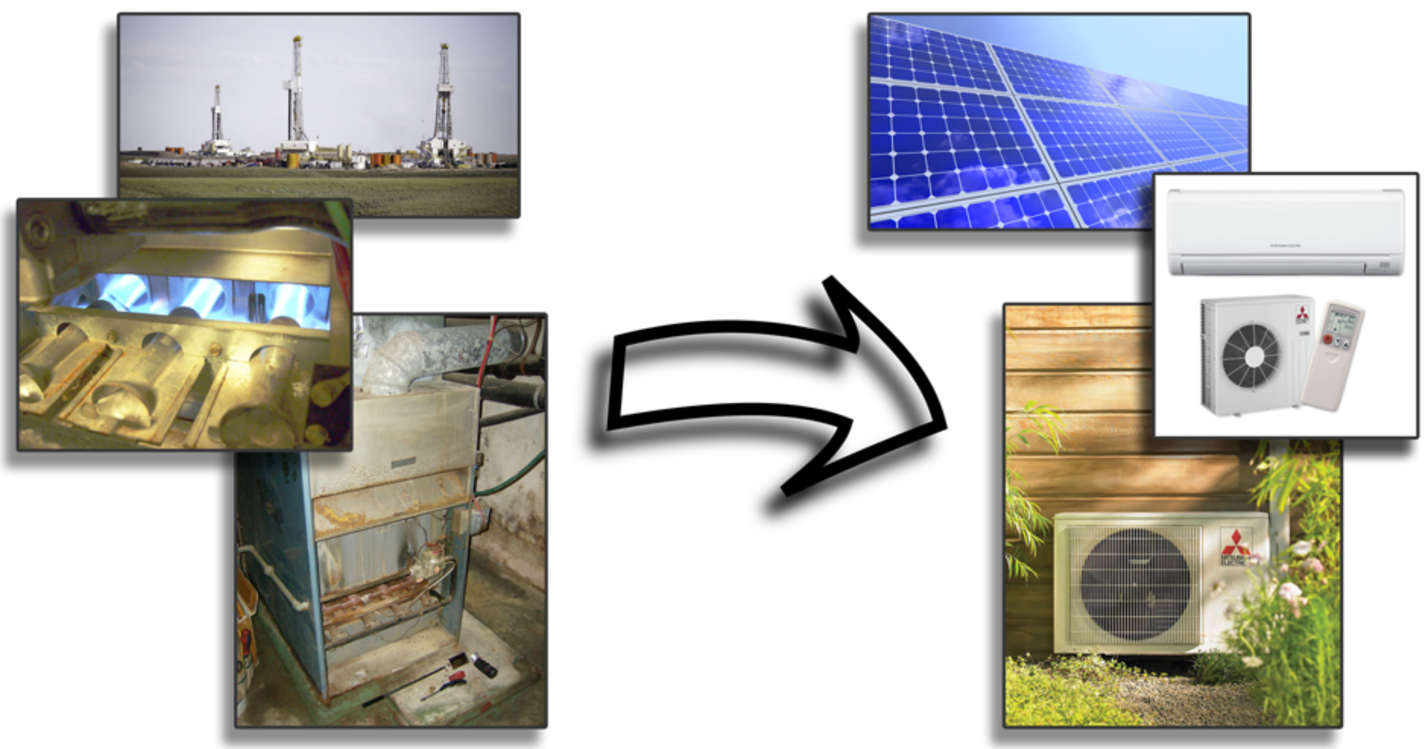
Building a Market-based Renewable Heating and Cooling Transition Strategy for Single Family Residential Homes in Boulder, Colorado



Background—Why Residential Thermal Decarbonization Matters

A significant body of work and innovation has taken place in efforts to decarbonize the electricity and transportation sectors. Although it is a smaller percentage of overall emissions for many cities than electricity and transportation uses, thermal uses powered by fossil fuels have a disproportionate negative environmental, social and economic impact, and the opportunity for improvement is substantial.

Challenges Facing Boulder and Other Cities Attempting to Decarbonize Thermal Uses

A number of significant barriers currently inhibit cities from developing and implementing thermal decarbonization strategies. These include:

1. **Information** — Cities do not have simple access to information on which buildings are using gas, what their current gas usage levels are, what types of thermal systems are in those buildings, and what the energy use characteristics are for those buildings.
2. **Viable Replacement Systems** — Most cities do not currently have staff with experience in evaluating viable replacement technologies and how to integrate these systems into existing energy programs.
3. **Mature market support** — In many locations, there are very few, if any, active providers of viable replacement technologies.
4. **First cost barriers** — Where replacement systems are readily available, most are currently not cost competitive with conventional natural gas, fuel oil or other fossil-based thermal systems, particularly in comparing initial cost of replacement, even if longer term lifecycle costs are lower.

The Strategic Importance of Residential Thermal Decarbonization

While apparently a relatively small portion of the city's overall emissions, the development of a natural gas substitution strategy in the residential sector is an important stepping stone to a larger thermal decarbonization strategy for several reasons.

Mature replacement technologies — An important prerequisite to a decarbonization strategy is the widespread availability of a viable replacement technology. In the residential sector, a variety of companies now make heat pump technology—both ground source and air source—which can be readily substituted for existing natural gas or low efficiency electric models.

Established delivery systems — This sector is also well served in Boulder by a mature energy efficiency support network which includes public sector energy advising services—EnergySmart — with an effective contact and data management system into which a new product and service option could be integrated.

Rapid Prototyping and Adaptation — Because of this established foundation of trained service personnel, we believe we can rapidly test and modify strategies for deployment based on the direct experience of both advisors, product and service companies, and householders. The smaller scale of project and higher volume of contacts also enables a higher number of replications with which to test different systems and approaches.

Application to additional markets — The tools and systems being developed to serve the single family residential sector have direct application to other parts of the residential sector (multi-family) and are likely to be adaptive to a range of smaller commercial buildings where there are similar use characteristics and suitable available replacement technologies.

Additional carbon reduction impacts in through a growing need for cooling — The now well documented trajectory for significant temperature increases in the Boulder area, particularly seasonal heating extremes, is already resulting in significant increases in the use of air conditioning. A significant portion of the housing stock built prior to the 1990s in the Boulder area was not built with central air conditioning. As a consequence, many of these dwelling units rely, or are likely to, on highly inefficient window-based AC units to achieve cooling. This will in turn increase the use of electricity, adding to both overall energy usage and more difficult serving peak period demands.

Decarbonizing thermal energy uses

This report outlines the first stage of developing a thermal decarbonization strategy focusing on the single-family residential sector. The objective of this project was the development of information systems and that enable a dynamic collaboration between the public and private sectors that can rapidly scale the deployment of renewable heating and cooling technologies that replace natural gas-based furnaces and water heaters

The Boulder Case Study—Background and Objectives

Boulder's Decarbonization Initiatives

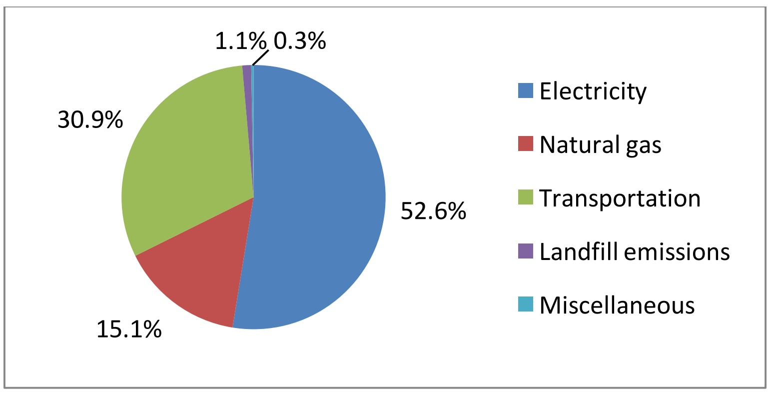
Boulder, Colorado has been actively engaged in efforts to reduce emissions since the passage of its first Climate Ordinance in 2002. The initial focus of efforts, as with most municipalities, was on the implementation of voluntary energy efficiency programs. These efforts were followed by city council actions implementing a series of codes and ordinances intended to require the integration of energy efficiency improvements in the residential, commercial and industrial sectors.

Recognizing that efficiency improvements alone would not achieve deep emissions reductions, the community called for active discussions with the incumbent electric utility provider, Xcel Energy, to push for a rapid decarbonization of the electric supply. In the city's analysis of pathways to achieve its 80% emissions reduction goal, it was determined that achieving 100% renewable electricity was the only pathway that would enable the city to achieve this goal. This recognition, and the inability of Xcel to commit to this transition within a known timeframe, were major factors in the city's decision to file for condemnation of the electric utility infrastructure within the city limits and the formation of a new municipal utility.

While these efforts — the development of a comprehensive energy efficiency program and the pursuit of a 100% renewable electricity utility — are both essential to achieving deep emissions reduction, they are not by themselves sufficient. As noted in the USDN's Energy System Transformation Framework and CNCA's Deep Emissions Reduction Handbook, the only viable path to deep emissions reduction requires both continued improvements in energy efficiency and the simultaneous decarbonization of the electric, thermal and transportation energy use sectors.

Natural Gas Use in Boulder

According to the city's 2012 greenhouse gas inventory, natural gas currently comprises approximately 15% of the city's GHG emissions. Residential systems account for roughly 1/3 of the natural gas usage in the city of Boulder with Commercial (~50%) and Industrial uses (~20%) accounting for the remainder. Figure 1—Emissions by Energy Source: Boulder, Colorado[1]



Building a Residential Renewable Heating and Cooling Strategy—Project Deliverables

With this context of Boulder's past efforts and current residential thermal, Boulder proposed a work plan intended to accomplish the following objectives:

1. Develop a preliminary estimate for the number of natural gas using appliances in the residential sector in Boulder.
2. Identify and evaluate the viability of existing and emerging technologies to provide suitable replacement options for the types of systems targeted for retirement in Boulder.
3. Evaluate the financial feasibility of replacement systems and the associated emissions reduction.
4. Develop a set of recommendations for accelerating adoption of low-carbon thermal systems and identify high-leverage initial action opportunities by including market sector development.

[1] Based on Boulder, Colorado 2012 Community Emissions Inventory. The city updates its inventory every three years. The 2015 inventory will be available in late 2016.

The remainder of this report will describe the strategy and associated tools developed to build this base of information, and the actual findings associated with each.

Project Strategy

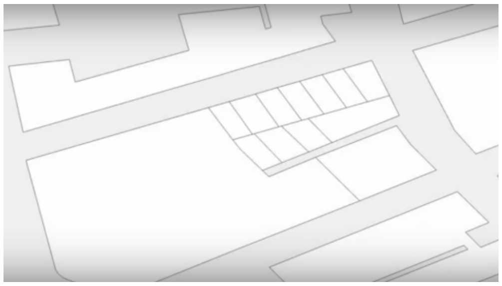
The four project deliverables outlined in the CNCA grant were intended to build a foundation of information with which Boulder could develop a residential thermal decarbonization strategy. To accomplish this, Boulder needs to:

1. **Develop a community-wide thermal database** — Develop an information database with the necessary data needed to
    a. Identify natural gas usage down to the household level
    b. Project the thermal energy needs down to the household level
2. **Assess and Evaluate Replacement Technologies** — Evaluate best available information on the performance and market readiness of suitable thermal replacement strategies.
3. **Build or Integrate Analytical Tools —** Utilize or create analytical tools capable of:
    a. evaluating and comparing the performance of proposed replacement technologies against existing natural gas systems at a household level including financial, energy usage and carbon intensity measures.
    b. aggregating this information at a community scale
    c. easily visualizing this information in ways that facilitate program development and resource targeting
4. **Developing implementation strategies** — Based on these analytical capabilities, work with both public and private sector partners to create an implementation strategy capable of utilizing this information to accelerate renewable heating and cooling deployments.

Strategy Element 1: Thermal Database Development

To develop an effective natural gas replacement strategy, the city needs a database of households that have natural gas appliances and key characteristics of the building that will help to assess both when appliance replacements are likely to take place and what the most cost and performance effective configuration for a replacement technology would be based on existing options.

Identifying usage by household — While it is known that natural gas systems were the predominant form of heating for these applications, no compiled data is available on which households utilized gas appliances. Currently the existing natural gas utility, Xcel, is not required to disclose more than aggregate usage by major sector — residential, commercial/industrial. To develop an initial estimate of the households using natural gas, the project team began by building a database synthesizing two data sources — **County Assessor's data** and **building permit data**. From the Assessor's data, we could get an initial indication of whether the house was hooked up to natural gas (a field in the assessor data). From the permit data, we have more specific data on what types of heating systems were installed, the year, and other information that could help model system performance.



Step 1: Download and organize assessor data for every single family detached dwelling

CITY OF BOULDER CITY
BUILDING DEPARTMENT

PERMIT APPLICATION CHECKLIST

DATE SUBMITTED: DESIGN CODE:
ADDRESS:
OWNER:
OWNER'S ADDRESS:
OWNER'S PHONE: (H) DAY PHONE:

CONTRACTOR: STATE CONTRACTOR LIC:
ADDRESS: CITY BUSINESS LIC:
CONTRACTOR PH: (W) (FAX) (EMAIL)
CONTACT NAME: (CELL)

PLANS PREPARED BY:

REQUIRED DOCUMENTS:

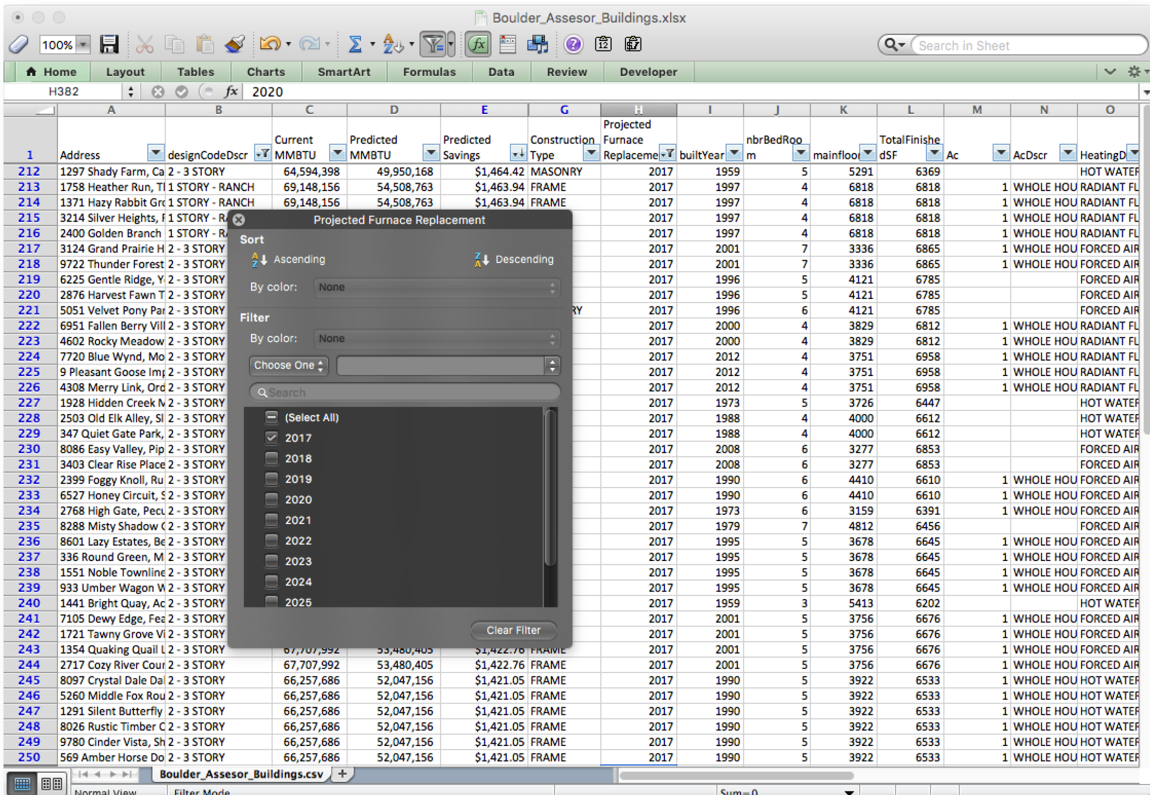
BUILDING PLANS - THREE COMPLETE SETS REQUIRED
ALL DOCUMENTS SHALL COMPLY WITH THE NEVADA BLUE BOOK GUIDELINES

Step 2: Download and organize permit data for every single family detached dwelling

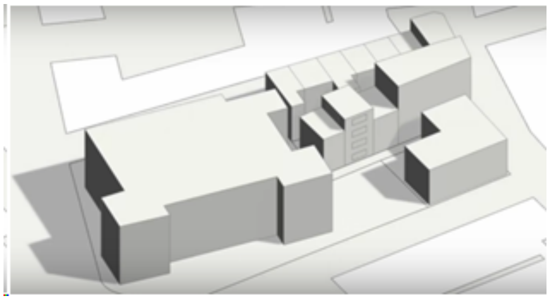
This synthesis was completed and a database was built capturing all 20,000 of the City of Boulder's single-family detached residences. This database included all of the fields available in the assessor's data (see attachment A for the database), as well as the additional information on heating systems scraped from the building permits. It should be noted that the Snugg Home Team developed a unique a new data scraping application to capture and classify information from both computer entry and handwritten field notes. This process also resulted in the City of Boulder updating its permit data fields and entry systems to improve the capture and monitoring of this information going forward.

The resulting Excel-based data set now enabled the project team to sort the data by a wide range of different attributes or combination of attributes. For example, the households with furnaces or water heaters over a projected useful life range could be identified. This set could then be further sorted by building construction type (stick or masonry, crawlspace or basement, number of stories), location, year built etc.

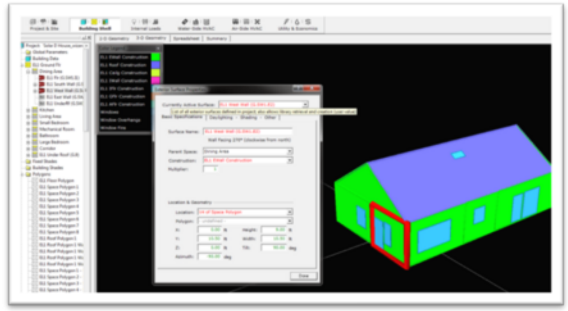
Step 3: Synthesize initial building database integrating Assessor and permit data



Projecting heating/cooling energy usage by household — Given the lack of access to actual usage data from the utilities, determining actual usage by household is not currently possible. The original project strategy was to associate the two-dimensional information provided by the County Assessor data with three-dimensional attributes available by parcel through additional LIDAR data and 3-D wireframes the city had compiled for every property in the city. This large assortment of residential structures was then going to be sorted into a smaller set of building "profiles". A representative number of actual houses from each profile were then going to be run through advanced energy modeling software to develop a preliminary energy performance model. Then every house in Boulder would be assigned to its most similar "profile" outputs to create an initial estimate of its energy performance and natural gas usage.

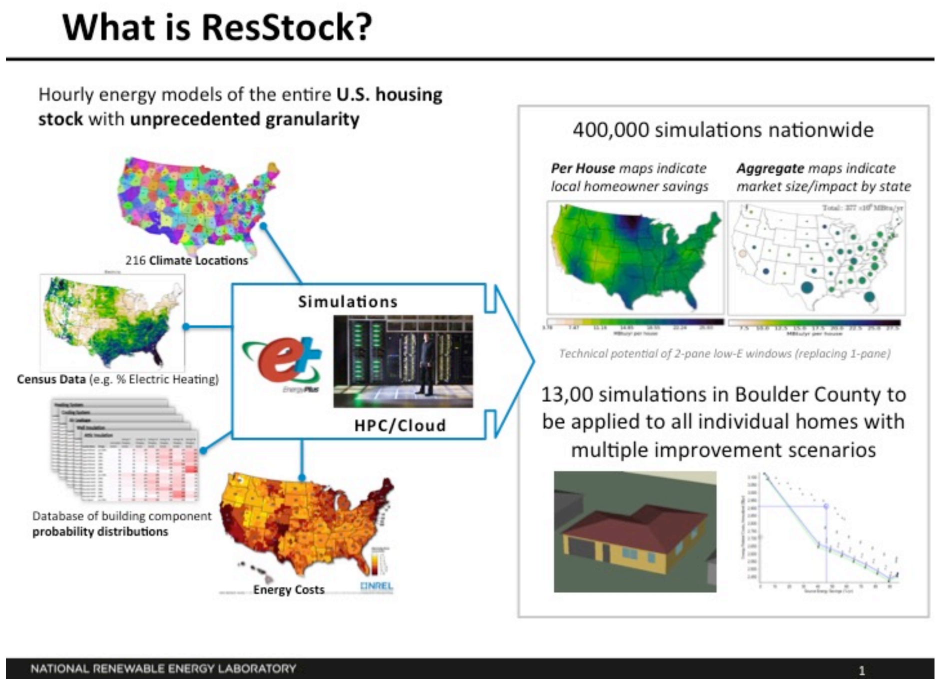


Step 4: Apply LIDAR and 3-D wireframes to create 3-D building envelop data and develop profiles



Step 5: Apply advanced energy modeling to representatives from each selected building profile group

An Unexpected Windfall — NREL's National Residential Building Modeling Initiative: ResStock



While exploring options for conducting the energy modeling on the selected profiles, the Snugg Home team made contact with the National Renewable Energy Labs (NREL) to discuss accessing their supercomputers for energy modeling. Through these discussions, they learned of NREL's recent efforts to develop energy modeling capable of projecting energy usage for every single family residential structure in the country. This program, ResStock, was built on more than a decade of building-modeling tools. NREL built a database of 400,000 building archetypes across the US with the intention that any house in the United States could be associated with one of those archetypes and a preliminary estimate of its energy performance and energy use could be conducted. This modeling includes hourly energy simulations. This is critical when assessing the ability of new types of technologies like low-temperature heat pumps to provide the level of heating needed during the coldest parts of winter seasons.

This energy modeling is also an enormously powerful tool for cities to project other important dynamics including:

- The level of emissions reduction that different scenarios of system change outs would have at a household and community level
- The grid impacts of energy systems change — total demand and peak demands by hour, day or season
- The potential impacts of climate change on both heating usage and cooling needs and associated energy and emissions implications.

Boulder energy modeling — In Boulder County alone, the ResStock model had already developed 3,300 archetypes to represent the housing types in this area. The NREL team immediately saw the potential value of a collaboration with this project because of the additional data the Snugg Home team could bring to the NREL models in ways that could improve the modeling accuracy. As one example, the Snugg Pro auditing platform is the Xcel Energy designated platform for all residential energy efficiency audits in Xcel's Colorado service territory. As a consequence, there are over 3,000 actual home audits with associated utility information available for "truing up" the NREL model runs.

This opportunity significantly accelerated the profiling plan strategy originally developed for this project and created a much more scalable and replicable energy modeling approach to represent all homes across the US.

Based on assessor and permit data provided by the Snugg Home project team, NREL was also able to significantly expand the number of archetypes in the Boulder County area, from the original 3,300 to 13,000.

Strategy Element 2: Assess and Evaluate Replacement Technology

To identify and evaluate viable renewable heating and cooling (RHAC) systems, the project team utilized three types of resources

Industry Experience — The Snugg Home team have extensive experience in both designing for, evaluating and installing heat pumps. This experience was especially useful in ground-truthing the listed specifications of different heat pump options against direct experience in the local environment.

Published research on renewable thermal technologies — Reference sites with useful background on RHAC systems include:

- Bonneville Power Authority — https://www.bpa.gov/EE/Sectors/Residential/Pages/Ductless-Heat-Pumps.aspx
- Department of Energy — http://energy.gov/energysaver/heat-pump-systems
- Northeast Energy Efficiency Project (NEEP) — http://www.neep.org/initiatives/high-efficiency-products/emerging-technologies/ashp/cold-climate-air-source-heat-pump

The NEEP site also maintains a regularly updated list of cold climate air-source heat pumps (ASHP) that includes all of the manufacturers and their associated models that have been rated for cold climate uses along with a very comprehensive set of performance specifications under 4 different temperature range performance conditions.

The results of this secondary research are summarized in **Appendix A** of this report.

Home Performance Modeling — Based on this secondary research and in-field experience, the project team contracted with a local green building design and engineering firm, Sustainably Built, to conduct advanced energy modeling to evaluate the cost and performance comparisons between conventional efficiency gas furnaces, high efficiency gas furnaces, air source heat pumps, solar thermal, and ground source heat pumps.

Five homes were selected to represent as many homes as possible in the City of Boulder and Boulder County, as shown in Table 1. The home sizes and other attributes were chosen to approximately mirror the distribution of homes in the area. Real homes were chosen from assessor's records, which were narrowed down by filtering according to size and attributes. For instance, crawlspaces are predominantly seen in houses less than 2,500 sq. ft., and in the overwhelming majority of houses less than 1,500 sq. ft. So, the home chosen to represent the range up to 1,499 sq. ft. was a home with a crawlspace.

Table 1 - Five suggested homes

Home Size	# Stories	Below grade	Fuel
950 sq. ft.	1	Crawlspace	natural gas
2000 sq. ft.	1	Basement	natural gas
2700 sq. ft.	2	Basement	natural gas
3470 sq. ft.	2	Basement/Crawlspace	natural gas
4493 sq. ft.	2	Basement	natural gas

Extensive modeling was performed on each of the homes described above. In addition to assessor's records, images were used from Google Maps to approximate the dimensions of the home.

This modeling is described in detail in **Appendix B** of this report.

Strategy Element 3: Build an Analytics and Data Visualization Tool

The third strategy area focused on developing tools that can analyze and visualize the large volumes of data compiled in ways that can inform the development of a renewable heating and cooling replacement strategy and portray the information in ways that help inform both program managers and policy makers.

Data Analytics — The Snugg Home team went considerably beyond the original scope of work and has begun developing a series of tools that can model a wide variety of information useful for both RH&C (Residential Heating and Cooling) program development and for larger energy system transition planning. These tools include:

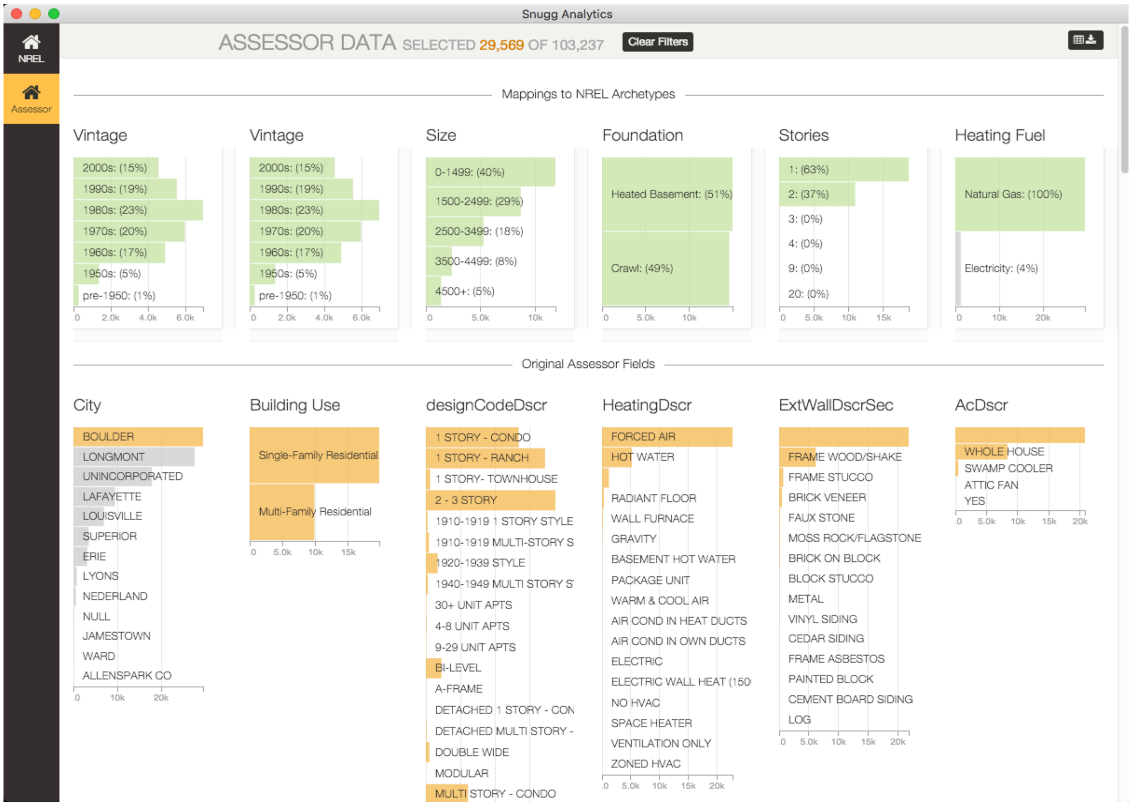
- **RH&C cost estimator** — The integration of the databases built from city data and the NREL ResStock archetypes will give the city the capacity to provide every single family detached household in the community the potential costs (both first costs and annualized operational costs) and carbon emissions reduction potentials for a conversion to a RH&C system.

- **Community-wide impacts** — This information can then be aggregated to create a community scale analysis of transitioning households to RH&C systems. In addition to the questions originally intended to be addressed in this analysis (options for viable residential RH&C systems, cost and carbon implications of replacement, number of high propensity adoption households in Boulder), these tools will also be able to answer the following questions:

    - Total kWh increase caused by adoption of RH&C — household and community scale
    - Peak kW demand increase by time of day and season
    - Carbon savings (CO_2) under different electricity carbon intensity scenarios
    - Total natural gas reduction by adoption scenario
    - Retained wealth in community based on both energy cost savings and for systems utilizing self-generation of electricity
    - Offsite solar/wind requirements to provide necessary RH&C energy
    - Battery storage requirements to manage energy demands from RH&C
    - Necessary financing to support large scale implementation
    - Projected impact of climate change on local energy needs
    - New AC installations impacts based on different climate change scenarios
    - Implications on local installer base: equipment stocking, installer workforce etc

Data Visualization Tools — The Snugg Home team has begun to develop a series of data visualization tools that will assist City and County program managers to utilize the data aggregated during this project. Figure 1 shows a snapshot of an interactive data visualization tool that enables the user to select from a series of attributes to create customized profiles of homes to be considered for RH&C replacements. The analytic tools can then automatically calculate the cost, energy savings and carbon emissions consequences for each different scenario calculated and extract a database of the contact information and attribute profiles for each of the houses covered in that scenario.

Figure 1 — Data Sorting and Visualization Tool



Strategy Element 4: Develop Implementation Strategies

The city's implementation strategy has two major elements. A local implementation approach and a national/market scale component.

Local RH&C Implementation Strategy — The City and Boulder County jointly developed the Energy Smart Program in 2010 to create an advisor supported energy efficiency approach within Boulder and across the city. This program has been highly successful in its audit-to-action ratio around conventional energy efficiency measures. However, like most programs, its focus in the thermal heating area has been primarily around providing incentives to upgrade inefficient gas furnaces to higher efficiency models.

Recognizing the importance of creating program features that can support the conversion to RH&C systems, the County joined the city in funding the aggregation of all of its building data as part of the Snugg Home Team's data aggregation process. As a consequence, all 80,000 of the County's single family detached residences are also in the databases developed for this project. Following a review and evaluation of this report, the City and County will begin to develop program implementation measures that use the propensity-for-conversion analysis developed by the Snugg Home team to target households for early stage piloting of a RH&C technology replacement program. The elements currently being discussed for inclusion in this program include:

1. **Financial Incentives** — The City and County are exploring dedication of a portion of the current energy efficiency incentive funds to provide financial incentives to households willing to replace gas appliances with RH&C systems.
2. **Special technical assistance** — Existing advisors will be given additional training to provide guidance and support for households to consider natural gas appliance replacements during the household audit and assessment program.
3. **Integration with group purchase discount programs** — The City and County have run highly successful solar and EV group purchase programs. They will explore developing a similar approach with manufacturers of RH&C equipment.
4. **Coordination with the HVAC providers** — As part of the development of these programs, the City and County will also work with local suppliers and installers to identify ways to most effectively coordinate adoption efforts that insure high quality customer experience.

National Market Aggregation Strategy — Boulder has also taken the lead in organizing a group of cities through the Carbon Neutral Cities Alliance (CNCA) the Urban Sustainability Director's Network (USDN) to begin a dialogue with manufacturers on developing a public-private sectors collaboration to accelerate the scaling of RH&C system adoption. This approach will have likely have four major components

- **Data aggregation to optimize RH&C adoption prospects** — A current impediment to the dissemination of RH&C technologies is the high cost of customer acquisition for firms with new types of heating and cooling solutions. Through the development of tools similar to the ones developed in this project, it is likely that cities can use publicly available data to provide more efficient exposure and access to potential customers for companies with these RH&C solutions.
- **Outreach and education** — An important asset the cities bring to this market development process is the ability to serve as a respected "honest broker" of information and opportunity that helps households have a greater trust and confidence in an RH&C system choice that may otherwise be unfamiliar.
- **Coordinated incentives** — Both the public and private sectors currently create financial incentive programs to drive adoption of actions or technologies. Public sector incentives typically focus on household first cost reduction incentives (rebates), while private sector incentives typically focus on dealer/installer "upstream" incentives that increase profit margins. By coordinating these types of incentives, the public and private sectors can support a more sustainable expansion of the RH&C industry.
- **Industry development** — Currently most cities do not have an HVAC industry that is supplied, incented or trained to prioritize RH&C systems. Rapid scaling of adoption of these systems will require an equally aggressive effort to grow the base of suppliers, installers and service providers necessary to support the installation and ongoing support of high quality RH&C systems. An important role for cities in this process is to work with the industry to implement a QA/QC process that insures a positive experience for those making a switch to these systems.

Findings and Recommendations

Natural Gas Appliances in Boulder

The first deliverable for this project was to develop an estimate for the number of natural gas appliances in Boulder. Using the database systems developed to integrate Boulder County Assessor data, we have an indicator of the primary heating fuel. It can be deduced with relative certainty that homes with natural gas will use it for water heating as well and possibly for cooking. Natural gas clothes dryers aren't nearly as common. It's also possible for homes to have more than one furnace, boiler, or water heater.

Through integrating the City of Boulder permit data we can create an additional data source to verify the presence of natural gas appliances. It should be noted that not all installations of natural gas water heaters and furnaces are permitted. Further, appliances such as dryers or stoves do not require permits. To proceed with the analysis at this stage of data availability, it was assumed that for all homes with the designation of Natural Gas have at least one gas fired heating system and one gas fired water heater. The compiled data base count shows that there are 29,569 residential buildings[2] in the City of Boulder that have natural gas as the primary heating fuel and therefore at minimum, 59,138 natural gas appliances. For single family detached dwellings alone, the count is 19,952 buildings. There are an additional 9,847 Multi-Family buildings showing gas service.

Replacement Technology Options

The analysis provided and summarized in the attachments to this report demonstrate that there are available and mature technologies for both space heating and cooling and domestic hot water (DHW) heating. This is one of the significant advantages of the residential sector at the present time—there are a wide variety of models and features available and a demonstrated and documented history of performance.

Cost Related Considerations

The analysis also indicated that for one of the three primary thermal uses—domestic hot water heating, currently available technology is already cost competitive, even with relatively low natural gas prices. In contrast, currently, both Ductless Heat Pump and Ground Source Heat Pump systems are significantly more expensive than the furnaces they seek to replace. However, a number of factors could quickly change this cost differential.

The role of local generation — It is important to underscore the significance of the PV factor. At current installed costs, the 20 year amortized cost of electricity for a PV system is approx. $.07/kwh. The models above assume that the PV system essentially pays for itself over this period—there is no added cost to the installed cost of a zero-carbon heating system other than the initial "first cost" of the DHP or GSHP systems. When energy cost and use of photovoltaics are considered, the payback for a net-zero home with a zero annual carbon footprint (excluding embodied carbon) is reduced to as little as 4 years.

[2] It should be noted that this is the number of buildings not the number of housing units. There are significantly more housing units given multiple units per building.

The role of natural gas prices — The simple payback analysis shown above is based on the current cost of natural gas, a cost many view as artificially low and likely to increase significantly during the next decade. As the cost parity analysis above demonstrates, natural gas would only need to reach a $1/therm level for these systems to be comparable in price. Natural gas continues to be one of the most volatile commodities traded. Local natural gas prices have been more than double the current price as recently as 2010. Even without PV, the modeling suggests DHP systems would be competitive with high efficiency natural gas furnaces at a gas price of $1.15/therm. With PV, it would only take an additional four years of savings to make the costs of the systems similar. If gas prices were to increase above those modeled, the current four year simple payback differential between a high efficiency gas furnace and a DHP could be significantly reduced—or reversed (the high efficiency gas furnace may become more expensive on an annualized basis) if natural gas prices increase above the current price parity level of $1/therm.

Current "first cost" differences — The current prices of heat pump heating and cooling systems are in the context of a relatively new and immature market sector. The relatively limited number of local providers and wide variation of quoted prices for similar systems underscores this dynamic. As this sector matures and economies of scale reduce manufacturing and other related "hard costs", we would expect to see the price differentials between mature fossil-fuel based systems and emerging heat pump based systems to be significantly reduced.

Project replacement opportunities for RH&C systems

Of the 19,952 single family residences showing gas service in the assessor's data, 11,044 have pulled permits for either an air conditioner (AC), a furnace or a water heater. The remaining 8,908 homes do not have permits for these appliances on file. 2,337 of this remainder are homes built since 2000 and are likely not to have reached their expected natural replacement transition (NRT) for those appliances. Many of the remaining 6,571 houses without permits showing are likely to have had at least one of these appliances replaced without a permit. A number of methods are currently being considered to determine the age of appliances in these households as well as likely appliance replacements not covered by permits in the 11,044 that have pulled permits (because many houses in that dataset only show permits in one of the three types of appliances.

The figure below shows a screenshot of the database showing the types of fields that can be used for sorting and scenario development among the 11,044 single family detached homes in Boulder with RH&C related permits. This sort was designed to identify the households with the highest likelihood of needing an AC, furnace or water heater replacement today.

Figure 2 — High Propensity for RH&C Adoption Opportunity

City of Boulder Homes to Target for Thermal Decarb.xlsx [Read-Only] - Excel

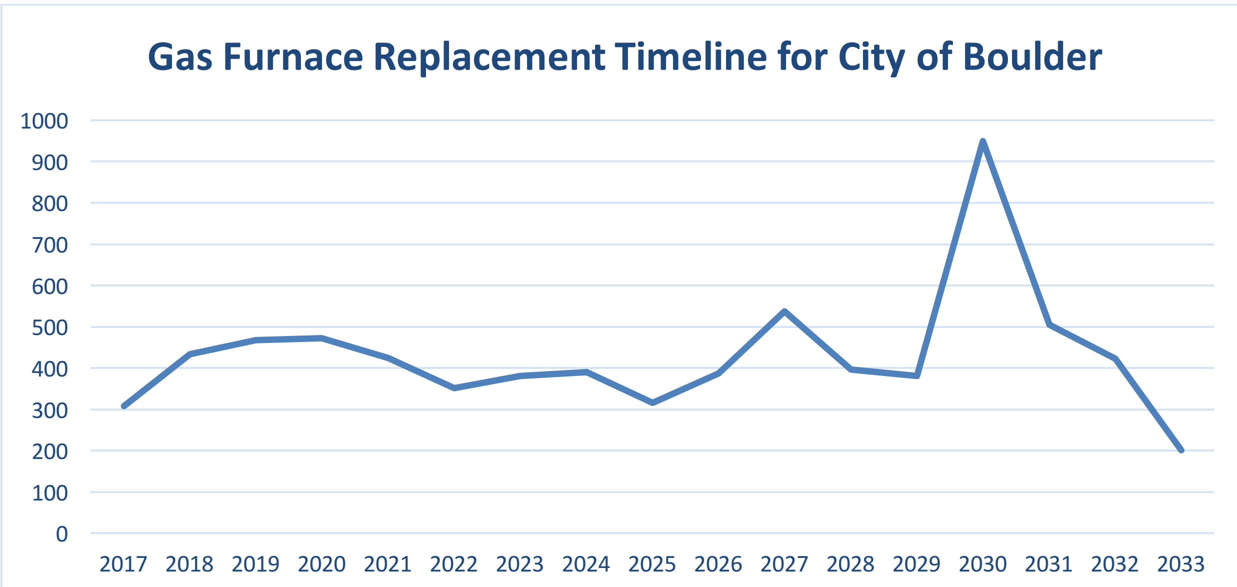
File Home Insert Draw Page Layout Formulas Data Review View Acrobat Tell me what you want to do

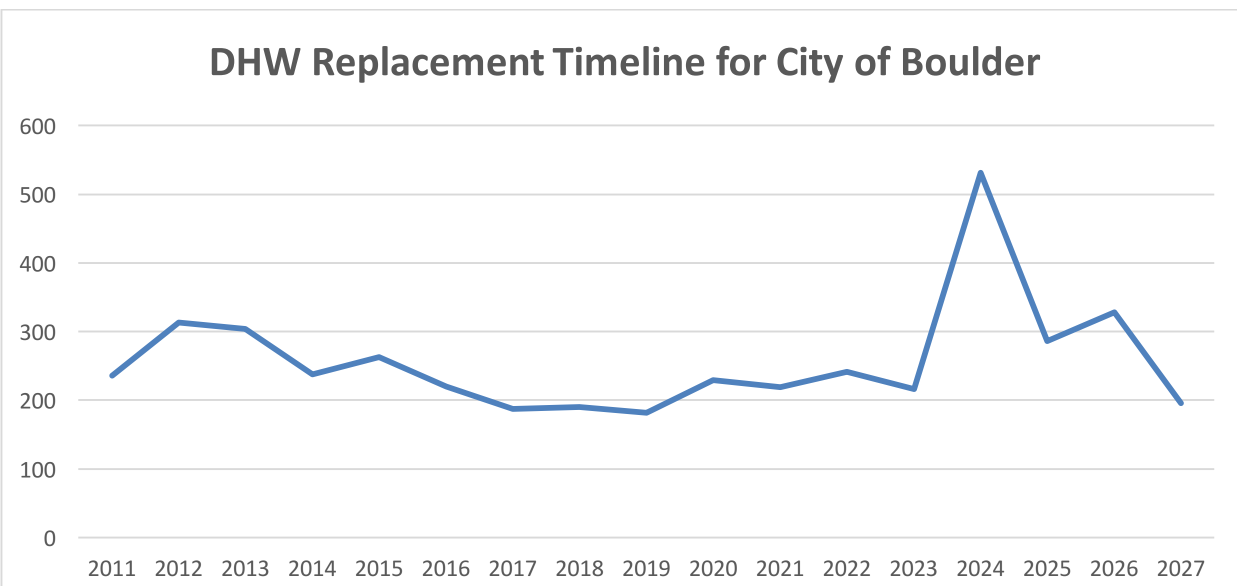
O4 Single-Family Residential

DATABASE OF 11,000 City of Boulder HOMES TARGETING REPLACEMENT OF AC/Domestic Hot Water/Gas Furnace BASED ON YEAR OF LAST PERMITTED INSTALLATION

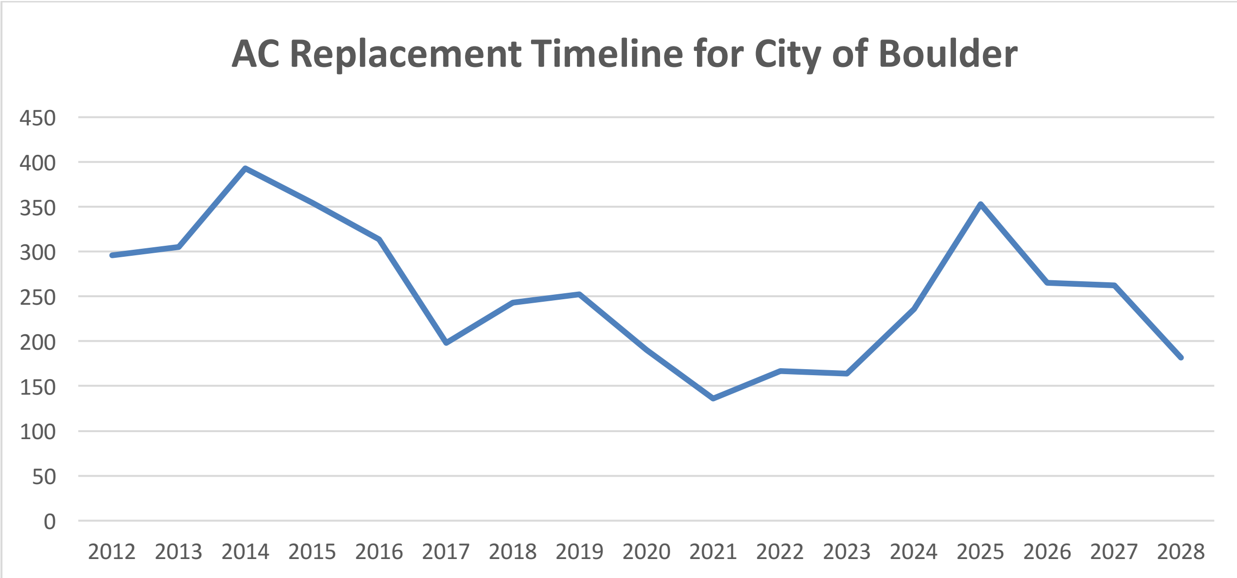
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	
3	ExtWallDscrPrim	AcDscr	Roof_CoverD	ConstCodeD:	nbrBedRoon	ExtWallDscrSec	HeatingDscr	bsmtTypeDscr	designCodeDscr	Vintage	Stories	Size	Foundation Type	Heating Fuel	Building Use	Oldest of AC/DHW/GF	Elec
4	FRAME STUCCO	WHOLE HOUSE	ASPHALT	FRAME	4		FORCED AIR	WALK-OUT BASEMENT FINISHED AREA	1 STORY - RANCH	2000s	1	4500+	Heated Basement	Natural Gas	Single-Family	1999	
5	BRICK VENEER			FRAME	3	FRAME WOOD/SHAKE	FORCED AIR	SUBTERRANEAN BASEMENT FINISHED	1 STORY - RANCH	1970s	1	2500-3499	Heated Basement	Natural Gas	Single-Family	1999	
6	BRICK VENEER		ASPHALT	MASONRY	3		FORCED AIR	0	1 STORY - RANCH	1990s	1	0-1499	Crawl	Natural Gas	Single-Family	1999	
7	BRICK VENEER		ASPHALT	MASONRY	3	FRAME WOOD/SHAKE	HOT WATER	0	1 STORY - RANCH	1960s	1	0-1499	Crawl	Natural Gas	Single-Family	1999	
8	BRICK VENEER			FRAME	3	FRAME WOOD/SHAKE	HOT WATER	SUBTERRANEAN BASEMENT FINISHED	MULTI STORY- TOWNHOUSE	1980s	1	1500-2499	Heated Basement	Natural Gas	Multi-Family F	1999	
9	BRICK VENEER	WHOLE HOUSE	ASPHALT	MASONRY	2	FRAME STUCCO	FORCED AIR	0	MULTI STORY TOWNHOME-C	1980s	1	1500-2499	Crawl	Natural Gas	Single-Family	1999	
10					0			0	SINGLE WIDE	1980s	1	0-1499	Crawl	Natural Gas	Single-Family	2000	
11					0			0	SINGLE WIDE	1980s	1	0-1499	Crawl	Natural Gas	Single-Family	2000	
12					0			0	SINGLE WIDE	1960s	1	0-1499	Crawl	Natural Gas	Single-Family	2000	
13					0			0	SINGLE WIDE	1960s	1	0-1499	Crawl	Natural Gas	Single-Family	2000	
14					0			0	DOUBLE WIDE	1970s	1	0-1499	Crawl	Natural Gas	Single-Family	2000	
15					0			0	SINGLE WIDE	1960s	1	0-1499	Crawl	Natural Gas	Single-Family	2000	
16					0			0	SINGLE WIDE	1970s	1	0-1499	Crawl	Natural Gas	Single-Family	2000	
17	FRAME WOOD/SHAKE			FRAME	3		FORCED AIR	LOWER LVL GARDEN FINISHED (BI-SPL	BI-LEVEL	1980s	2	1500-2499	Heated Basement	Natural Gas	Single-Family	2000	
18	BRICK ON BLOCK		ASPHALT	MASONRY	10		FORCED AIR	SUBTERRANEAN BASEMENT FINISHED	2 - 3 STORY	1980s	2	3500-4499	Heated Basement	Natural Gas	Single-Family	2000	
19	FRAME STUCCO	WHOLE HOUSE	ASPHALT	FRAME	4		FORCED AIR	SUBTERRANEAN BASEMENT UNFINISH	2 - 3 STORY	2000s	2	4500+	Heated Basement	Natural Gas	Single-Family	2000	
20	BRICK VENEER	WHOLE HOUSE	ASPHALT	FRAME	3	FRAME WOOD/SHAKE	FORCED AIR	0	1 STORY - RANCH	1980s	1	0-1499	Crawl	Natural Gas	Single-Family	2000	
21	BRICK VENEER		RUBBER MEME	MASONRY	2		FORCED AIR	0	1 STORY - CONDO	1980s	1	0-1499	Crawl	Natural Gas	Multi-Family F	2000	
22	FRAME STUCCO		ASPHALT	MASONRY	3	MOSS ROCK/FLAGSTONE	FORCED AIR	SUBTERRANEAN BASEMENT UNFINISH	2 - 3 STORY	1990s	2	3500-4499	Heated Basement	Natural Gas	Single-Family	2000	
23	BRICK VENEER		ASPHALT	MASONRY	5		HOT WATER	SUBTERRANEAN BASEMENT FINISHED	1 STORY - RANCH	1990s	1	2500-3499	Heated Basement	Natural Gas	Single-Family	2000	
24	BRICK VENEER			MASONRY	2		FORCED AIR	0	1 STORY - RANCH	1970s	1	1500-2499	Crawl	Natural Gas	Single-Family	2000	
25	FRAME WOOD/SHAKE		ASPHALT	FRAME	3		HOT WATER	SUBTERRANEAN BASEMENT FINISHED	MULTI STORY TOWNHOME-C	1960s	1	0-1499	Heated Basement	Natural Gas	Single-Family	2000	
26	FRAME WOOD/SHAKE		ASPHALT	FRAME	3		FORCED AIR	WALK-OUT BASEMENT FINISHED AREA	1 STORY - RANCH	1980s	1	1500-2499	Heated Basement	Natural Gas	Single-Family	2000	
27	FRAME WOOD/SHAKE		ASPHALT	FRAME	3		FORCED AIR	SUBTERRANEAN BASEMENT UNFINISH	2 - 3 STORY	1970s	2	1500-2499	Heated Basement	Natural Gas	Single-Family	2000	
28	FRAME WOOD/SHAKE		ASPHALT	MASONRY	3	BRICK ON BLOCK	HOT WATER	0	2 - 3 STORY	1970s	2	1500-2499	Crawl	Natural Gas	Single-Family	2000	
29	FRAME STUCCO		ASPHALT	MASONRY	3		FORCED AIR	0	1 STORY - RANCH	1970s	1	0-1499	Crawl	Natural Gas	Single-Family	2000	
30	FRAME WOOD/SHAKE	WHOLE HOUSE	ASPHALT	FRAME	4		FORCED AIR	SUBTERRANEAN BASEMENT FINISHED	2 - 3 STORY	1980s	2	1500-2499	Heated Basement	Natural Gas	Single-Family	2000	
31	BRICK VENEER	WHOLE HOUSE	ASPHALT	MASONRY	3		FORCED AIR	SUBTERRANEAN BASEMENT FINISHED	1 STORY - RANCH	1990s	1	2500-3499	Heated Basement	Natural Gas	Single-Family	2000	
32	BRICK ON BLOCK		ASPHALT	MASONRY	3		FORCED AIR	0	2 - 3 STORY	1970s	2	1500-2499	Crawl	Natural Gas	Single-Family	2000	
33	FRAME WOOD/SHAKE		ASPHALT	FRAME	4		FORCED AIR	SUBTERRANEAN BASEMENT FINISHED	1 STORY - RANCH	1970s	1	2500-3499	Heated Basement	Natural Gas	Single-Family	2000	
34	BLOCK STUCCO	WHOLE HOUSE	ASPHALT	MASONRY	5		FORCED AIR	0	2 - 3 STORY	1980s	2	2500-3499	Crawl	Natural Gas	Single-Family	2000	

Despite the gaps in the information, this analysis gives us for the first time the ability to project the appliance replacement cycle for over 50% of the existing households and provides a framework for estimating the remainder. Using conservative replacement life cycle estimates[3], the figures below shows the projected number of RH&C replacements for all three major appliance categories — Gas furnaces, domestic hot water heaters (DHW) and air conditioning units (AC). The available City of Boulder permit data set started in the year 2000, so these graphs start on the first year of replacements where the type of equipment would traditionally wear out.



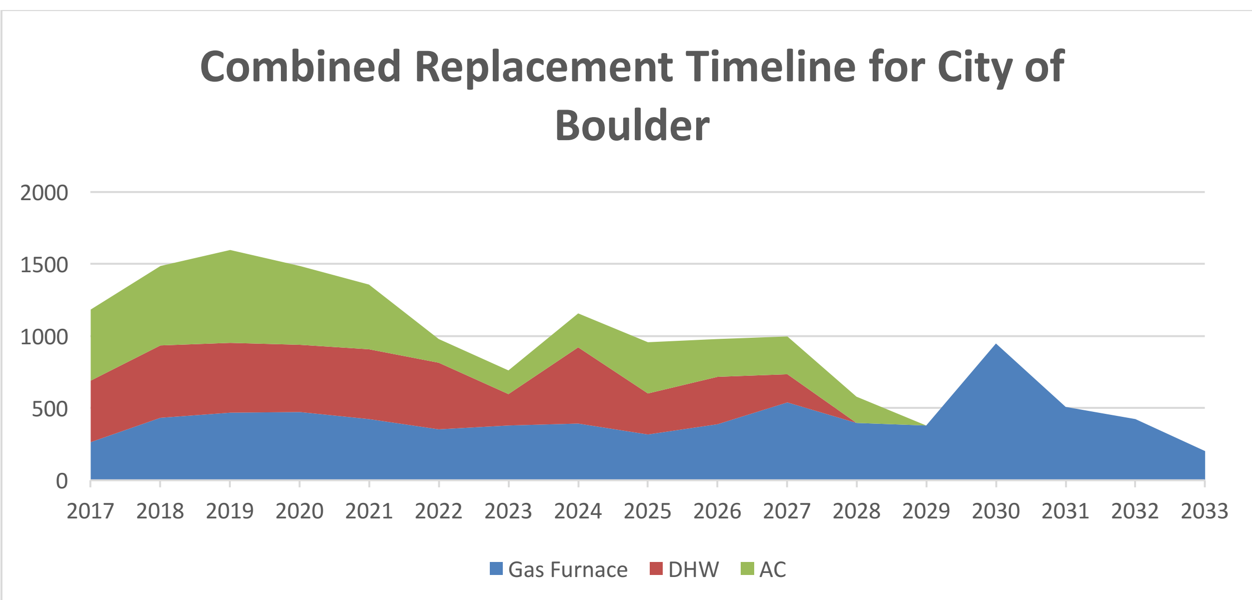


[3] The following replacement assumptions were used: furnace replacement-17 years; water heater replacement-11 years; AC replacement-12 years.



These replacement projections can then be combined into a single projection for the number of units in each category that have a high probability for replacement by year. It should be emphasized that each of these data points can be associated down to a household address to enable program managers to develop targeted outreach and support for those who are anticipated to be reaching the natural replacement timeframe for that appliance. Projected replacements for DHW and AC from years prior to 2017 were combined in consecutive years past 2017 to smooth out the targeting of those appliances.

It is also interesting to note that the large spike in anticipated installations in 2030 for Furnaces and 2024 for AC and DHW represents the many appliances that were installed following the wide spread flood damage caused by the 2013 Boulder floods.



Project Cost and Emissions Implications for Boulder RH&C Initiative

The following tables provide a summary assessment of what the overall energy and emissions reduction potential would be for full integration of an RH&C program in Boulder.

kWh	
Total for all homes	
Lowest kWh Savings	(45,287,087)
Average kWh Savings	(29,373,198)
Highest kWh Savings	(18,117,831)
Average of all homes	
Lowest kWh Savings	(5,533)
Average kWh Savings	(3,589)
Highest kWh Savings	(2,214)

Therms	
Total for all homes	
Lowest Therm Savings	5,044,013
Average Therm Savings	5,928,369
Highest Therm Savings	6,985,895
Average of all homes	
Lowest Therm Savings	616
Average Therm Savings	724
Highest Therm Savings	853

Dollars	
Total for all homes	
Lowest $$ Savings	$(1,601,000)
Average $$ Savings	$980,776
Highest $$ Savings	$3,135,140
Average of all homes	
Lowest $$ Savings	$(196)
Average $$ Savings	$120
Highest $$ Savings	$383

Carbon Savings (Metric Tons)	
Total for all homes	
Lowest Carbon Savings	(2,879)
Average Carbon Savings	12,241
Highest Carbon Savings	25,228
Average of all homes	
Lowest Carbon Savings	(0.35)
Average Carbon Savings	1.50
Highest Carbon Savings	3.08

Job Costs	
Total for all homes	
Lowest Job Costs	$100,555,934
Average Job Costs	$111,232,213
Highest Job Costs	$121,766,877
Average of all homes	
Lowest Job Cost	$12,285
Average Job Cost	$13,590
Highest Job Cost	$14,877

Constants	
Price per kWh	0.12
Price per Therm	0.76
Carbon Ton per kWh	0.000654983960
Carbon Ton per therm	0.005310000000

Policy Recommendations

The final section of this report provides overall policy recommendations for developing RH&C programs targeting the residential sector. These recommendations were provided by the Meister Consulting Group, an earlier leader in working with cities, states and the federal government on RH&C development.

Recommendations for Deploying Community Outreach Programs

Boulder has the option of designing and implementing community outreach programs alongside EnergySmart that can drive residents towards the Snugg Home platform and adopting technologies necessary to achieve whole-home gas replacement. Community procurement campaigns for renewable energy technologies have been successful around the country at increasing local technology adoption and education. In particular, the Solarize model, pioneered in Portland, OR in 2009 has been credited with driving greater solar PV procurement while providing consumers with cost reductions and leading to a greater increase in PV installations even after the conclusion of the campaign.[4] The Solarize model has been deployed across the country and has been adopted by state government and quasi-government agencies in Massachusetts, New York, and Rhode Island, where grants and resources to individual municipalities throughout these states help them design and implement their own Solarize campaigns.

The success of the Solarize model has inspired various entities to adapt the model for other renewable energy technologies. Notable examples include:

- **Solar Benefits Colorado —** (electric vehicles & PV)**.**[5] Boulder County, Adams County, and the City and County of Denver launched a joint initiative in 2015 entitled "Solar Benefits Colorado," which aimed to provide residents throughout the state with an opportunity to not only bulk purchase solar PV systems, but also to purchase Nissan LEAFs. The program offered participants an $8,349 discount (26% discount on the 2015 Nissan LEAF S) on three models of 2015 Nissan LEAFs and a flat rate of $3.50/W for residential PV systems (in addition to an incentive for a signed contract). 248 LEAFs were sold through the program, contributing to a greater than three-fold increase in sales for 2015 in Boulder County compared to 2014. Remarkably, only 28% of the participants who purchased EVs indicated that they were already considering an EV.
- **WePowr —** (renewable thermal & PV)**.**[6] With support from the Massachusetts Dept. of Energy Resources' Renewable Thermal Business Investment Financing Program, Meister Consultants Group developed WePowr, an online and technical assistance platform targeted at supporting communities in designing and implementing renewable energy purchasing campaigns. The online platform provides a one-stop shop for educational content about renewable thermal technologies, as well as a flexible, state-of-the-art web platform and light customer relations management tool that community organizers can

[4] L. Irvine, A. Sawyer, and J. Grove. (2011). The Solarize Guidebook: A community guide to collective purchasing of residential PV systems. Available at: http://www.nrel.gov/docs/fy12osti/54738.pdf

[5] M. Salisbury and W. Toor. (2016). Evaluation of Colorado Electric Vehicle Group Purchase Programs. Available at: http://www.swenergy.org/data/sites/1/media/documents/publications/documents/Colorado_EV_Group_Purchase_Programs_Mar-2016.pdf

[6] http://www.wepowr.com

customize to serve as their campaign websites. The platform was piloted for two ASHP campaigns in Massachusetts, as well as for two Solarize campaigns in Florida and Pennsylvania. WePowr will be utilized for five renewable thermal campaigns across New England in 2017.

- **HeatSmart Tompkins** (energy efficiency & renewable thermal).[7] Solar Tompkins, a community non-profit organization based in Tompkins County, NY, had previously launched a successful Solarize campaign (Solar Tompkins Program) in 2014. In 2015, Solar Tompkins launched HeatSmart Tompkins, a new initiative aimed at leveraging lessons learned from the previous year's solar program to drive adoption of energy efficiency measures and high-efficiency heat pumps for space and water heating. Homeowners in Tompkins County received free home energy assessments (funded by the NYSERDA Home Performance with ENERGY STAR program) were provided with a menu of fixed-price options for building envelope upgrades, after which they could also take advantage of fixed pricing for HPWH, ASHP, and GSHP. In total, 95 contracts were signed, including 52 building envelope-only contracts, 26 envelope upgrade + ASHP contracts, 12 envelope upgrade + GSHP contracts, and 11 envelope upgrade + HPWH contracts.

While each of the three programs were based on the Solarize model, modifications were needed to adapt the model to the different technologies and to differences in local and regional contexts. Nonetheless, these three programs have demonstrated that all of the technologies included in the bundled approach proposed by Boulder can be effectively marketed and discounted to the general public. Attempts to package technologies together have met initial success, suggesting that it may be possible for Boulder to drive consumer interest, education, and adoption of all or part of the bundled technologies through a community campaign.

If Boulder is interested in pursuing this approach, there are a number of key considerations to take into account:

- **Complexity of the offer —** One of the widely-touted positives of the Solarize model is that it aims to greatly simplify the act of going solar — often providing a single installer and a fixed based price to participants. With as many as five distinct technologies included in Boulder's bundled approach, Boulder will need to consider how best to break down and simplify what many consumers may view as a complicated process involving a number of unfamiliar technologies.
- **Contractor engagement —** With multiple technologies in Boulder's bundled approach, it will be challenging for Boulder to find contractors that can offer all of the (non-EV) technologies with discounted pricing. Multiple contractors will likely need to be engaged to ensure all technologies are adequately addressed. However, multiple contractors may dilute the possible volume savings that can be passed on to consumers and may add complexity: while HeatSmart Tompkins engaged three contractors with success, homeowners in other Solarize jurisdictions have reported difficulties in evaluating quotes from different contractors for technologies they are unfamiliar with. Additionally, HVAC and home performance contractors may be unfamiliar with the Solarize model and its goals.

[7] http://www.solartompkins.org/heatsmart-tompkins-program.html

Boulder should strongly consider significant local contractor outreach prior to selecting contractors for the program (i.e. via a competitive solicitation).

- **Campaign timing —** Most Solarize campaigns (as well as the aforementioned programs) operate on a limited-time basis in order to overcome customer inertia. However, with multiple, very different technologies and conflicting natural replacement timelines, a different approach may be needed to drive customers to adopt all or most of the technologies Boulder aims to promote. Boulder might consider designing a sequenced campaign, with the first round focusing on low-cost energy audits, followed by PV, heat pumps, and EVs in subsequent rounds.

Municipal Codes, Ordinances, and Regulations

Municipal codes, ordinances, and other regulations can serve to enable or restrict the uptake of the various technologies included in the bundled approach. For example, costs (e.g. from fees and labor) related to permitting, zoning, code enforcement, and interconnection can be passed on to consumers as soft costs. However, other regulations such as building stretch codes when paired with incentives can drive consumers towards pursuing better buildings and more efficient, renewable technologies.

This section discusses both high-level opportunities for streamlining local and utility regulations in order to reduce installation soft costs and opportunities for building on ongoing work to develop a new net zero energy building code for Boulder.

Opportunities for soft cost reduction

- **Permitting and inspection.** Adopting the bundled approach will require multiple home improvements (likely by multiple contractors) that will require filing various permits with the City of Boulder and multiple inspections by city inspectors. To date, Boulder has made numerous improvements to permitting and inspection processes for solar PV (e.g. full solar checklist posted online, fixed permitting/inspection fee for solar), though there are opportunities to continue streamlining the process — and for the bundled approach as a whole.

  Installing all of the technologies in Boulder's bundled approach could require multiple permits pulled by different contractors, some of which must be delivered by hand while others can be filed online or faxed. For example, a PV installation will require a building permit (over $400 for a $25,000 system) and an electrical permit ($69) (and potentially a roof permit prior to installation), while a $10,000 heat pump installation will require a building permit (nearly $200) and a mechanical permit (over $350). While the individual permitting costs constitute a small portion of the overall cost of the bundled upgrades, contractor labor and potential redundancy in permits and inspection can drive up the installed cost for consumers.

  There may be an opportunity for "bundling" the permitting and inspection process in conjunction with bundling the proposed upgrades in order to reduce the soft costs passed on to customers. While this would result in a reduction in associated municipal revenue from permitting fees, it would also reduce the soft costs passed on to consumers as well as the operational costs to the City through reduced inspections. Internal collaboration with the City Planning and Development Services Department, as well as an analysis of the breakdown of permitting and inspection costs and processes for pilot customers, could identify opportunities for streamlining. Alternatively, for homeowners aiming to complete all of these upgrades in pursuit of the bundled approach (or net zero energy code), the City could consider waiving or providing a full or partial rebate for permitting fees.

- **Interconnection processes.** A 2015 NREL study found that improvements could be made to Colorado's interconnection processes that would reduce the timeline for bringing PV systems online and the associated soft costs. While Colorado requires that interconnection for residential solar PV systems (<10 kW) be completed in 25 business days (10 days for completeness review and 15 days for application review), the study found that 58% of all residential interconnection applications exceed this time requirement, with a 50 business day median time to approval for these applications.[8]

  While interconnection processes are outside of the jurisdiction of the City of Boulder, there may be opportunities for Boulder to work with the Colorado Public Utilities Commission to expedite this process for residential installations. For example, the Massachusetts Dept. of Public Utilities issued Order DPU 11-75-F in 2014, which created a timeline enforcement mechanism for solar interconnection requirements. The Order established incentives for meeting timelines, as well as a penalty schedule that increased based on the degree of delay (capped at over $3 million per year for the four main distribution companies at the time).[9]

Opportunities for incentivizing compliance with net zero energy code

At the request of the City of Boulder, MCG reviewed approaches from other jurisdictions to incentivizing pursuit of net zero energy retrofits and construction specifically related to natural gas reduction. At present, there are a limited number of net zero energy building codes, incentive programs, and road map that are in development or have been adopted by various jurisdictions. Most of the programs that have been implemented do not specifically discuss or incentivize the elimination of natural gas (e.g. Oregon Energy Trust Path to Net Zero, PG&E Zero Net Energy Pilot Program).

The City of Cambridge, MA completed a 25-year action plan in 2015 for moving the city towards net zero energy. In particular, two incentive programs were proposed for further study that could dis-incentivize use of natural gas technologies:

- **Emissions-based incentives.** Similarly, to "pay for performance" incentive models, Cambridge proposed a retrofit incentive program that moves beyond flat rebates for more

[8] K. Ardani, et. al. (2015). A State-Level Comparison of Processes and Timelines for Distributed Photovoltaic Interconnection in the United States. Available at: http://www.nrel.gov/docs/fy15osti/63556.pdf.

[9] D.P.U. 11-75-F, Massachusetts Dept. of Public Utilities. (2014). Order on a Timeline Enforcement Mechanism. Available at: http://web1.env.state.ma.us/DPU/FileRoomAPI/api/Attachments/Get/?path=11-75%2fOrder.pdf

efficient/renewable technologies towards a model where the incentive amount is determined by the potential GHG emissions reduction associated with the project. In assessing the emissions reductions, a zero energy ready building (i.e. a high performance home that could achieve net zero once PV is added) could treat its heat pump system as zero emissions (once PV is added), whereas there are no opportunities for natural gas systems to achieve a similar level of reductions.

- **Market-based incentives.** Cambridge also proposed a separate incentive program that utilizes a modified permitting schedule to provides rebates based on relative building performance. When a contractor applies for a permit for a major renovation, they would need to pay a significantly higher permitting fee for the renovation. A rebate would then be provided based on the performance of the home on a highly-incremental sliding scale, with net zero/near-net zero homes receiving a large (or full) rebate and standard code buildings receiving no rebate. The sliding scale would be adjusted over time to incentivize pursuit of higher performance over time. Considerations for strongly weighting the performance score based on ability to offset emissions with on-site renewables could drive consumers towards electrification of heat instead of more-efficient natural gas systems.

Industry Engagement

In order to support the scale-up of Snugg Home and the City's overall decarbonization strategies, Boulder should consider implementing a robust industry engagement process. This engagement process should include: **(1)** working with local contractors to move beyond the historical focus on gas furnaces and towards full integration of renewable heating and cooling (RH&C) and other clean energy technologies, and **(2)** engagement of manufacturers and distributors to identify market opportunities, and mobilize public and private resources to drive adoption of RH&C and other clean energy technologies, and support the contractor engagement process. The goal of the industry engagement process would be the development of a three- to five-year action plan for scaling-up RH&C and the bundled approach to decarbonization.

This process could include the following steps:

- **Convene major HVAC manufacturers and distributors.** A facilitated meeting of national HVAC industry leaders familiar with the Boulder region could serve to discuss and assess key market opportunities and identify forward-thinking local industry leaders in the Boulder region who represent the range of local contractors and could serve as roundtable members for the larger engagement process.
- **Convene multiple local industry roundtables.** Boulder could then convene approximately 10-20 of these local industry leaders for three to four half-day, facilitated workshops. During these workshops, Boulder would engage the roundtable leaders to identify concrete actions that can be taken to build momentum for scaling up the RH&C installations and bring contractors onboard for using Snugg Home. In particular, if Boulder seeks to develop community outreach and purchasing campaigns (see 3.1.2), preliminary information about these campaign designs could be provided to and vetted by the industry leaders.

- **Develop near-to-medium term action plan.** Based on roundtable discussions, interviews with additional contractors, and surveys disseminated among the broader HVAC community, Boulder could then complete an Action Plan for driving the scale-up of RH&C and the bundled approach as a whole. This Action Plan might include: tools and training needs; key resources for enabling contractors to participate effectively in and utilize the Snugg Home tool and associated programs; financing and policy solutions for encourage adoption of technologies that are part of the bundled approach; and other high priority topics identified by the broader HVAC community.

APPENDIX A

Heating and Cooling Technology Evaluation

SPACE HEATING

The following table provides a summary of the space heating characteristics for each of the major Natural Gas replacement systems considered.

Space Heating							
Equipment	**Installed Costs**	**Operating Costs**	**Heating**	**Cooling**	**Works at Low Outside Temps**	**Requires Ductwork**	**Needs Backup**
Ductless Heat Pumps	Medium	Medium	Yes	Yes	Yes	No	Sometimes
Ground Source Heat Pumps	High	Low	Yes	Yes	Yes	Yes	No
Solar Thermal	High	Low	Yes	No	No	Sometimes	Yes
Electric Baseboard	Medium to Low	High	Yes	No	Yes	No	No

Ductless Heat Pumps (Ductless Mini Splits)

In the same way that a refrigerator works, heat pumps use electricity to move heat from a cool space to a warm space, making the cool space cooler and the warm space warmer. During the heating season, heat pumps move heat from the cool outdoors into a warm house and during the cooling season, heat pumps move heat from a cool house into the warm outdoors. Because they move heat rather than generate heat, heat pumps can provide equivalent space conditioning at as little as one quarter of the cost of operating conventional heating or cooling appliances.

Ductless heat pumps have been used for many years in nearly all parts of the United States, but until recently they have not been used in areas that experienced extended periods of subfreezing temperatures. However, in recent years, air-source heat pump technology has advanced so that it now offers a legitimate space heating alternative in colder regions. Since this analysis focuses on a cold region, we will only be looking at very high efficiency low temperature systems and primarily in the ductless mini split format.

DHP systems make good retrofit replacements for "non-ducted" heating systems, such as hydronic (hot water heat), radiant panels, and space heaters (wood, kerosene, propane). They can also replace ducted forced air systems, and some manufacturers produce combination systems that have both ducted and non-ducted distribution.

Like standard air-source heat pumps, DHPs have two main components — an outdoor compressor/condenser and an indoor air-handling unit. DHPs have no ducts, so they avoid the energy losses associated with the ductwork of central forced air systems. Duct losses can account for more than 30% of energy consumption for space conditioning, especially if the ducts are in an unconditioned space such as an attic.

DHPs, as well as their associated ducted variable speed heat pumps are the preferred choice in our analysis due to their combined installed cost and operating cost as well as the significant comfort improvements they employ including multi-zone control, variable speed fan flow, and extremely quiet operation. They also provide extremely high efficiency air conditioning with SEER ratings as high as 30.5 (the highest ratings of any air conditioning equipment available). For Boulder and Boulder County, the addition of Air Conditioning will become more desired as only 25% of homes currently have some form of air conditioning. Climate change is likely to drive a significant increase in the desire for air conditioning and therefore, these units are the perfect candidates for this addition.

In order for DHPs to be used as the primary heat source, an adjustment in sizing best practice will be necessary, as capacity is reduced at the coldest temperatures. An alternative could include sizing for 80-90% of demand hours, with conventional strip heating augmentation for the coldest hours.

A disadvantage of DHPs is that the less expensive and most efficient systems require a wall mounted box that some homeowners find unsightly. Options such as recessed heads, or an air handler replacement are available, but at increased cost and/or decreased efficiency.

Pros: Very high efficiency, multi-zone control, both heating and cooling, extremely comfortable, very quiet, no ductwork
Cons: Not as efficient at extremely low outside temperatures, aesthetics, high installed cost
Installed Costs: Medium
Operating Costs: Medium
Recommended Manufacturers: Mitsubishi, Fujitsu

Ground Source Heat Pumps

Ground source heat pumps, also referred to as Geothermal heat pumps, geo-exchange, or water-source heat pumps are similar to air source heat pumps in that they use electricity to move heat from a cool space to a warm space, making the cool space cooler and the warm space warmer. But instead of using the outside air, it uses the relatively constant temperature of the ground as the exchange medium. This allows the system to reach very high efficiencies (300% to 600%) on the coldest winter nights, compared to 175% to 250% for air-source heat pumps.

Although many parts of the country experience seasonal temperature extremes — from scorching heat in the summer to sub-zero cold in the winter—a few feet below the earth's surface the ground remains at a relatively constant temperature. Depending on latitude, ground temperatures range from 45°F (7°C) to 75°F (21°C). Like a cave, this ground temperature is warmer than the air above it during the winter and cooler than the air in the summer. The GHP takes advantage of this by exchanging heat with the earth through a ground heat exchanger.

As with any heat pump, geothermal and water-source heat pumps are able to heat, cool, and, if so equipped, supply the house with hot water. Some models of geothermal systems are available with two-speed compressors and variable fans for more comfort and energy savings. Relative to air-source heat pumps, they can be quieter, last longer, need little maintenance, and do not depend on the temperature of the outside air.

Due to their significantly higher installed cost GSHP systems would be a secondary recommendation after DHP systems. Homeowners may choose a GSHP if they are not as cost sensitive, and prefer a system that can use existing ductwork or an existing hydronic system.

Pros: Highest overall efficiency, maintains high efficiency and capacity at all outside temperatures, can provide both heating and cooling as well as water heating, very comfortable, very quiet, works with existing duct work or hydronic systems
Cons: Not easily zoned, very high installed cost, limited installer base
Installed Costs: High
Operating Costs: Low
Recommended Manufacturers: Bosch, Water Furnace, ClimateMaster

Solar thermal

Active solar heating systems use solar energy to heat a fluid — either liquid or air — and then transfer the solar heat directly to the interior space or to a storage system for later use. If the solar system cannot provide adequate space heating, an auxiliary or back-up system provides the additional heat. Liquid systems are more often used when storage is included, and are well suited for radiant heating systems, and boilers with hot water radiators. Both liquid and air systems can supplement forced air systems. Because of its prevalence in Boulder, this study focused on liquid solar thermal systems.

Solar Thermal are not recommended as an upgrade path, as systems have significant installation costs due to their complex nature, large storage tanks, pumps, and backup systems. The numerous moving parts require significant maintenance and understanding of the system, and solar thermal systems typically do not provide cooling.

Pros: Minimal electric or fuel backup required depending on size of storage system, works with hydronic systems
Cons: Performs poorly on cloudy days or with snow, heating only, high maintenance, very limited installer base, very expensive
Installed Costs: High
Operating Costs: Low
Recommended Manufacturers: Stiebel Eltron, Apricus

Electric Baseboards

Electric resistance heating is 100% energy efficient in the sense that all the incoming electric energy is converted to heat. It is typically provided in the form of electric baseboards as well as in a forced air furnace. Electric baseboard heaters are zonal heaters controlled by thermostats located within each room. Baseboard heaters contain electric heating elements encased in metal pipes. The pipes, surrounded by aluminum fins to aid heat transfer, run the length of the baseboard heater's housing, or cabinet. As air within the heater is warmed, it rises into the room, and cooler air is drawn into the bottom of the heater. Some heat is also radiated from the pipe, fins, and housing.

Electric baseboard heaters are very inexpensive if electric wiring is readily available. Costs can rise due to difficult runs for electric wiring, but for the most part, electric resistance heating is very inexpensive to install. However, it is also not very efficient in comparison to heat pumps which are 300 to 600% efficient. Electric Baseboard heat does continue to work at any outdoor air temperature and therefore is a great backup or easy addition where there are small heating loads or where an air source heat pump can't produce the necessary heat during peak heating loads.

At this time Electric Baseboard is only recommended as a supplemental heat source. As the cost of photovoltaics continues to drop, Electric Baseboards may become economical as a primary heat source.

Pros: Low to medium installed costs, multi-zone, no maintenance
Cons: High electricity use, heating only
Installed Costs: Low
Operating Costs: High
Recommended Manufacturers: Generic

WATER HEATING

The following table provides a summary of the Natural Gas replacement water heating systems considered.

Water Heating			
Equipment	**Installed Costs**	**Operating Costs**	**Needs Backup**
Heat Pump Water Heater	Medium	Medium	Sometimes
Ductless Heat Pump Sidearm Tank	Medium	Medium	No
Ground Source Heat Pump Sidearm Tank	High	Low	
Solar Thermal Water Heater	High	Low	Yes
Electric Resistance Tank	Low	High	No

Air Source Heat Pump Water Heaters (ASHP tank)

Heat pump water heaters use electricity to move heat from one place to another instead of generating heat directly. Therefore, they can be two to three times more energy efficient than conventional electric resistance water heaters. To move the heat, heat pumps work like a refrigerator in reverse.

While a refrigerator pulls heat from inside a box and dumps it into the surrounding room, a stand-alone air-source heat pump water heater pulls heat from the surrounding air and dumps it — at a higher temperature — into a tank to heat water. The most common heat pump water heaters are stand-alone systems that work as an integrated unit with a built-in water storage tank and backup electric resistance heating elements.

Heat pump water heaters require installation in locations that remain in the 40º— 90ºF (4.4º—32.2ºC) range year-round and provide at least 1,000 cubic feet (28.3 cubic meters) of air space around the water heater. Units tend to cool the space around them; cool exhaust air can be exhausted to the room or outdoors. Installation is recommended in a space with excess heat, such as a furnace room. Heat pump water heaters will not operate as efficiently in a cold space.

Pros: Fairly inexpensive, replace existing tank hot water heater, low maintenance, good lifetime, relatively low operating costs
Cons: Increases heating load in the room where its located
Installed Costs: Medium
Operating Costs: Medium
Recommended Manufacturers: Stiebel Eltron, GE

Ductless Heat Pump Sidearm Tank

Some air source heat pump manufacturers are in the process of or have already developed a system to utilize their existing outside units to work in tandem with a storage tank for domestic hot water. These units will not cool the inside of the home, but will use the heat from the outside air in the same way that they provide space heating. No pricing or efficiency numbers have been provided yet, but we expect the units to perform better than standalone air source heat pumps.

Pros: Uses outdoor air instead of cooling indoor space
Cons: Not yet available
Modeled Energy performance: Unknown
Recommended Manufacturers: Mitsubishi, Daiken

Geothermal Heat Pump Water Sidearm Tank

Some manufacturers also offer triple-function geothermal heat pump systems, which provide heating, cooling, and hot water. They use a separate heat exchanger to meet all of a household's hot water needs. Technologies such as desuperheaters were not considered in this study due to their significantly limited water heating contribution. If a geothermal system is being installed, it can be worthwhile to choose a triple function unit to cover the water heating requirement. The units are significantly more expensive, but they last a very long time.

Pros: Very high efficiency, excellent lifetime

Cons: Expensive
Installed Costs: High
Operating Costs: Low
Recommended Manufacturers: Water Furnace, ClimateMaster

Solar Thermal Water Heaters

Solar water heating systems include storage tanks and solar collectors. There are two types of solar water heating systems: active, which have circulating pumps and controls, and passive, which don't. Passive systems only work well in warm climates, so they were not considered in this study. Active solar water heaters circulate either household water through the collectors and into the home or use a non-freezing, heat-transfer fluid in combination with a heat exchanger that then heats the water that then flows into the home.

Solar thermals systems that are sized only for domestic water heating are typically much smaller than solar thermal systems for space heating. Like systems for heating, they require backup heat for extended periods of cloudy days in the winter.

Solar thermal water heating systems are not recommended due to cost, complexity and maintenance. Solar thermal system for water heating still costs around $10,000, when a heat pump water heater plus the necessary solar PV panels to cover the load would cost around $4,500 with much less maintenance.

Pros: Direct heat from the sun, very efficient
Cons: High upfront costs, backup heat required
Installed Costs: High
Operating Costs: Low
Recommended Manufacturers: Stiebel Eltron, Apricus

Electric Resistance Tank

Electric resistance water heaters are very inexpensive to purchase but are very costly to operate. They consist of a standard water tank with one or two electric elements that heat the water in the tank through electric resistance

Pros: Low upfront costs, works in all conditions
Cons: Very high operating costs
Installed Costs: Low
Operating Costs: High

OTHER RESIDENTIAL NATURAL GAS USES

Due to their very small contribution to the gas or electric consumption in a home, cooktops and dryers were not significantly modeled in our analysis.

Induction Cooktops

Induction cooking heats a cooking vessel by magnetic induction, instead of by thermal conduction from a flame, or an electrical heating element. Because inductive heating directly heats the vessel, very rapid increases in temperature can be achieved. Induction cooking provides faster heating, improved thermal efficiency, and more consistent heating than cooking by thermal conduction, with precise control similar to gas. The induction element has heating performance comparable to a gas burner, but is significantly more energy-efficient. The surface of the cooker is heated only by the pot and so does not usually reach a hazardous temperature. Because the temperature of the cooking surface matches that of the pot, this permits precise control of the cooking temperature. The control system shuts down the element if a pot is not present or not large enough. Induction cookers are easy to clean because the cooking surface is flat and smooth and does not get hot enough to make spilled food burn and stick.

Induction cooktops are not necessarily more efficient than modern smooth top electric resistance units, but are definitely more efficient than gas units. Induction units are nearly 3 times the cost of electric cooktops, but are preferred by homeowners because of their incredible accuracy, speed, and consistency of heating. Induction cooktops are now commonly replacing gas cooktops in the most high-end homes, and as the prices fall, more average consumers are making the switch. For consumers who aren't as picky about their cooking appliance, flat top electric resistance cooktops are still a great choice.

Pros: More efficient than gas or electric resistance cooktops
Cons: Higher cost than electric resistance and many gas systems, but cheaper than many high-end gas systems
Installed Costs: Medium to High
Operating Costs: Low
Recommended Manufacturers: Bosch

Heat pump dryers

A closed-cycle heat pump clothes dryer uses a heat pump to dehumidify the processing air. Such dryers typically use less than half the energy per load of a condenser dryer. Whereas condensation dryers use a passive heat exchanger cooled by ambient air, these dryers use a heat pump. The hot, humid air from the tumbler is passed through a heat pump where the cold side condenses the water vapor into either a drain pipe or a collection tank and the hot side reheats the air afterwards for re-use. In this way not only does the dryer avoid the need for ducting, but it also conserves much of its heat within the dryer instead of exhausting it into the surroundings. Heat pump dryers can therefore use up to 50% less energy required by either condensation or traditional dryers. Domestic heat pump dryers are designed to work in typical ambient temperatures from 5 to 30 °C. Below 5 °C, drying times significantly increase.

As with condensation dryers, the heat exchanger will not dry the internal air to as low a level of humidity as the typical ambient air. With respect to ambient air, the higher humidity of the air used to dry the clothes has the effect of increasing drying times; however, because heat pump dryers conserve much of the heat of the air they use, the already-hot air can be cycled more quickly, possibly leading to shorter drying times than traditional dryers, depending on the model.

Pros: No dryer ducting necessary, safer than gas or electric dryers
Cons: Higher upfront costs
Installed Costs: High
Operating Costs: Low
Recommended Manufacturers: Bosch

**** Primary Data Source: http://energy.gov/energysaver/energy-saver*

APPENDIX B

Energy modeling Comparing Natural Gas to Renewable Heating & Cooling Alternatives

SUSTAINABLY BUILT
Green Building Consultants

Report Date: August 30th, 2016

Renewable Heating & Cooling Replacement Technology Assessment

The objectives of this analysis were the following:

- Create 5 home profiles (case studies) that are a good representation of the various housing stock in the City of Boulder.
- Build a detailed hourly energy model of each of these home profiles.
- Perform a detailed analysis of the energy consumption of the existing homes and to determine the best types of technology replacements for each scenario.
- Assess the types of fossil fuel free equipment that are the best replacements for existing technologies.

Key Terms/Abbreviations

ASHP tank — Air source heat pump tank hot water heater

DHP — Ductless Heat Pump heating/cooling systems, commonly referred to as minisplits

DHW — Domestic hot water, used for showers, dishwasher, etc.

GSHP — Ground Source Heat Pump heating/cooling system

HSPF — Heating Seasonal Performance Factor — a measure of the efficiency of air source heat pumps.

NREL — National Renewable Energy Lab

Modeling Assumptions

All modeling was performed with BEopt v.2.6.0.1 from the National Renewable Energy Lab (NREL). Weather was based on the Boulder Table Mountain EPW TMY3 data.

Annualized Energy Related Costs

Most graphs in this report are based on the Annualized Energy Related Costs. This is calculated by first totaling the cost of energy related costs for the home, including utility bills, equipment replacement costs, loan payments, etc. over the 30 year analysis period. The present worth of that total cost is calculated, and that is annualized using the specified discount rate, in this case, 3.0%.

Financial Modeling

All modeling runs are based on a 30 year analysis period with a 2.4% inflation rate and a 3% discount rate. Improvements are financed at 6% for 10 years. This financing is based on commonly available loans for home improvements in the City of Boulder. As financing for solar photovoltaics (PV) or improvements as part of an energy efficiency program often have better financing terms, this rate is conservative.

Utility Costs

Utilities are based on average state of Colorado rates, from the Department of Energy's Energy Information Administration. Electricity is currently \$0.1071/kWh marginal, \$0.1218/kWh average. Natural gas is currently \$0.6472/therm marginal, \$0.76/therm average. These rates are used for all models except where explicitly changed as part of the analysis.

Photovoltaic costs

Solar photovoltaics are priced at approximately \$3/Watt, installed cost. Recent Boulder County programs have had installation costs of less than \$2.80/Watt, but installations not in the program can be somewhat higher.

Rebates and Tax Credits

No rebates were incorporated into this analysis. Because of the uncertainty of the tax credits for GSHPs, set to expire at the end of 2016, no tax credits were incorporated for GSHP systems. However, the 30% Federal Tax credit for solar PV remains and was applied to all PV modeling.

Ductless Heat Pump technology

DHP (ductless heat pump) systems are assumed to be "cold climate" models that can operate at temperatures as low as -13°F. As such, they are assumed to supply 100% of a home's heating load. It is acknowledged that because of a reduction of capacity at these low temperatures an adjustment to the way systems are sized would be required. The Heating Seasonal Performance Factor (HSPF) of 11.2 is based on a Mitsubishi Mr. Slim Hyperheat (i.e. "cold climate") model. The system was designed as a reasonable approximation of what would be installed in the 2,700 square foot home modeled, including number of indoor units, length of linesets, etc. From this design, the HSPF was calculated. Because these cold climate systems are relatively new, real world testing of the true efficiency would be a valuable area of further study.

Home Selection Process

Five homes were selected to represent as many homes as possible in the City of Boulder and Boulder County, as shown in Table 1. The home sizes and other attributes were chosen to approximately mirror the distribution of homes in the area. Real homes were chosen from assessor's records, which were narrowed down by filtering according to size and attributes. For instance, crawlspaces are predominantly seen in houses less than 2,500 sq. ft., and in the overwhelming majority of houses less than 1,500 sq. ft. So, the home chosen to represent the range up to 1,499 sq. ft. was a home with a crawlspace.

Table 2 - Five suggested homes

Home Size	# Stories	Below grade	Fuel
950 sq. ft.	1	Crawlspace	natural gas
2000 sq. ft.	1	Basement	natural gas
2700 sq. ft.	2	Basement	natural gas
3470 sq. ft.	2	Basement/Crawlspace	natural gas
4493 sq. ft.	2	Basement	natural gas

Extensive modeling was performed on each of the homes described above. In addition to assessor's records, images were used from Google Maps to approximate the dimensions of the home. Because of limitations of computing power, individual attributes, such as attics, basements, and mechanical (heating and cooling) systems were modeled separately to determine the best recommendation for that attribute. Once the thermal envelope recommendations were determined, these were held constant for the analysis of the heating system recommendations. Again this optimizes the use of limited computing power, but also making all reasonable improvements to the thermal envelope before improving the heating system fits with best practices in energy efficiency improvements.

Table 2 describes the recommended upgrades for the thermal envelope and for the domestic hot water. These recommendations agree with the typical recommendations an experienced auditor would make, but have been confirmed with modeling. The detailed results are presented in Appendix A: Energy Efficiency Upgrade Recommendation Analysis.

Table 3 - Recommended upgrades

Measure	Recommendation
Wall insulation	If insulation is present, do not upgrade. If wall cavity is not insulated, fill wall cavity with cellulose.
Ceiling insulation	If less than R-38, increase to R-50
Windows	If double paned, metal frame, or worse, upgrade to Low-e, non-metal frame
Basement/Crawl	If uninsulated, upgrade to R-10 minimum
Air sealing	Decrease building air leakage to 7 ACH50
Domestic Hot Water	50 gallon, ASHP tank, no solar thermal

Most of the simulations on the following pages reference the "existing home", but it is assumed that for the "existing home" the recommendations in Table 2 have been applied except for the measure being simulated. So, when performing the modeling for the window replacement measure, it is assumed that the basement is an R-10, air leakage is 7 ACH50, etc. Further, the heating system is assumed to be a high efficiency furnace.

As mentioned, the recommendations in Table 2 are in line with best practices for energy efficiency recommendations. The assumption of implementation of these recommendations simplifies the analysis of replacement technology for natural gas heating, which is the thrust of the rest of this analysis.

Extensive modeling was performed on all homes in Table 1. This includes analysis of all thermal envelope improvements, hot water systems, and initial analysis of heating systems. Because the modeling results and trends (and the conclusions that would be drawn from the results) were very similar for all home sizes, further modeling was only done on the 2,700 sq. ft. home for simplicity and time efficacy, as well as for simplification in presenting results.

Limitations

Several limitations of the study were identified, many of which point to possible further study.

Costs

Costs were especially difficult because they have a large impact on the results, but can be extremely difficult to determine because of the wide range of attributes seen in existing homes across decades, the variability in quality and the quantity of replacement options, and the unknown variable of homeowner preference. The costs used were based on a combination of NREL’s cost data (in BEopt libraries), anecdotal installation quotes from contractors in the City of Boulder, and the project team’s general experience with local costs. The significant variation in quoted costs from installers is another indication of the relatively immature nature of this market sector at this time.

Performance

Some studies have suggested the real world efficiencies of both GSHP and DHP systems are lower than the rated efficiencies. For DHPs, these studies often analyze older models that only operate at 5°F and above. Real world studies of newer models with lower operating temperatures could help refine the results of this study. Further analysis of the sensitivity of the results of this study in relation to the efficiency of both GSHP and DHPs could broaden the applicability of this study.

Existing Homes

As mentioned in “Costs” above, Boulder building stock has a considerable amount of variation, as do most municipalities in the U.S. This variation creates a challenge when establishing best-practice recommendations. Additionally, because most existing homes were not designed with photovoltaic systems in mind, roof space may not be adequate for the size PV system needed. However, even with the high use of coal for Colorado’s electricity generation, switching to heat pump based electric heating while relying on grid electricity still reduces the carbon footprint of a home.

Modeling Analysis

Domestic Hot Water (DHW)

Domestic Hot water systems were modeled independent of mechanical system and thermal envelope considerations because changes to the DHW system will have little impact on the overall model, and stronger conclusions can be drawn when variables are minimized.

Table 3 shows that electric resistance tanks are a poor investment and were not considered as a recommendation. The air-source heat pump tank option, at cost parity with the standard gas heater, is the main recommendation. While a solar thermal system would increase energy savings for approximately $200/yr, the added complexity of a system, and its attendant maintenance over the life of the system, is likely to make it an unattractive option to homeowners.

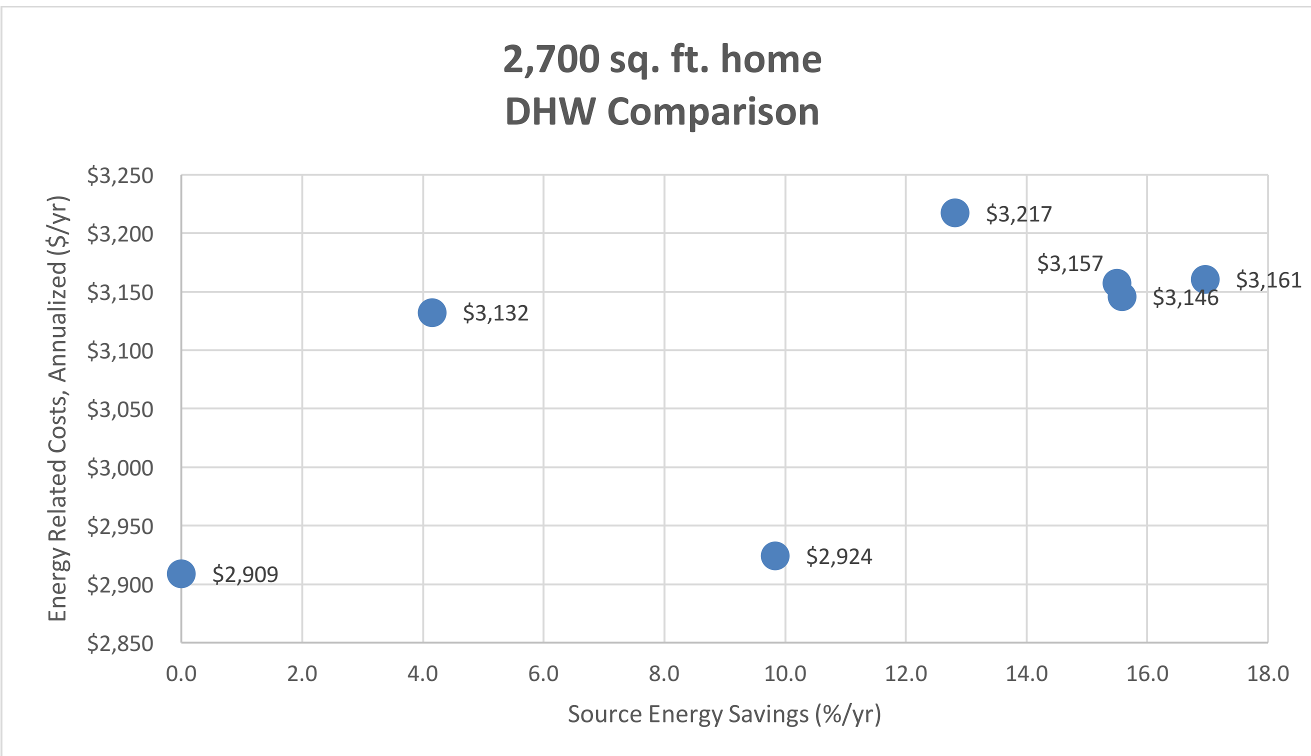


Table 4 — Analysis of DHW options

Graph Pt	DHW	EF	Solar Thermal collector size	Notes
$2,909	Standard gas tank	0.59	None	Existing
$3,132	Electric resistance tank	0.96	None	
$2,924	ASHP tank	3.3	None	
$3,217	Electric resistance tank	0.96	40 sq. ft.	
$3,157	Electric resistance tank	0.96	64 sq. ft.	
$3,146	ASHP tank	3.3	40 sq. ft.	
$3,161	ASHP tank	3.3	64 sq. ft.	

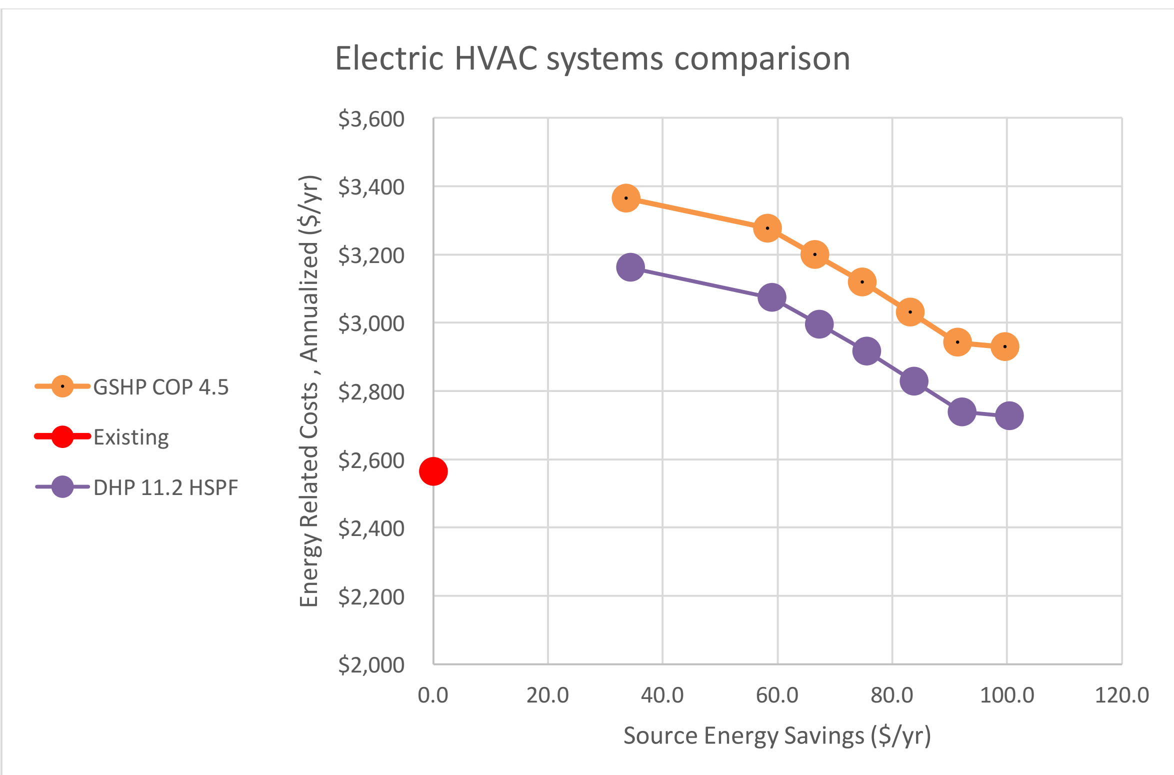
Heating/Cooling Systems Replacement Technology Assessment

The modeling for mechanical systems assumes that all energy efficiency recommendations have been applied to the thermal envelope and the hot water heating system. Electric baseboard heat was eliminated as an option in the early stages of modeling due to its high operating cost. Due to idiosyncrasies present in BEopt, an individual graph of these results was not produced.

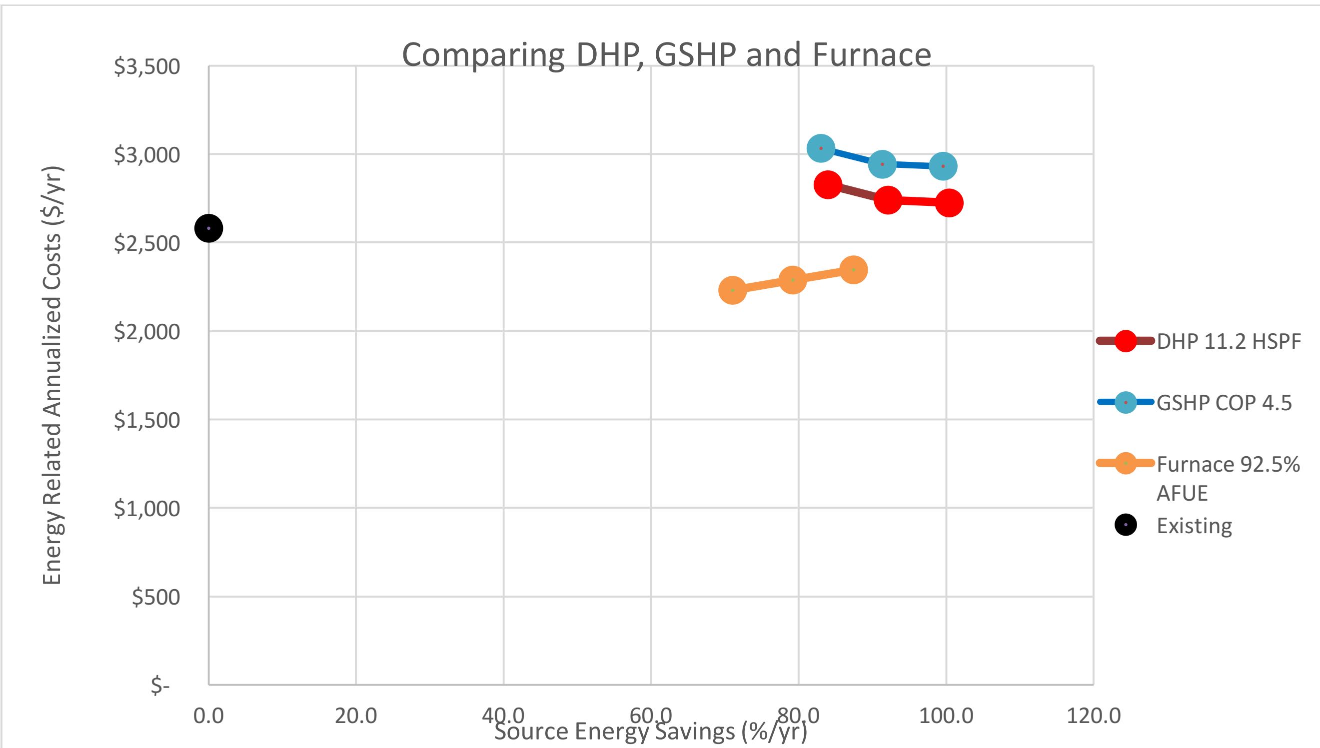
Mechanical Systems Comparisons (with and without PV)

A comparison of DHP and GSHP systems in the graph below shows that the annualized cost of a DHP system is somewhat less than a GSHP system. This annual cost is not so significant as to eliminate GSHP systems from consideration, however. For larger homes, homes with existing duct systems, and homeowners who don't like the aesthetics of DHP systems, a GSHP system may be more desirable. The Existing HVAC system shown in this example is an 80 AFUE furnace and 13 SEER air conditioner that is replaced with the same 80 AFUE furnace and 13 SEER air conditioner over the 30 year analysis period.

For both GSHP and DHP systems, installing PV until the home reaches net-zero energy results in a lower annualized cost.

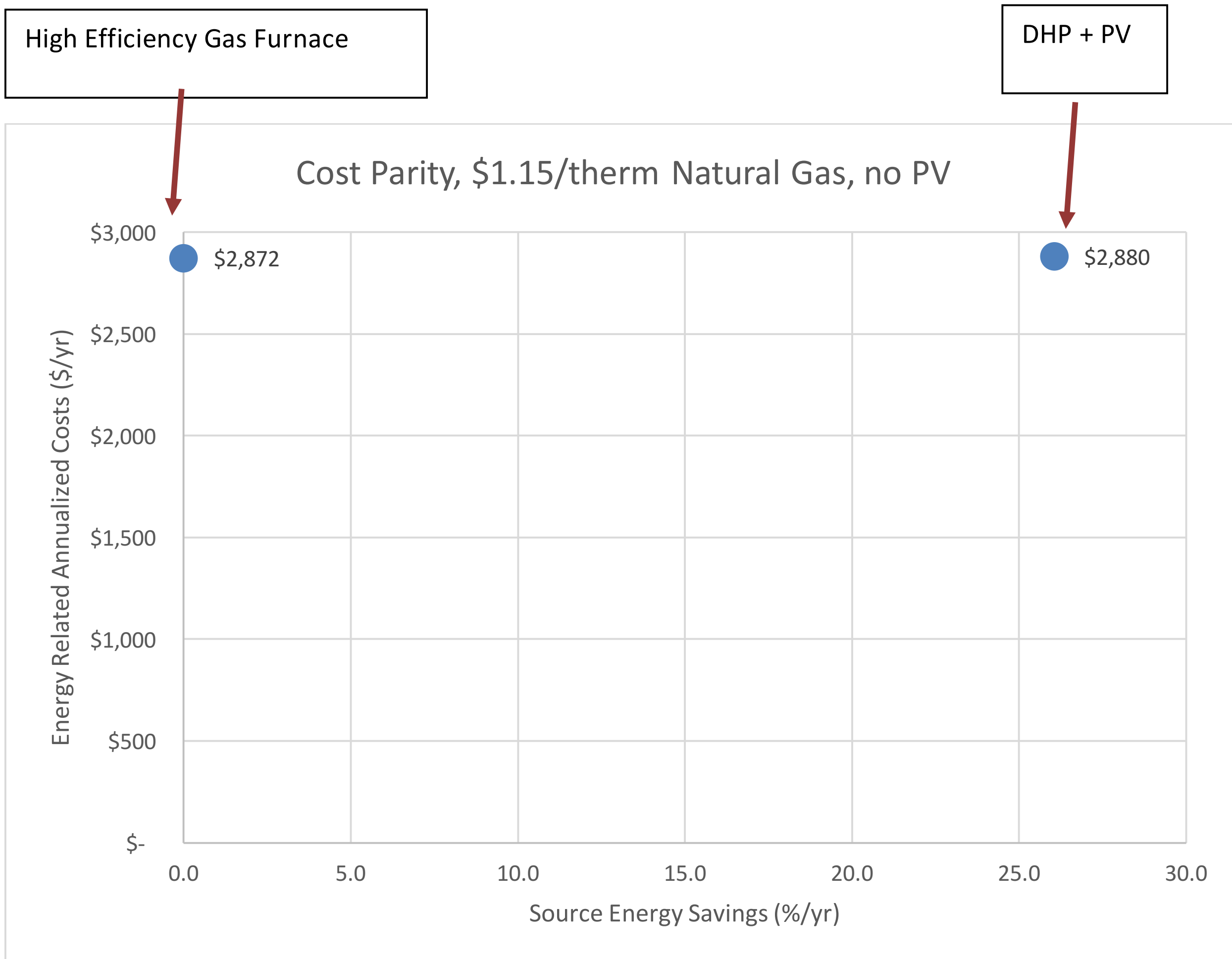


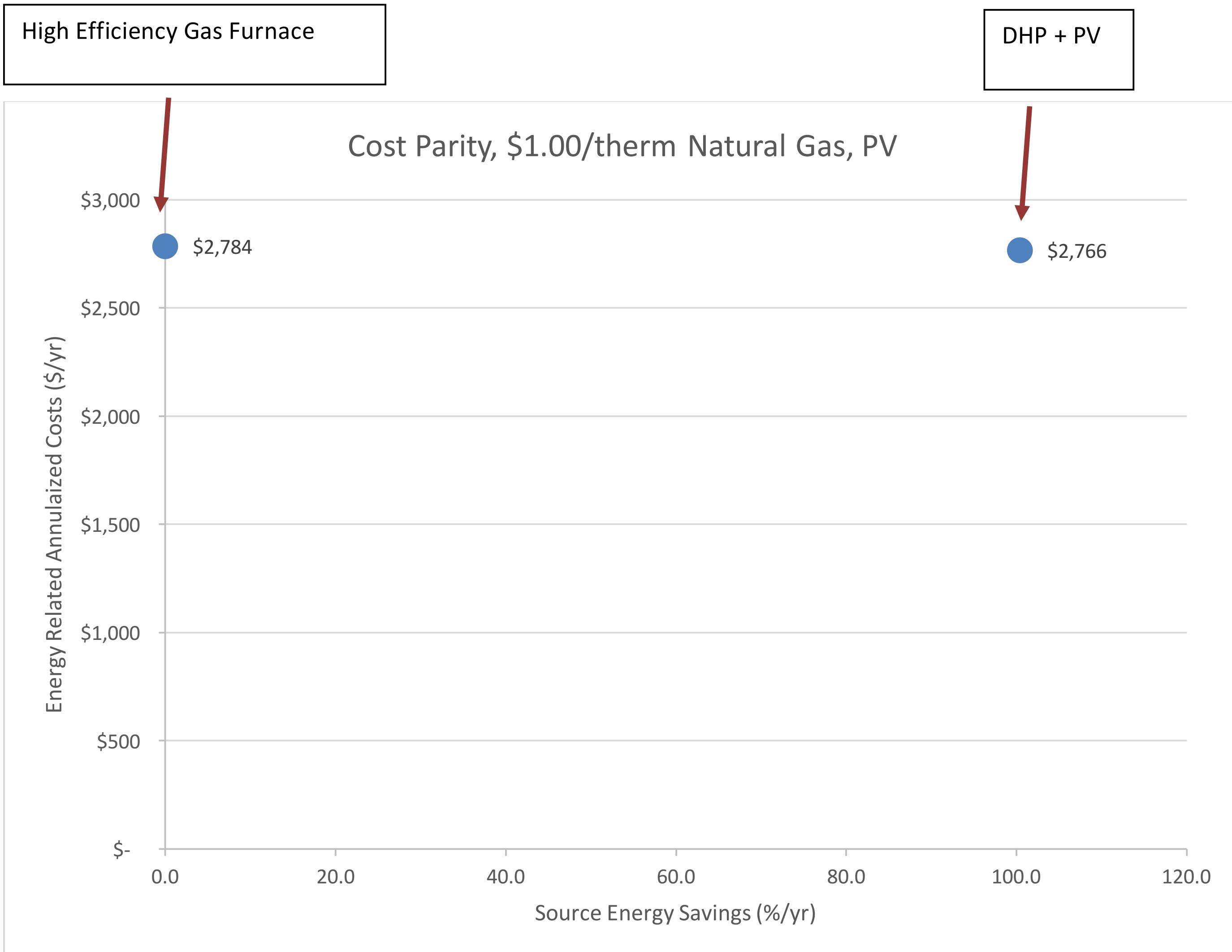
In the graph below, the high-efficiency furnace scenario was added with the same size PV systems (6 kW, 7 kW, and 8 kW, from left to right) as the DHP and GSHP. Because at a source energy savings of 63% all of the home's electricity (non space heating energy) has been offset by PV for the furnace scenario (as calculated in the "Simple Payback" section below), further addition of PV results in an increased annualized cost. The right-most points (with 8kW) are net-zero for the DHP and GSHP, but the furnace scenario has only reduced its source energy by 87%. In order to get to "net-zero" (on a Btu offset basis, since natural gas is burned by the furnace), significantly more PV would need to be added to the furnace scenario.



Annualized Cost Parity

As can be seen in the graph above, the annualized cost increase to upgrade to DHP and PV from a high efficiency furnace is approximately $400/year (though only $150/yr more than the existing system, and results in a net zero home). This is largely due to current, unusually low natural gas prices. Annualized cost parity is the cost of natural gas ($/therm) at which the annualized cost of the DHP scenario and the Furnace scenario are equal. At this natural gas cost, investment in a DHP system is viable, regardless of other goals such as decarbonization. For a home that doesn't invest in PV, but upgrades to a high-efficiency furnace, the parity with a DHP occurs at $1.15/therm, and results in a 26% reduction in energy by installing the DHP. It's significant to note that when PV is added to the DHP scenario (resulting in a net-zero home), but not added to the furnace scenario, the parity occurs at $1.00/therm, and results in a net zero home for the same cost as a standard home with only a high-efficiency furnace.


High Efficiency Gas Furnace
DHP + PV
Cost Parity, $1.15/therm Natural Gas, no PV
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$-
Energy Related Annualized Costs ($/yr)
$2,872
$2,880
0.0
5.0
10.0
15.0
20.0
25.0
30.0
Source Energy Savings (%/yr)

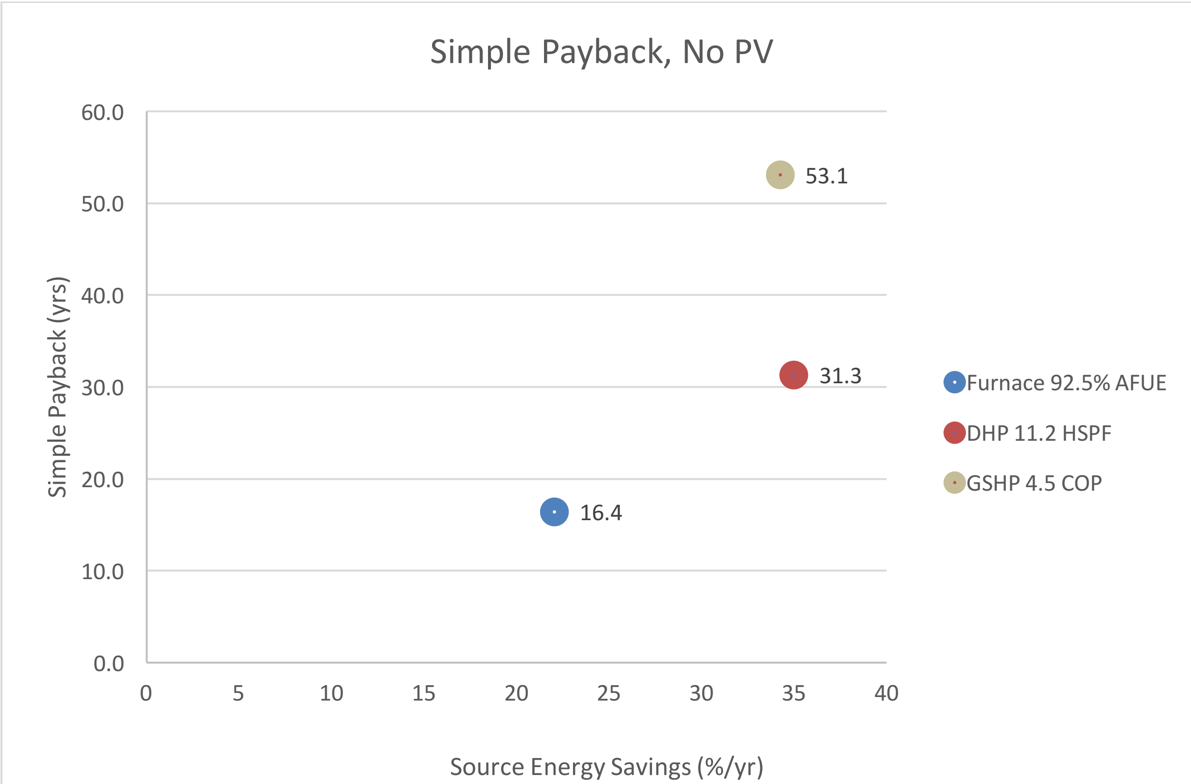


Simple Payback

The simple payback of three systems was analyzed for the 2,700 square foot home, including a high efficiency furnace, a ductless heat pump, and a ground source heat pump. The baseline for comparison is a home with an existing, 20 year old, 78% AFUE furnace and 13 SEER central air conditioner. To accurately model the differences in the heating systems, the baseline model assumes that all improvements recommended in Table 2 have been implemented.

Because the baseline furnace is assumed to be 20 years old, it requires immediate replacement. The analysis conservatively assumes replacement with a 92.5% AFUE furnace, even though less efficient (~80% AFUE) furnaces are commonly available and often installed.

While simple payback for a DHP system without PV appears to be a lengthy 31.3 years (and the GSHP 53.1 years), using the high efficiency furnace as a baseline, the payback for the high efficiency furnace (16.4 years) needs to be subtracted to get the relative value. Therefore, the DHP investment, as an incremental cost, has a payback of approximately 15 years, and the GSHP has a payback of a still lengthy 37 years.



Because the addition of photovoltaics to offset electricity is cost effective, with photovoltaics the differential payback for the DHP system is reduced to four years, while the GSHP is reduced to approximately 11 years. In this analysis, photovoltaics are applied to offset electric usage. For the DHP and GSHP, 8 kW of PV is applied to achieve net-zero. In the case of the furnace, in order to keep all things equal, 5kW of PV offsets the electric loads (including appliances, air conditioning, etc) resulting in a 63% reduction in source energy (including the natural gas savings from the more efficient furnace).

It is important to underscore the significance of the PV factor. At current installed costs, the 20 year amortized cost of electricity for a PV system is approx. $.07/kwh. The models above assume that the PV system essentially pays for itself over this period—there is no added cost to the installed cost of a zero-carbon heating system other than the initial "first cost" of the DHP or GSHP systems.

It is also important to note that this simple payback analysis is based on the current cost of natural gas, a cost many view as artificially low and likely to increase significantly during the next decade. As the cost parity analysis above demonstrates, natural gas would only need to reach a $1/therm level for these systems to be comparable in price. Natural gas continues to be one of the most volatile commodities traded. Local natural gas prices have been more than double the current price as recently as 2010.

Consequently, the current four year simple payback differential between a high efficiency gas furnace and a DHP could be significantly reduce—or reversed (the high efficiency gas furnace may become more expensive on an annualized basis) if natural gas prices increase above the current price parity level of $1/therm.

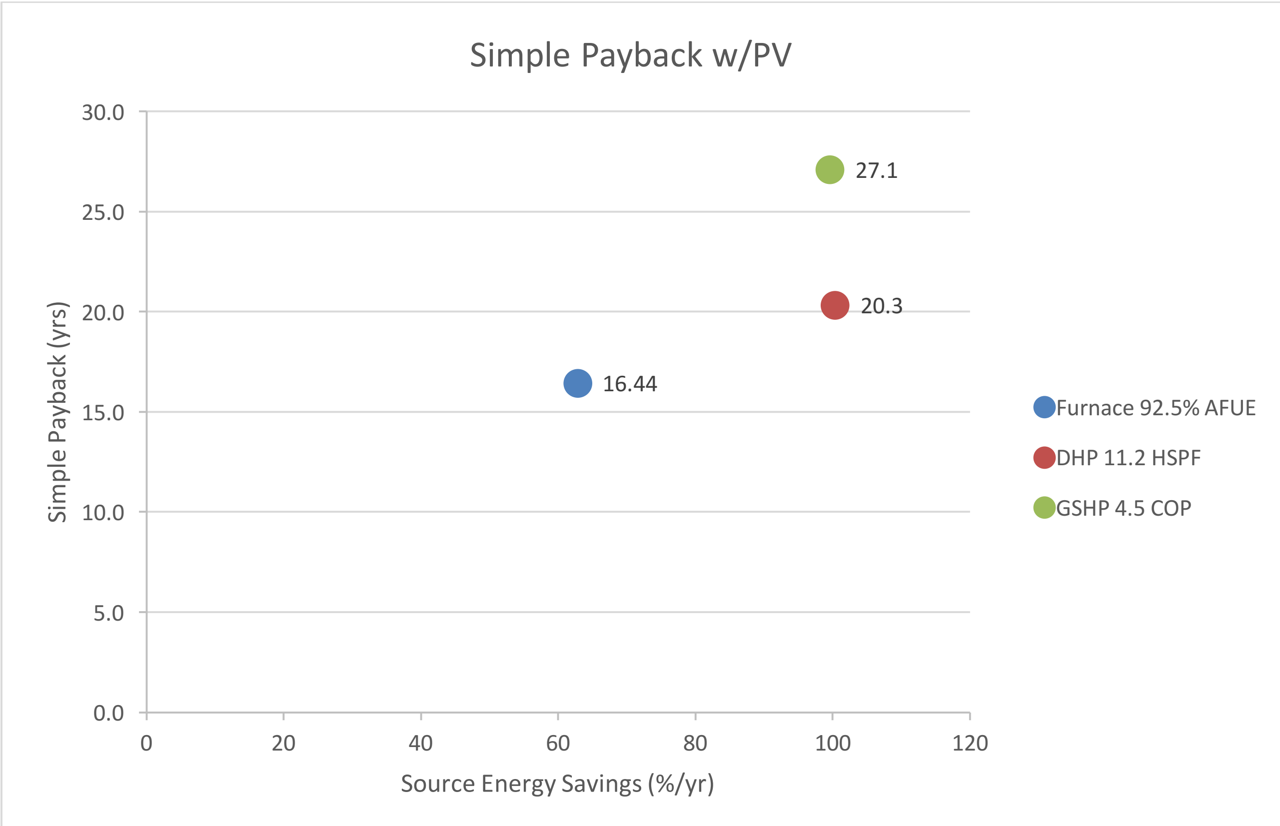


Table 5 — Heating System Costs

Heating/Cooling system	Installed cost
92.5% AFUE Furnace/14 SEER Air conditioner	$5,935
11.2 HSPF/23 SEER DHP	$18,030
4.5 COP/20 EER GSHP	$29,376

It should be noted that there are several significant points that make this a worst-case scenario:

- The cost of the DHP and GSHP systems is likely high. Because of the difficulty of generalizing cost of replacement systems across many different styles and constructions of existing homes, a high cost was assumed.
- The cost of the furnace assumes existing ducts, but doesn't include costs for optimizing that duct system, including sealing, repair, or even replacement of under-performing duct runs, where possible.
- A cost for carbon has not been assigned, which would reduce the additional 4 year payback for the DHP, perhaps even reversing it in favor of the DHP.

Modeling Conclusions

Cost Comparison — Currently, both Ductless Heat Pump and Ground Source Heat Pump systems are significantly more expensive than the furnaces they seek to replace. When energy cost and use of photovoltaics are considered, the payback for a net-zero home with a zero annual carbon footprint (excluding embodied carbon) is reduced to as little as 4 years.

The role of local generation — It is important to underscore the significance of the PV factor. At current installed costs, the 20 year amortized cost of electricity for a PV system is approx. $.07/kwh. The models above assume that the PV system essentially pays for itself over this period—there is no added cost to the installed cost of a zero-carbon heating system other than the initial "first cost" of the DHP or GSHP systems.

The role of natural gas prices — The simple payback analysis shown above is based on the current cost of natural gas, a cost many view as artificially low and likely to increase significantly during the next decade. As the cost parity analysis above demonstrates, natural gas would only need to reach a $1/therm level for these systems to be comparable in price. Natural gas continues to be one of the most volatile commodities traded. Local natural gas prices have been more than double the current price as recently as 2010. Consequently, the current four year simple payback differential between a high efficiency gas furnace and a DHP could be significantly reduce—or reversed (the high efficiency gas furnace may become more expensive on an annualized basis) if natural gas prices increase above the current price parity level of $1/therm.

Current "first cost" differences — The current prices of heat pump heating and cooling systems are in the context of a relatively new and immature market sector. The relatively limited number of local providers and wide variation of quoted prices for similar systems underscores this dynamic. As this sector matures and economies of scale reduce manufacturing and other related "hard costs", we would expect to see the price differentials between mature fossil-fuel based systems and emerging heat pump based systems to be significantly reduced.

Other considerations

As we investigate the conversion of fossil fuel based thermal systems to renewable ones, there are many non-cost related benefits to this conversion.

Interior Air Quality and Safety — Combustion appliances require careful venting of the carbon monoxide and other gasses that are released from the burning of the fuels. In order to vent properly, most of these systems require outside combustion air to be vented into the space. This further increases the heating requirements of the system making it much less efficient. Electric based and renewable systems have zero combustion requirements and keep the home free of major contaminants.

Ability to utilize zero carbon energy — All-electric based systems can be powered by rooftop solar or a 100% renewable energy grid for carbon emission free heating. Also, many electric based systems offer zone control which allows different rooms of the home to be kept at different temperatures.

Integrated cooling capacity — The significant projected increases in local summer temperatures over the next 15-30 years will drive many households that currently do not have air conditioning or have insufficient air conditioning to install some sort of AC system. Without economically viable alternatives, many of these homes will install inefficient AC window units. The cooling capacity of heat pump units can significantly reduce this phenomena, saving both energy and the associated emissions impacts.

Areas of further study

Many of the above results suggest important areas of further study that were beyond the scope of this analysis.

Cost sensitivity — Due to the challenges in generalizing costs for retrofit installation of DHP and GSHP systems, modeling a range of costs for a specified system would help determine the sensitivity of the analysis to cost, and might suggest scenarios that are better or worse for replacement. It would also provide important information for rebate programs, and would inform the industry of the price point that would be needed for market transformation.
In addition to modeling sensitivity, working with industry stakeholders to refine cost estimating methods would greatly improve the results of the modeling.

Efficiency sensitivity — Similar to a cost sensitivity analysis, an efficiency sensitivity analysis could broaden the available systems that would be considered as viable replacements. For instance, air-to-water heat pumps are rare, with some manufacturers having left the US market due to lack of demand. These units also tend to be less efficient than their DHP counterparts, but they could be excellent options for homes with hydronic baseboard and radiant in-floor heating.

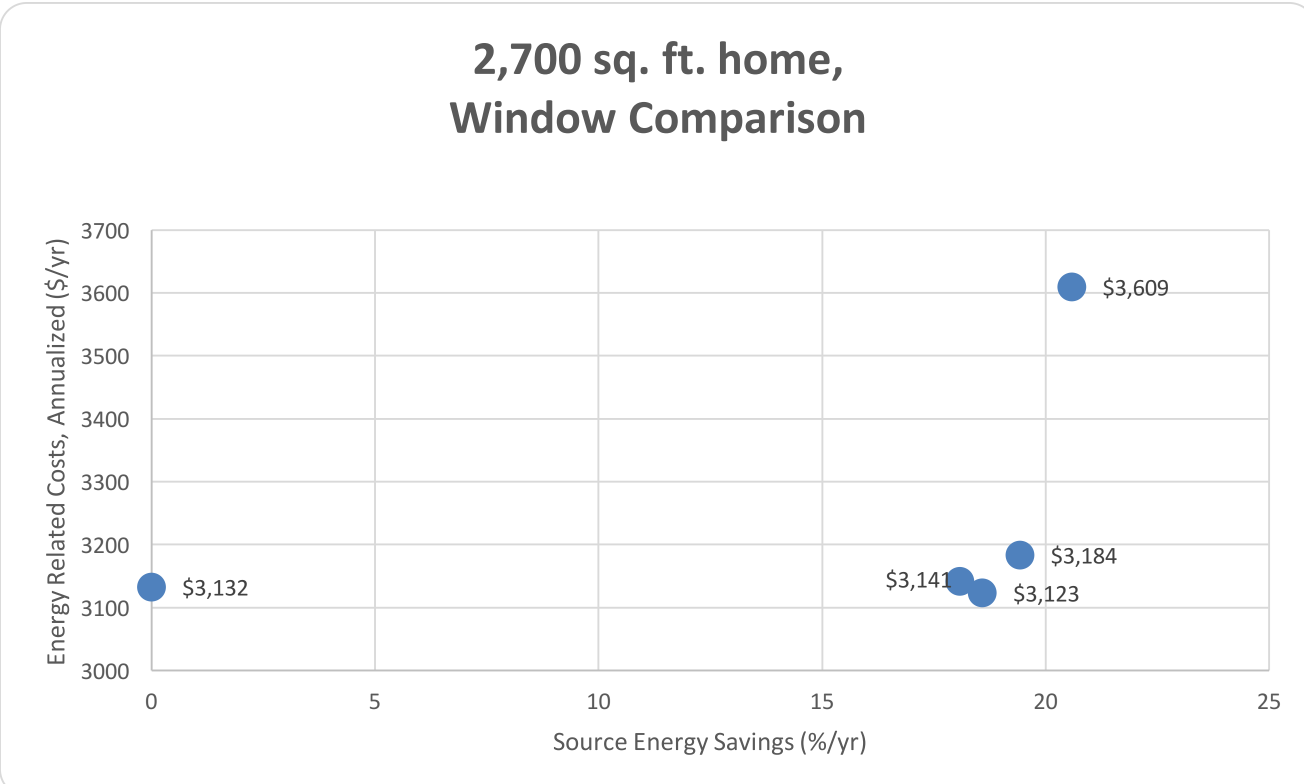
Financing sensitivity — Because of the plethora of financing options available, further analysis of the impact of different scenarios would help local governments, utilities, manufacturers and financing providers offer products to incentivize market transformation. Creating packages of financing options would also increase likelihood of homeowner adoption, as they could choose the package that works best for their home and financial situation.

Geographic expansion — This analysis is tailored to the Boulder area, using local weather data , construction costs, natural gas and electricity pricing. Further study in different markets, with appropriate weather data and costs would show the viability of expanding market transformation beyond Colorado.

Attachment to Energy Modeling Report

Energy Efficiency Upgrade Recommendation Analysis

The following is a summary of the modeling done to arrive at the recommendations for the thermal envelope components summarized in Table 1 under "Modeling Assumptions".



Windows

Table A1 — Window analysis

Energy Related Costs, Annualized	Window U-value	Window SHGC	Notes
$3,132	0.76	0.67	Existing
$3,141	0.29	0.31	Low-e, low SHGC windows
$3,123	0.3	0.46	Low-e, high SHGC windows
$3,184	.27	0.46	Low-e, argon fill, high SHGC windows
$3,609	0.17	0.27	Premium windows, triple-paned, argon filled

Several windows were modeled, ranging from off-the-shelf systems, to high end custom tripe-paned windows. A variety of U-values and SHGCs were modeled, and the analysis shows that U-value is more important to performance than SHGC (with the caveat that this home did not have good passive solar design).

Based on this analysis, window replacement is recommended for metal framed windows (Table A1). Given cost parity for the upgrade, the comfort and operability improvements would be well worth the upgrade. Further study could include a consideration of frame materials in the cost. The chosen windows are "non-metal" frame (from the NREL database) and is likely an average of wood and vinyl. Vinyl windows don't have the longevity of other frame materials, and could result in leaky, difficult to operate windows within a few years.

Basement Insulation

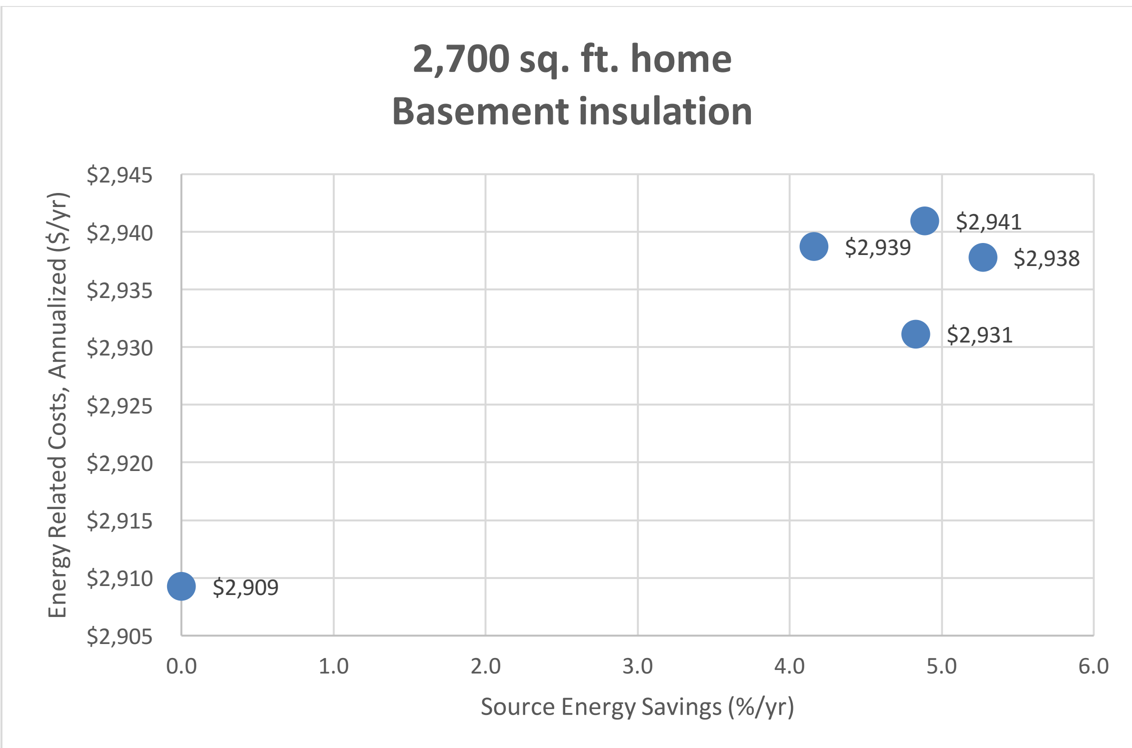


Table 6 - Basement insulation options

Graph Pt	Basement Wall insulation	R-value	Notes
$2,909	Uninsulated	0	Existing
$2,939	Whole wall, 2" XPS	R-10	
$2,941	Whole wall, 3" XPS	R-15	
$2,931	2x4 Cavity, Fiberglass	R-13	
$2,938	2x6 Cavity, Fiberglass	R-19	

All the options for basement insulation (Table 5) are equivalent in price, and only vary in energy savings by about 1%, resulting in a recommendation of a minimum of R-10. Beyond that recommendation, choice of type and amount of insulation will likely be dictated by homeowner preference and the opportunities/challenges of the particular home.

Air Sealing

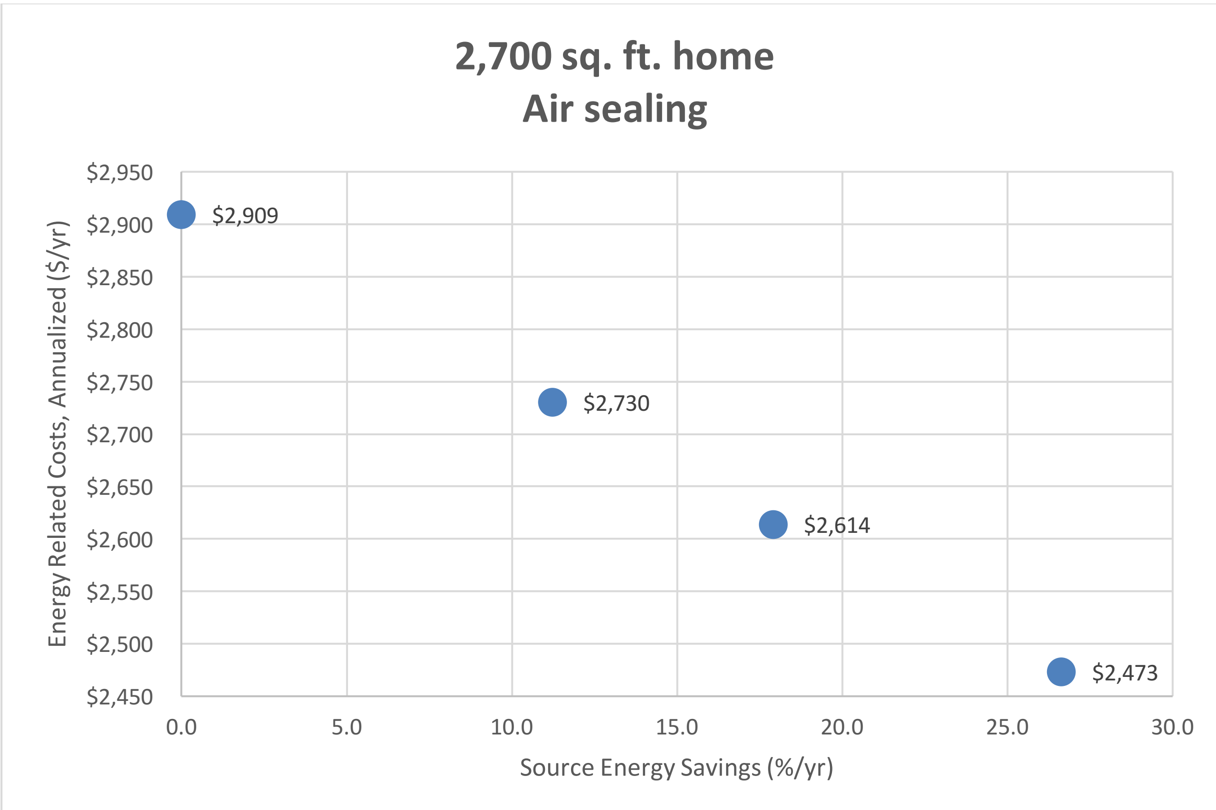


Table 7 - Air sealing cost analysis

Graph Pt.	Air leakage	Notes
$2,909	15 ACH50	Existing
$2,730	10 ACH50	
$2,614	7 ACH50	
$2,473	3 ACH50	

Based on NREL's air sealing costs, it's always prudent to invest more in air sealing (Table 6). The reality is that for many houses it's likely difficult to achieve significantly better than 7 ACH50, and if a home achieves significantly better than 7 ACH50, mechanical ventilation would likely be required.

Walls and Ceilings

Because the walls on all homes modeled had insulation present, increased insulation levels were not modeled. For homes built before 1980 with R-11 or less in the walls, it is possible to increase insulation levels to an R-13, but this process is often expensive. Because of this wall cavity insulation is generally recommended only when the cavity is uninsulated. Another possibility for improvement of wall insulation is the addition of rigid insulation when the siding is replaced.

The ceiling in the 2,700 square foot house is a vaulted ceiling, with an assumed R-19 batt insulation. The most cost effective improvement would be to install rigid insulation at time of roof replacement. For homes with attic insulation, the models show that if the insulation level is below R-38, improvement to R-50 is the most cost effective option.