and are able to be stacked, or used simultaneously. This method is called "incentive layering," or incentive stacking," however, there is still a large cost to GV-HEAT after receiving the maximum amount of aid through these programs.

The final cost for these upgrades for GV-HEAT is estimated to be $10,000 per household based on conversations with ASHP installers. This estimation is made using a range for purchasing and installing cold-climate heat pumps between $19,000 and $38,000 based on sizing and heating requirements. Completing the installations assumes 40-60 hours in labor costs. To reach the final estimate the lower cost for purchasing, and the maximum amount of rebates were used.

Although this is an estimation, we were able to receive more accurate information about the type of ccASHP needed in one of the 3 homes studied.

6. Notes on Equity

The presented strategy for electrification is equitable. By starting work with communities who need help the most, we can also save their communities from further financial burden. It is essential that we get the lower-income households off the gas grid first, because a lower gas demand will lead to increased prices which might not be affordable, further increasing their expenditures.

Income-qualified community members have a higher energy cost burden, meaning that more of their income is spent on home energy than what is typical for others in the community[16]. Outlined later in the document, we show the energy cost burden of up to 8% for a representative GV-HEAT home. Environmental justice advocates recommend that the energy burden is less than 5%.

[12] Appliance Rebates. Gunnison County Electric Association; 2023. Available from: gcea.coop/energy-efficiency/rebates/appliance-rebates.

[13] High Efficiency Heat Pump Program. Municipal Energy Agency of Nebraska. Available from: cms8.revize.com/revize/gunnisonco/Departments/Finance/Utility%20Billing/MEAN%20Energy%20Efficiency%20Flyer%20High%20Efficiency%20Heat%20Pump.pdf.

[14] Air Source Heat Pumps Tax Credit. Energy Star; 2022. Available from: energystar.gov/about/federal_tax_credits/air_source_heat_pumps.

[15] Clean Energy for All. The White House; 2023. Available from: whitehouse.gov/cleanenergy.

[16] Low-Income Community Energy Solutions. Office of State and Community Energy Programs. Available from: energy.gov/scep/slsc/low-income-community-energy- solutions.

Additionally, 22.38% of the City of Gunnison's population is living in poverty, according to the U.S. Census[17].

> The combination of energy burden and the poverty level makes affording energy and housing, let alone housing renovations, very difficult.

With CARE subsidies, this alleviates the need for these households to spend extra money they may not have because their housing burden is too high.

The results of poor equity and substandard housing lead to poor air quality, heat vulnerability, and more household safety issues. These issues can have long-lasting effects on the population of this area, which creates more public health issues.

While the CARE program helps with the costs, the existence of these electric appliances can also positively impact these communities. The pilot homes that will be picked do not have air conditioning, and there are not many houses in the Gunnison Valley that do have air conditioning.

One step towards climate resiliency with these marginalized communities is the cooling potential and air filtration as a result of using heat pumps. Since ASHPs can be reversed and act like conventional air conditioners, the electrification of these homes will also bring cooling to communities who may benefit from it the most. Furthermore, ASHPs can improve the air quality in homes. The burning of gas in gas powered furnaces releases toxins into the air that can lower air quality and cause health implications such as asthma.

By subsidizing the costs of improving these homes for a better quality of life, we successfully eliminate some of the adversity these communities experience, while giving them the luxury of new home amenities.

7. Selection Process for Electrification

The process homeowners follow to receive aid and electrify their homes starts with applying for the CARE Program, specifically through GV-HEAT[18]. Below are the criteria required to be considered eligible through the program:

- Applicants must be homeowners or renters with landlord approval.
- Applicants must live in Gunnison or Hinsdale County in a house, townhome, condo, apartment, or mobile home.
- Applicants' gross annual household income is at or below 80% the annual median income (AMI) for Gunnison County.
- Applicant utilities are serviced by Atmos Energy, Gunnison Electric, or Gunnison County Electric Association.

The criterion that is most important in this process is a household's AMI, which changes according to the number of residents living in a home. Income qualification amounts can be seen in the Table 1 below.

Number of People Per Household	CARE
One	$49,600
Two	$56,640
Three	$63,760
Four	$70,800
Five	$76,480
Six	$82,160
Seven	$87,840
Eight	$93,520

Table 1: Income qualifications for GV-HEAT SOURCE, according to Gunnison Valley Regional Housing Authority[18]

After applicants are accepted into the program, home audits and preliminary upgrades must be completed to maximize effectiveness and efficiency before implementing electrification.

After homeowners receive approval through CARE, they can receive a free home assessment conducted by a certified contractor. During this assessment, contractors look at the home's structural integrity, insulation, air flow, air quality, plumbing, radon emissions, and existing appliances to understand the homeowners' needs. The contractor then communicates

[17] Gunnison, Colorado Population 2023. World Population Review; 2023. Available from: worldpopulationreview.com/us-cities/gunnison-co-population.

[18] CARE – Colorado's Affordable Residential Energy Program. Gunnison Valley Regional Housing Authority; 2022. Available from: gvrha.org/gv-heat-program/care-colorados-affordable-residential-energy-program.

findings with GV-HEAT and makes recommendations for home upgrades. GV-HEAT then receives approval from the client prior to making any changes to the house. The list of upgrades completed in the past includes, but is not limited to:

- Replacing incandescent or fluorescent light bulbs with high-efficiency LED options
- Sealing penetrations in homes to reduce air leakage, such as sealing windows or adding storm windows
- Installing an insulation jacket to the water heater if safety requirements of the appliance allow it
- Replacing existing thermostats with a programmable option
- Replacing or installing carbon monoxide sensors and smoke detectors
- Adding insulation to pipes, attics, sublevels, or walls
- Tuning and cleaning the furnace and replacing dirty furnace filters
- Replacing refrigerators that are older than 10 years with EnergyStar refrigerators

In addition to making these changes, GV-HEAT and the contractor will educate the homeowner on user instructions, expected maintenance, and energy saving strategies to reduce gas and electricity consumption.

Once these home upgrades are completed, the home is ready to receive additional upgrades to help maximize savings, improve the residents' quality of life, and decrease carbon emissions. Examples of the additional upgrades this plan recommends is installing ccASHPs systems to replace existing or outdated gas or propane HVAC systems.

8. The Process for Electrifying GV-HEAT Homes

Once the primary upgrades are completed, contractors can replace existing gas or propane appliances with ccASHPs. The level of importance in relation to a homeowner's quality of life and initial costs are listed in Table 2.

Proposed Upgrade	Effect on Quality of Life	Cost	Replacement Options
HVAC	**High** (Improves air quality, may reduce utility costs, adds air conditioning, reduces carbon emissions)	$$$	ccASHP
Cooking Surface	**Medium** (Improves air quality, reduces emissions)	$$	Induction Stove
Water Heating	**Medium** (Improves air quality, reduces emissions)	$$	Heat pump water heaters or Electric Resistance
Clothes Dryer	**Medium** (Improves air quality, reduces emissions)	$$	Electric Energy Star Appliance

Table 2: Upgrade Recommendation Table

Cold-climate air-source heat pumps come in multiple configurations, and new technologies are still being created, but two configurations that are the most feasible in Gunnison County have been preferred. The available options recommended for ccASHPs include a central ducted configuration for houses that already have ducting from prior HVAC systems and mini-split systems for houses that do not already have ducting installed. These two configurations have been chosen based on findings in studies conducted by the National Renewable Energy Laboratory (NREL) and the Northeast/Mid-Atlantic Air-Source Heat Pump Market Strategies Report[19,20]. Both these systems utilize an energy transfer unit outside of the house, also known as

[19] Desai J, Wu K. Cold Climate Air Source Heat Pumps (ccASHPs) Technology. National Renewable Energy Laboratory; 2022. Available from: nrel.gov/docs/fy22osti/83290.pdf.

[20] Northeast/Mid-Atlantic Air-Source Heat Pump Market Strategies Report. Northeast Energy Efficiency Partnerships; 2014. Available from: neep.org/sites/default/files/resources/NortheastMid-Atlantic%20Air-Source%20Heat%20Pump%20Market%20Strategies%20Report_0.pdf.

the condenser, which transfers heat through a series of coils to either outside or inside air.

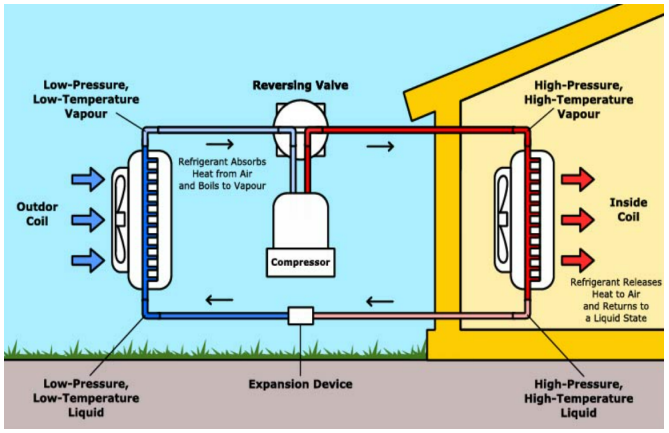

Figure 2: How an Air-Source Heat Pump Works[21]

For a ducted system, an air handling unit moves air through the ducts inside the house providing central heating and cooling to the entire home. This configuration is one of the most efficient options for ccASHPs with a performance rating showing a COP above 2 and up to 4, according to NREL[19]. The drawbacks to this system are the initial cost of installation due to ducting modifications within the house and needing more than one air handling unit for large square foot houses. For this plan we will only be showing the process for electrifying smaller homes.

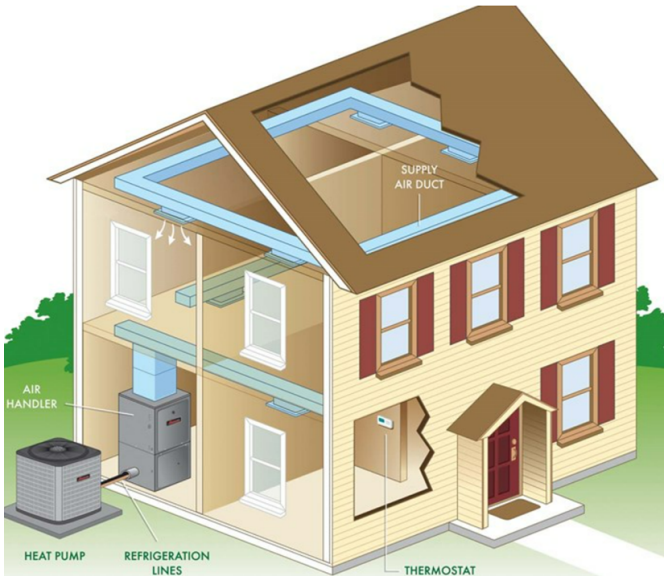

Figure 3: Ducted ASHP[22]

The second option, mini-split ductless ASHPs, may be more desirable than the prior system for the houses GV-HEAT works with that do not have ducting previously installed. The mini-split configuration has multiple air handling units inside the house that heat or cool the different rooms. These systems do not require any ducting; however, they are usually more expensive than their alternative. The lack of ducting is not necessarily a disadvantage, though, because it will reduce material cost for duct installation, duct insulation, and the air handling unit does not lose heat through the ducts. It should be noted that the outdoor condenser(s) will require housing to protect it from excessive rain, snow, and extreme cold, to keep them functional and to keep air flowing through them.

Figure 4: Ductless ASHP[23]

For either option, the capital costs for equipment and labor costs are much higher than some alternative options available today. A manner in which money could be saved is through implementing a hybrid system which monitors when the ambient outdoor temperature reaches a certain limit, at that point the gas or propane system in the house turns on. After speaking with a current contractor in the Gunnison Valley, we

[21] Types of Air-Source Heat Pumps. Energy.gov. Available from: energy.gov/energysaver/air-source-heat-pumps.

[22] Air Source Heat Pumps. Take Control and Save; 2020. Available from: takecontrolandsave.coop/welcome-to-our-blog/posts/2020/may/air-source-heat-pumps.

[23] Mangano, Lauren. Ductless Heat Pumps: A Comprehensive Guide. ECI Comfort Blog; 2021. Available from: ecicomfort.com/blog/ductless-heat-pumps-a-comprehensive-guide.

found that this system is not well tested and is rarely used. The recommendations included adding electric resistance heaters in the ducting or in the form of baseboard heaters to supplement the heating into the house. This strategy saves the homeowner money by reducing the amount of work, and monthly energy costs, these heat pumps have to do when the temperatures drop. Additionally, if a house is already wired for baseboard heating, this transition to a hybrid system of this nature is very easy. If hybrid systems become more utilized in the valley, it could also reduce installation costs that come with removing and discarding the older system. However, this may not be feasible until this strategy is more widely adopted.

Depending on the specific needs of the homeowner, a cost benefit analysis must be conducted to determine whether or not a new heating system should be implemented immediately or keep the current system until failure. Advantages and disadvantages are considered below to help contractors and homeowners discuss their options.

Advantages

- *Improves heating efficiency:* Cold-climate air source heat pumps are more efficient than gas heating appliances in certain temperature ranges and can be altered to include a hybrid system.
- *Potentially reduces annual energy costs*: Studies conducted by Minnesota Center for Energy and Environment saw a 14%-29% decrease in yearly energy costs through the use of a hybrid HVAC system between 3 different sites.[5]
- *Equipment rebates are available:* Up to half of the cost of a heat pump can potentially be covered by rebates for income-qualifying homeowners.
- *Adds air conditioning:* Homes generally do not have air conditioning in the Gunnison Valley, but they will likely need it in the future, due to increasingly variable climates.
- *Improves indoor air quality and ventilation:* By filtering out chemicals and particulates in the air, heat pumps replace dirty, stagnant air indoors with filtered outside air.
- *Provides flexibility:* ASHPs come in numerous options, suiting a wide range of different floor plans.
- *Easy installation process:* This depends on the existing systems, unique to each household.
- *Low maintenance:* By simply ensuring the airflow is not restricted by changing filters, the life of the unit can be lengthened without much thought required by the homeowner.

Disadvantages and Possible Remedies

- *Cold climate:* Efficiency is reduced during extreme cold climate events, but can be supplemented with other, existing systems to assist this issue. These additional systems will increase the capital cost.
- *Capital cost:* Cost per unit is much larger compared to gas alternatives, however the savings in utility costs will, hopefully, exceed this initial cost over the life of the system.
- *Installation:* Installation costs are high for homeowners without existing ducting in their houses, and the outdoor condensers will require a housing to keep it clear from the elements.
- *Emergencies:* There are no distributors in Gunnison County for replacement in an emergency, but homeowners are able to apply for emergency replacement options if they are income-qualified in Colorado through Low-Income Energy Assistance Program (LEAP's) Crisis Intervention Program (CIP).
- *Electrical requirements:* Installation may require electric panel upgrades to accommodate the additional load on the system.
- *Refrigerant concerns:* Refrigerant leakage from these systems could prove harmful to the environment as discussed below in Section 9.

Capital Cost: Heat Pump vs Gas Furnace:

- Heat Pump:
    - Equipment costs for a ccASHP range from $19,000 to $38,000. This covers the cost for the unit, refrigeration lines, refrigerant, and other hardware involved.
    - Labor costs for installation of a ccASHP can range from $2,000 to $4,000[19].

    - Oftentimes, especially in the case of the three chosen homes, upgrades to the ductwork and electrical panel's service may add up between $500 to $5,000 onto this final cost as well[24].
- Gas Furnace:
    - New single-stage gas furnaces can range from $4,000-$6,000 for equipment and installation[25].
    - Capital cost of a gas furnace depends on the quality and efficiency of the unit.
    - Installation costs are generally less for gas furnaces.
    - The capital cost depends on the state of the house and what upgrades are needed.

Replacing gas cooking systems, water heaters, and clothes dryers all make substantial improvements to indoor air quality and also reduces the amount of gas a household consumes. According to Harvard Medical School, children living in houses with gas appliances are 42% more likely to develop asthma than children who do not live in houses with gas appliances[26]. The change to implement new energy star appliances throughout a house will not only save money for the homeowners but will also improve the quality of life and overall health for those who live in them.

HPWHs cost between $1,500 and $3,000 on average, and installation can range between $1,200 to $3,500[27]. However, they tend to reduce energy costs by up to $330 per year and $3,400 in the unit's lifetime.

Air Source Heat Pump Installation

Since we have determined the installation of ASHPs is one of the best ways to improve homeowners' quality of life, and hopefully over time monthly costs, we have included the common steps for the installation of these systems.

Key Criteria for Successful Implementation of an ASHP

1. The number one priority is to make sure the home is very well sealed and has no points that air can leak in or out. This will make sure the home can keep the desired climate for long periods of time.
2. To ensure the walls are properly insulated, the walls need to have at least R-19 insulation while the attic can have R-49 to R-60 insulation*. This will ensure that the air inside the house cannot escape through the walls and that the outside air will not enter through the walls.
3. If the home has ductwork, it should be in excellent shape with no leaks before ASHP installation. Ideally the pressure of the ducts should be at or under 1 Pascal.

* R-Values are directly proportional to the conductive heat-transfer coefficient, but also factoring in material thickness. The higher the R-Value, the more insulative a material is[28].

Before installation:

1. The home's electrical service needs to be verified to be large enough to handle the increased load from electrification. It is recommended that the homes have a minimum service size of 200 Amps. If the home service cannot handle the new load, a service upgrade may be required. Another option could be to use smart switches on breakers to manage energy use. A smart switch monitors and manages the load through the breaker. They can be used to avoid short-circuits and provide overvoltage protection[29].

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[25] Jacobs, Amanda. How Much Does It Cost to Replace a Furnace?; 2022. Available from: jacobsheating.com/much-cost-replace-furnace.

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[28] How Insulation Works. Energy.gov. Available from: energy.gov/energysaver/insulation.

[29] How Does a Smart Circuit Breaker Switch Work? Geya Electrical Equipment Supply; 2021. Available from: geya.net/how-does-a-smart-circuit-breaker-switch-work.

2. The building's ducting needs to be analyzed and determined if any upgrades are needed. If the building does not have ducting, consider installing ducting or using a ductless system.
3. A covered area to place the heat pump's condenser needs to be located or built. This area must be covered and placed above the maximum snow depth for the climate. Ensure there is good airflow to the condenser. Avoid any areas where water will drip onto the unit. Check with the homeowner to make sure this location will satisfy them.

At this point, the building should be ready for a heat pump installation. The contractor must be EPA 608 certified. This certification ensures the contractor has experience with the refrigerants present in ASHPs. While this is the only required certification, contractors are expected to have previous HVAC experience. A list of local HVAC contractors can be referenced in Appendix A. It is also important that the installer knows how to form quality flares on the copper tubing to ensure that leaks don't occur and the fittings will last for the life of the heat pump. Using an automatic flaring tool is recommended for making consistent flares. The main tools required are a pressure gauge set, torque wrench, flare tool, vacuum gauge, digital scale, amp meter, monometer, and thread sealant. Installers should have sufficient knowledge of HVAC systems and know what condition the building is in.

After Installation:

Like any heating unit, the ASHP will require occasional maintenance. The air filter should be replaced annually. Ducts, blowers, and coils should be inspected for excessive wear or dirt.

Based on contractor feedback, it is assumed that most heat pumps will have a lifespan of 10 -15 years. After this time, it is highly recommended to renew or upgrade the heating system of the home. Annual inspection is important to ensure the efficiency and reliability of the heat pump.

9. Selecting Homes for Further Improvement

As stated before, there are currently 14 homes that have completed the initial upgrade process. We have chosen three of these houses for this plan because of their different sizes, layouts, and HVAC systems, which can be seen in Table 3. We believe these differences will help GV-HEAT be able to apply a wide variety of tactics to fully electrify homes. This application to very different homes also helps gauge the feasibility of large-scale electrification in the Gunnison Valley through a retrofitting process. We will be using the three selected pilot homes for the following reasons:

Home 1

This is a relatively small home at 831 ft², which will be a good starting point to begin electrification. There are a few important inefficiencies within the heating system in this house. First off, they use gas space heaters, which can be more expensive to run and present safety issues while lowering the air quality inside the home. Electric space heaters are also in use, which is an issue because they are far less efficient than ccASHPs. Next, there was a gas leak detected in the home's energy audit. This signifies that the gas system in the house requires some maintenance. By electrifying this home, we could eliminate the need for gas and avoid repairs to the gas lines. We will be making this home far more energy efficient while improving existing damages to the house. This house is also equipped with a wood stove, which will be a reliable backup heat source for the home. The City of Gunnison's municipal electric utility and Atmos Energy provides utilities to this home. Through a home tour, we discovered that this house operates on a 100 amp service, shown in figure 6.

Figure 6: Electrical panel detailing 100A service specification

Also, throughout the house tour, measurements were taken for the windows to make an estimate on equipment requirements and available rebates. The ASHP installer we spoke to recommended a mini-split

ccASHP with a 30k BTU (2.5 Ton) output. The outdoor unit would connect to three heads inside different rooms in the house and would require a backup heat source to supplement the heat pump during extreme cold weather events. Because of the wood stove, the house should have an effective backup heat source. Using the Energy Star Product Finder Website the ccASHP that meets all the requirements is the Carrier 38MG-series unit number 38MGHBQ30DA3. Because this is a larger system with multiple heads, the installation may be on the higher end of the expected costs as listed in the section above. Because of the sizing, this configuration will also allow the largest amount offered for rebates which helps offset some of the costs.

Home 2

This house is slightly larger than Home 1 but also uses inefficient heating sources. The size of this home is 1091 ft². Baseboard heaters are used, which are still less efficient than heat pumps. A propane fireplace is also in use, which is less efficient than a ccASHP while lowering the home's air quality. One concern with this house is that the electric water heater lies in the crawl space where seasonal water flooding occurs. We may think about installing a new, more efficient water heater to help improve the quality of the home. Again, we are increasing the efficiency of the home to allow for less overall energy consumption. Gunnison County Electric Association and Amerigas provide utilities to this home.

Home 3

This double wide mobile home has a size of 2,128 ft² and was partly chosen because we wanted to include a mobile home in our plan. This house has the most room for improvement out of all the mobile homes as a gas furnace is used and gas leaks were detected. The house is equipped with ducting which will make installation of an ASHP easier. The size of the home will be interesting since it is the biggest (by floor area) out of the mobile homes and will probably show different results than the smaller homes. Gunnison County Electric Association and Amerigas provide utilities to this home.

A summary of the information listed above can be seen below in Table 3:

Home Type	Size (ft²)	Current Heating Systems
Single Family	831	Uses gas space heater, electric space heaters, older wall heater, and wood stove
Single Family	1091	Electric baseboard heaters and propane fireplace insert
Double Size Mobile Home	2128	Propane with ducting

Table 3: Home Information

The second home is a good candidate because it uses propane. This house is heated by electric baseboard heaters, which are very energy intensive, and a propane fireplace that pollutes the air inside the house. They also have seasonal leaks in their water heater. What makes this home the best candidate is that it already has good insulation and has good pressure. An electric baseboard heater is present which is advantageous because we can use the existing breaker for an ASHP. This home would be a great option for a mini-split.

The third home is probably the home that needs to be electrified more than any other home on this list. It is a 2,128 ft² mobile home that runs on propane. This house is heated by propane furnaces in certain rooms causing the energy bill to be higher than most houses. This house is an ideal house for electrification because it has gas leaks and ducting installed. The pressure in the third home's ducts is not ideal, this house would become a much better candidate if the leaks in the ducting were fixed.

10. Community Engagement

We had the opportunity to meet with one tenant in Home 1, who is part of the GV-HEAT program. The purpose of this tour was to understand the concerns of homeowners and tenants that may not have been considered. Additionally, we were able to look at the home to get a better understanding of the home's layout, looking for areas to put a heat pump and to verify if ducting sources could be retrofitted. It was noted that the tenant was mostly worried about the

timeline of the process and communication with the landlord. A problem that was unthought of by our team was that there was concern with space being taken away from the backyard with the installation of the condenser and how that can affect pets' quality of life.

Figure 7: Possible ccASHP location on north side of house

We found that this home's main heat source is a wood stove, which consumes a high amount of wood. The resident told us that wood had to be restocked several times throughout the winter, and it was fairly expensive and time consuming. This was still cheaper than running their gas furnace, which was estimated to cost $200-$300 every month in the winter.

Meeting with this tenant provided us a better understanding on how electrification will impact the life of the end user. This also benefits the team because it highlights different perspectives that may have not been thought of previously and a better understanding of where appliances and a heat pump could be placed.

Figure 8: Potential ccASHP location in basement of house

11. Quantifying, Equity, and Environmental Impacts

GHG Emissions

Using the annual energy usage in therms, or 100,000 BTUs, in a house as provided by GV-HEAT, the GHG emission savings from gas and propane to electricity were calculated. These were calculated annually and assuming gas furnaces run at 80% efficiency and propane furnaces run at 90%. Emission factors were taken from US EPA's eGrid and ICLEI's US Community Protocol for electricity and gas respectively. The gas and propane emission factor will stay constant throughout time while the electricity emission factors change over time. The expected annual GHG emissions

from one representative home in 2023 for gas, propane,and electricity are as follows:

- GHG emissions from gas: 2.484 metric tons of carbon dioxide equivalents ($mtCO_2e$)
- GHG emissions from propane: 2.297 $mtCO_2e$ annually
- GHG emissions from electricity:
    - 2023: 2.286 $mtCO_2e$
    - 2030: 1.119 $mtCO_2e$
    - 2040: 0.559 $mtCO_2e$

We found that emission savings are expected to increase over time because the gas, and propane,

emission factors stay constant over time while the electricity decreases.

Electricity emissions were also calculated using emission factors from MEAN and activity data statistics, which are provided for the house in the City of Gunnison sector. Assuming this emission factor also decreases linearly over time, the GHG emissions from electricity for MEAN are:

- 2023: 1.415 $mtCO_2e$
- 2030: 1.048 $mtCO_2e$
- 2040: 0.524 $mtCO_2e$

Total emission savings from 2023 to 2050 are expected to be 44.495 $mtCO_2e$. This number will help the environment and will only come to fruition if a switch from a propane furnace to a ccASHP occurs. Savings can be visualized in Figure 9.

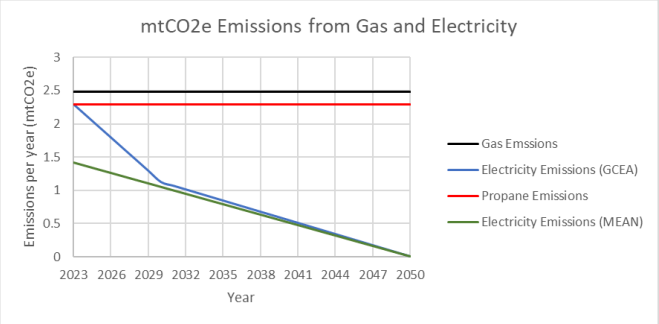

Figure 9: Comparing Emissions from Gas and Electricity

Energy Burden

GCEA has provided average operational costs for homes in Gunnison for gas and electricity. The average energy use per year was taken from interviews with GCEA's chief executive officer, Mike McBride. These numbers were used to calculate the energy burden for income-qualified households. The energy burden that was calculated was 8%.

> With the energy use reductions expected with electrification, the energy burden is expected to decrease as well.

Refrigerant Impact

A disadvantage of using ccASHP is the potential risk of refrigerant leaks. The global warming potentials (GWP) of refrigerants are extremely high so the emissions are far more detrimental to the environment than the average GHG. A typical ASHP uses 8 pounds of refrigerant. The common ASHP uses R410A. The emissions of these using a 5% leakage rate were calculated to be 0.367 $mtCO_2e$. This number should be taken into consideration. As technology improves, different refrigerants are able to be used. Refrigerants such as R-32 and R454-B are becoming more common in newer ASHPs. These replacements have lower GWPs than R410A, so they will have less of an impact on the environment. Also, these refrigerants are more efficient in terms of heating and energy. However, most current systems that are available are only capable of using R410A.

Upon conversation with industry experts, however, a properly installed system should not have any leakage at all, even over time. This should also be taken into consideration when choosing contractors and methods of installation. Therefore, if the contractors are credible and knowledgeable about heat pumps and their intricacies, the risk of leakage can be minimized, negating any potentially negative connotations the refrigeration cycle may have with regards to the environment.

Manual J Calculations

A manual J calculation for a home considers specific factors of a specific home to calculate the heat load of the house. Some aspects of the house that need to be considered for calculation are the dimensions of the windows of the house, as well as the cardinal direction the windows are facing. With the information that was given to the team and the help from an industry expert with the proper software, the heat load for Home 1 was able to be accurately calculated. It is estimated that a 30,000 BTU outdoor unit with 2 to 3 splits inside would suffice, depending on the available setup of the home. This calculation is expected to be done on the rest of the homes going forward to estimate the size of heat pump needed for each home.

12. Next Steps

A primary goal of this project is to continue and expand this work amongst the Gunnison Valley for decades to come. In order for this to happen, more community engagement must take place. Public surveys are a great way to gather community based opinions and perspectives. City council member engagement is a necessary method for receiving community feedback as well. As community education increases, the longevity of this project will increase as

well. In the valley, contractors certified to install ASHPs are sparse. An expanded or refined contractor list will help continue this project. This will require further research and examination of where contractors can be outsourced from.

A large section of this project that needs expansion is finding funding opportunities to cover GV-HEAT costs. The Federal Inflation Reduction Act offers dozens of credits regarding community projects in scope of climate action, resilience, and mitigation. The act has approximately $370 billion in investments. To be specific, there are $4000 for electrical upgrades and $2500 for wiring, all in income qualified homes. This new legislation is a primary resource regarding future funding opportunities.

Another part of future engagement for this project is in regards to data collection and analysis. It is desired to accumulate a 12 month data set from GV-HEAT homes. This data set will consist of total energy use and energy distribution. From this dataset, effects of ccASHPs can be quantified. This data can be spread amongst the community to ground truth the benefits of electrification.

13. Conclusion

Beneficial building electrification is paramount to not only the decarbonization, but the equity in the communities of the Gunnison Valley. By using the modern technologies found in air source heat pumps, these under-resourced communities will benefit from cleaner air, more consistent heating, and the addition of cooling, which is a great step towards improved quality of life.

It is known that strategic grid planning must be used to transition away from the dependence of fossil fuels, which these three pilot homes are being utilized for, working closely with GV-HEAT. These homes will likely be the first to be electrified, with the goal of these strategies applying to all homes in the Gunnison Valley in the future. We have developed the key criteria to select the correct homes for electrification, justifying the benefits of doing so, outlining costs, and steps of action to ease the process. This continued work will ensure that the Gunnison Valley can effectively meet the unanimous goals of a renewable, heated and cooled future.

To conclude, the Design for Community class of The Western Colorado University/University of Colorado at Boulder partnership program has worked hard in developing a beneficial electrification plan for homes in Gunnison County. Working closely with GV -HEAT, we were able to select three pilot homes to base our plan on. These homes will likely be the first to be electrified, but our goal for the plan was to make it applicable to all homes in Gunnison. We have developed criteria to select the right homes for electrification and justified the benefits of doing so. Costs and steps for action have been stated to help ease the process for everyone involved. This plan has been fully developed and thought out and we hope to see beneficial electrification implemented in Gunnison County in the near future.

Appendices

Appendix A: Contractor List

	Name	Phone	Address	Email	Notes
	HVAC installers & equipment providers				
1	Alpha Mechanical Solutions	641-4157	37610 Highway 50, Gunnison, CO 81230	fred.n@alphamechanical.co	installed geothermal in Gunnison Valley
2	Dragon Sheet Metal	349-6231	PO Box 365, Crested Butte, CO 81224	dragonsheetmetal@gmail.com	installed ASHP in Gunnison Valley
3	Hearth Design Build LLC	802-595-9576	2006 County Road 742, Almont, CO 81210	hearthdesignbuild@gmail.com	installed ASHP in Gunnison Valley
4	Hisson HVAC Corp	642-0399	193 Ute Lane, Gunnison, CO 81230		
5	Isham Plumbing & Backhoe	641-6183	1370 CR 8, Gunnison, CO 81230		
6	Johnstone Supply	970-765-4169	3192 Hall Ave, Grand Junction, CO 81504	galen.betz@johnstonesupply.com	
7	Keenan's Plumbing & Heating	249-3284		office@keenansplumbing.com	
8	Mesa Mechanical	641-4096	108 Tomichi Ln, Gunnison, CO 81230		installed Water Heater Heat Pump in Gunnison Valley
9	Pioneer Mechanical	349-2631	PO Box 353, Crested Butte, CO 81224	pioneer00608@msn.com	
10	Plumbline Mechanical	641-0987	405 Sierra Vista Way, Gunnison, CO 81230	stiger@pcrs.net	
11	Precision Plumbing & Heating	901-8634	825 Red Lady Ave, Crested Butte, CO 81224		
12	Ridgeline Service Plumbing	970-258-0615	200 S Wisconsin, Gunnison, CO 81230		
13	RML Mechanical	349-1995	PO Box 3701, Crested Butte, CO 81224		
14	Timberline Mechanical	349-5679, 641-1780	2 Andreas Cir, Crested Butte, CO 81224	info@timberlinemech.com	
15	Vman Plumbing	641-0204	300 N Main St, Gunnison, CO 81230		
16	Wise Mechanical	641-4771	709 Ute Lane, Gunnison, CO 81230		
17	Grizzly Air HVAC, Ryan Miller	970-985-2042		ryan@grizzlyairhvac.com	
18	Wise Owl Energy, Justin Wiseman	970-485-3853	Crawford, CO	jwiseman@nwccog.org	
19	Snipps Heat & Air, Inc. Custom Sheet Metal	970-240-8152	Montrose, CO	bri@snipps.com	installed ASHP in Gunnison Valley
20	One Hour Heating and Air Conditioning	970-240-0412, 970-5(	Montrose, CO		installed ASHP in Gunnison Valley
21	Energy IQ, Jeremy Miller	970-456-7470	Rifle, CO	energyiqcolorado@gmail.com	