CITY OF BOULDER

Renewable Heating and Cooling in Boulder: Strategies for Electrification of Residential Heating & Cooling

Project Funded by USDN, CNCA, and DNV GL

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1 INTRODUCTION: RENEWABLE HEATING & COOLING 2017

This Renewable Heating and Cooling (RHC) study focuses on the electrification of space and water heating in Boulder's residential building stock. DNV GL, in collaboration with Radiant Labs, Meister Consulting Group, and intern Graduate Students from University of Colorado Boulder, have determined heat pump technology to be the most scalable, cost effective, flexible, and efficient electric technology to shift fuel consumption for thermal energy use in buildings from fossil fuels to clean electricity.

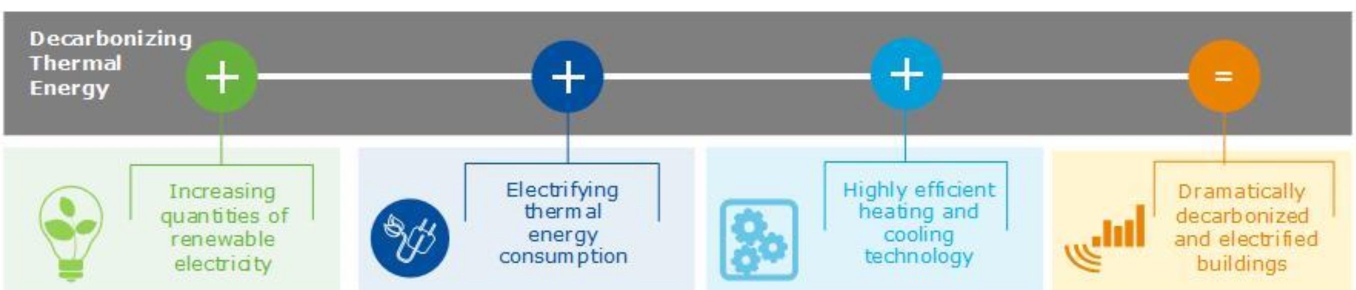
Key Acronyms
Air Source Heat Pump: ASHP
Renewable Heating a Cooling: RHC
Air Source Heating & Cooling: ASHC
Heat-Pump Water Heating: HPWH

This study focuses primarily on air-source heat pump (ASHP) space heating and cooling, including ductless and ducted systems, and heat-pump water heaters (HPWH).

The project was conducted simultaneously with three other cities as part of an Urban Sustainability Directors Network (USDN) Innovation fund project. It is part of a multi-year, multi-city project with New York City, Burlington VT, Washington DC, and Boulder; these leading cities along with 20 other observer cities have set thermal decarbonization as a priority.

Decarbonizing thermal energy use in buildings depends on *first* increasing quantities of renewable electricity and prioritizing the use of clean electricity over fossil fuels, then electrifying thermal systems for space heating/cooling and water heating using highly efficient technology. Figure 1 illustrates the path to a dramatically decarbonized building sector.

Figure 1. Thermal Decarbonization Pathway



A growing trend in leading cities around the world is the push toward electrification, both in transportation and heating/cooling technologies. This study followed the steps in the chart below to develop key strategies to dramatically increase electrification (switching from fossil fuel combustion systems to clean electric technologies) and decarbonization of thermal energy. Figure 2 describes the process the city used to better understand their market, key leverage points and concrete action steps to increase air source heating and cooling technology adoption rates.

Figure 2. RHC Project Process 2017

1. Frame the initiative.
Establish a heat-pump market development initiative and how the technology works.

2. Form local advisory boards, map key stakeholders; then analyze local barriers and opportunities.

3. Aggregate data and segment market.
Analyze data sources, establish baseline of systems installed to date, and set renewable thermal adoption targets by building/customer segment.

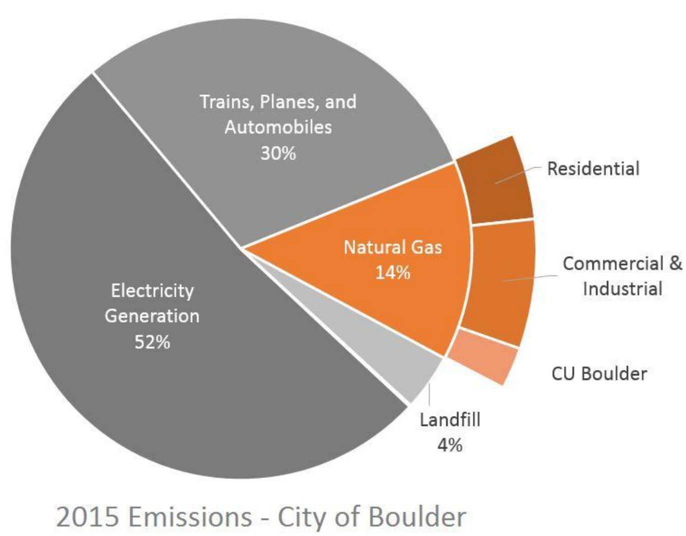
4. Develop key partnerships for market edcuation.
Leverage private sector partners for market education, outreach and incentives. Work with regional and state partners to shift policy.

5. Develop local strategies, programs, pilots, and policies.
Design new policies, finacing pathways and integrative (solar PV, EE, EV) programs with specific strategies and implementation actions. Generate demand, develop the supply chain and establish partnerships locally and national industry development collaborations.

1.1 The significance of natural gas emissions

Natural gas usage represents nearly one-fifth of the City of Boulder's emissions (shown in orange in Figure 3), and one-third of non-electricity emissions. While efforts to decarbonize the electricity sector and source renewable energy have been significant over the past decade, there has been very little progress in reducing dependence on natural gas usage in either the residential or commercial/industrial sectors.

Figure 3. City of Boulder Sources of Emissions



In 2016, as part of approval of its new climate action plan, the City committed to achieving 100% renewable electricity by 2030. As progress is made toward that goal, the share of emissions being generated by natural gas will increase significantly and may represent as much as 50% of the city's emissions by 2030.

In addition to its increasing share of Boulder's remaining fossil fuel dependence, the climate impacts of natural gas may also have been significantly underestimated. Methane, the key constituent of "natural" gas is a highly damaging agent in the upper atmosphere with estimates ranging between 30-70 times the impact of CO_2. As new information emerges regarding the increased leakage rates for natural gas at both the generation and distribution levels, the overall impact of natural gas on the climate—and local environments—is being revised, showing significantly higher impacts than previously thought. For every 1% increase in leakage rates, the estimated impacts of natural gas on the climate increase by 10%.[1] While natural gas was promoted as a clean fuel decades ago, science now shows that renewable electricity is the "clean fuel" that cities need to switch to, to achieve their long-term greenhouse gas reduction goals of 80% by 2050 or sooner.

As part of its approved 2016 climate action goals, the city has set specific targets around the reduction in natural gas usage. These efforts are described as a part of larger efforts to replace fossil fuels with renewable energy alternatives. The section of Boulder's climate action plan outlining these actions and the specific targets set for achieving this objective is displayed in the figure below.

Figure 4. Climate action plan targets for natural gas reduction

	2015	2020	2030	2050
Reduction in Residential Natural Gas	1%	15%	40%	85%
Reduction in Commercial and Industrial Natural Gas	5%	6%	15%	35%

Replace

Replace all building systems that rely on fossil fuels, particularly heating and cooling systems and water heating. In other words, switch from natural gas equipment to electric equipment, such as air, water or ground-source heat pumps.

Infrastructure Assessment & Transition Planning

- Assist building owners in identifying clean energy alternatives to existing systems dependent on natural gas and create a retirement and replacement plan consistent with the normal replacement cycles of these systems.
- Use city facilities and other leading edge businesses and institutions to develop and test new clean energy systems and develop the technical and financial information needed to support broader scale adoption.

[1] http://e360.yale.edu/features/with_new_tools_focus_on_urban_methane_leaks

1.2 Electrification of residential heating & cooling

The significance of decarbonizing residential heating and cooling and the potential impact of increased fugitive emissions is illustrated in Figure 5.

This graphic assumes that the electricity used for either charging EVs or running a household air-source heating/cooling (ASHC) system come from 100% renewable sources. As the graphic shows, decarbonizing household heating can eliminate even more climate damaging greenhouse gas (GHG) than driving an electric vehicle if a full accounting of natural gas' fugitive emissions is included. For an average household in Boulder, replacing their existing natural gas furnace with renewable electricity-driven air-source heating could reduce emissions by over 5 tons annually. If all 40,000 of Boulder's single family housing units were similarly decarbonized, this would represent a savings of approximately 200,000 million cumulative tons CO_2 ($mtCO_2e$) saved by 2050, as illustrated in Figure 6.

Figure 5. Emissions reduction potential of Boulder electrification strategies (MT CO_2e)

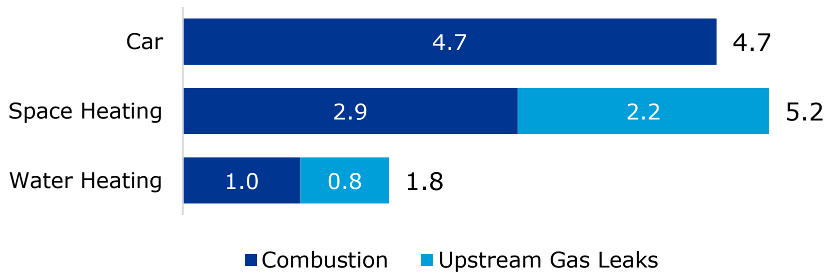
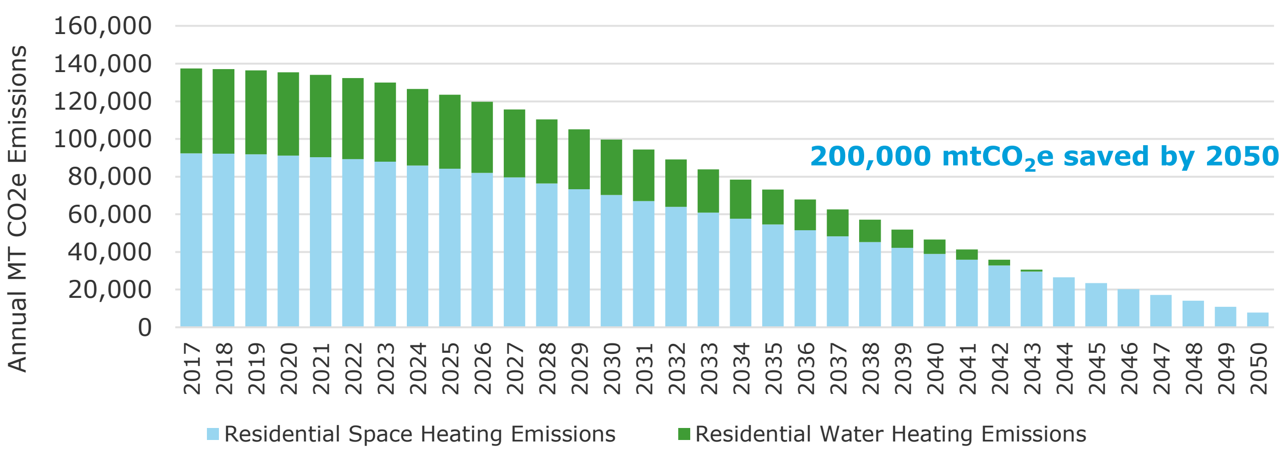


Figure 6. Annual emissions of residential thermal systems



Overall, switching to clean electricity sources and uses will enable Boulder to meet stated climate goals while also improving ambient air quality in the region and inside Boulder resident's homes.

1.3 Transition to 100% renewable electricity & electrification

Achieving deep decarbonization of residential heating and cooling is contingent on parallel efforts to source 100% renewable (or low carbon) electricity for air sourced electric heating and cooling systems to effectively decarbonize. Low carbon electricity and electrification together are referred to as "strategic electrification" or "beneficial electrification." Boulder has been actively engaged in efforts to achieve this goal through pursuit of municipalization of its local electric distribution and generation system. That effort is still underway. Whether it is through creating a municipally owned and managed electric utility or through state utility policy reform, or community choice aggregate renewables purchasing, Boulder is committed to achieving 100% renewable electricity by 2030. Figure 7 shows Boulder's climate and energy goals.

Figure 7. City of Boulder climate and energy goals

The pathways to achieving this objective will likely include a combination of both local generation and regionally procured utility scale renewable generation. While full decarbonisation of all residential electricity used will require this larger effort, Boulder's residential RHC strategy is being designed to enable significant emissions reductions by pairing electric heating and cooling system adoption with solar deployment—either household scale or community solar subscription. This is being coordinated through a larger initiative referred to as the "Roadmap to Renewable Living" that provides homeowners with a simple four-step process to transition all their household energy needs—including transportation—to renewable energy-based systems. More information on this bundled approach to household energy system transition can be found at bouldercolorado.gov/climate.

1.4 Benefits of electrifying natural gas heating & cooling systems

The basis of Boulder's renewable residential heating and cooling initiative is the replacement of natural gas furnaces, boilers, and water heaters with a new generation of high efficiency electricity-based air-source heating/cooling appliances. This technology utilizes the same "heat pump" technology that has successfully driven both household and commercial refrigeration for nearly 100 years. These technologies are now the dominant form of heating and cooling in most of the world, and have dramatically increased in efficiency since the invention of old heat pumps 150 years ago.

Due to the prevalence of natural gas in the United States and other parts of North America, air-source heat pump systems have been slower to penetrate heating and cooling markets in this country.

Air Source Heating and Cooling

ASHC works like a refrigerator by using electricity and refrigerants to transfer heat from one space to another. In heating mode, heat is transferred from the outside air to the inside of the house. In cooling mode, the process is reversed and heat from inside the house is transferred out of the house, resulting in cooler indoor air.

Heat pump space and water heaters offer many benefits, beyond carbon reduction, including improved comfort and safety, the ability to provide both heating and cooling, greater flexibility and controllability, and the potential use in larger management of local and regional grid energy demand. The top benefits include:

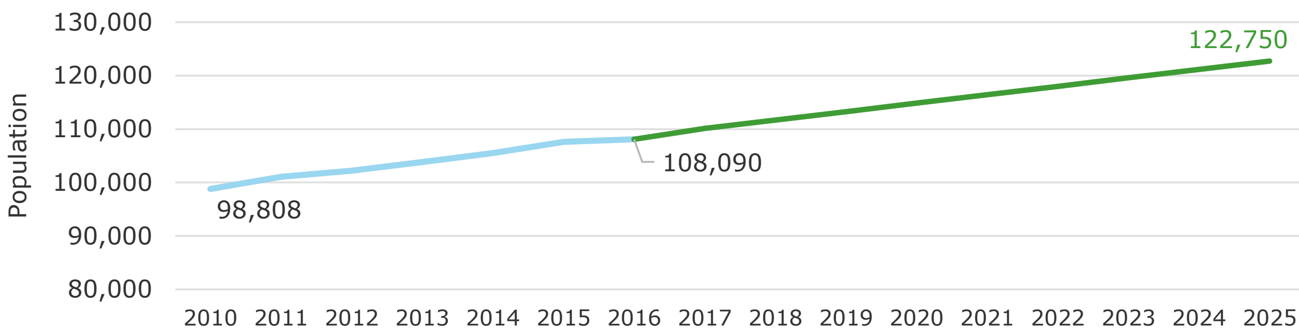
- **Improved household comfort**
  - Flexible installation options ideal for urban home comfort, including zone control
  - Heat pumps provide hot water for the home and for pools
- **Cooling with e-heating in one technology**
  - Heat pumps provide high-efficiency space heating and cooling at a compelling price point
  - Residents are facing increasing air conditioning needs as temperatures rise; heat pumps offer heating and cooling in one piece
- **Improved health and safety**
  - Elimination of carbon monoxide poisoning – On average, 430 Americans die from carbon monoxide poisoning per year. Poisoning is directly related to off-gassing from imperfect combustion related to fossil-fuel powered heaters, water heaters, cooking equipment, and vehicles.
  - Reduced home fires and explosions – On April 17, 2017 a home explosion in Firestone, CO killed two people and has been linked to a gas leak, which seeped into the basement.
  - End to pipeline explosions – The deadly pipeline explosion in San Bruno, CA brought aging natural gas pipelines into focus. Since 2010, over 3,300 incidents of crude oil and liquefied natural gas leaks or ruptures have occurred on U.S. pipelines, killing 80 people, injuring 389 more, and costing $2.8 billion in damages, releasing toxic, polluting chemicals in local soil, waterways, and air.
- **Efficiency**
  - Heat pumps are a highly efficient heating/cooling technology with emerging and growing state and utility rebate support
- **Strategic electrification and energy resilience**
  - If pursuing zero net energy (ZNE) buildings, all electric is the easiest way to go
  - Core component of urban electrification; pairs well with solar photovoltaic (PV), electric vehicles (EVs), and weatherization
- **Environmental**
  - Reduced demand on fracking derived resources
  - Local fugitive emissions impacts— decreased distribution leak impacts on local urban forests
  - Lower emissions compared to fossil fuels with continued reductions over time
- **Economic**
  - By accelerating innovation in the clean electric technology space, and the more carbon is beholden as a valuable metric in Boulder, the more sustainable energy jobs will result
  - Many ASHP owners experience lower energy bills due to efficiency of the technologies

2 FORECASTING BOULDER'S RESIDENTIAL HEATING & COOLING

2.1 Characterizing Boulder's building stock

Boulder is a city of 107,000. It has grown from a population of close to 86,000 in 1990 and is projected to reach 122,750 by 2025 based on its projected land use build out capacities (Figure 8).

Figure 8. Population and forecasted growth (US Census Data)

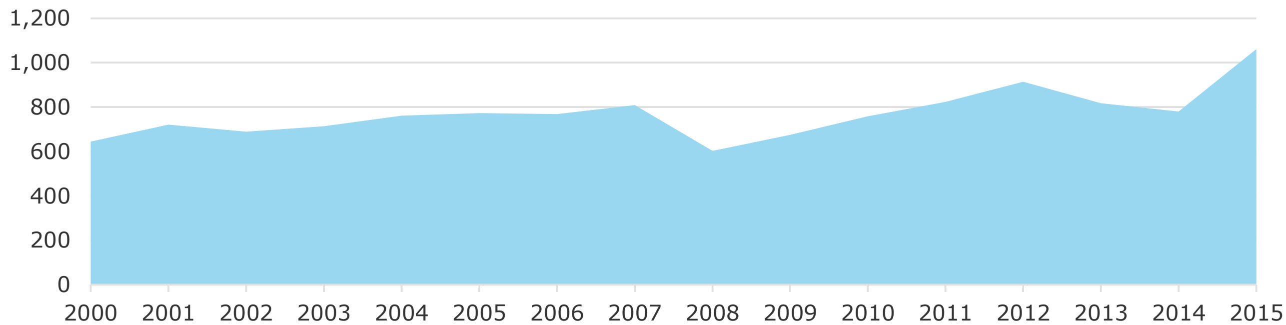


The primary residence of the existing population is single-family detached homes, half of which are owner-occupied properties (Figure 9). Boulder's homeownership rate is well below that of other surrounding communities and the county due to the presence of the University of Colorado Boulder, and its 32,775 students (2015).

Figure 9. Boulder home-ownership demographics

Additions and remodels provide an opportunity for the City of Boulder's development services department to influence the type of heating system that is installed or replaced. Figure 10 outlines the number of permits seen in each year for additions or remodels. At approximately 1,000 permitted projects per year, a full quarter of Boulder homes seek an addition or remodel per decade.

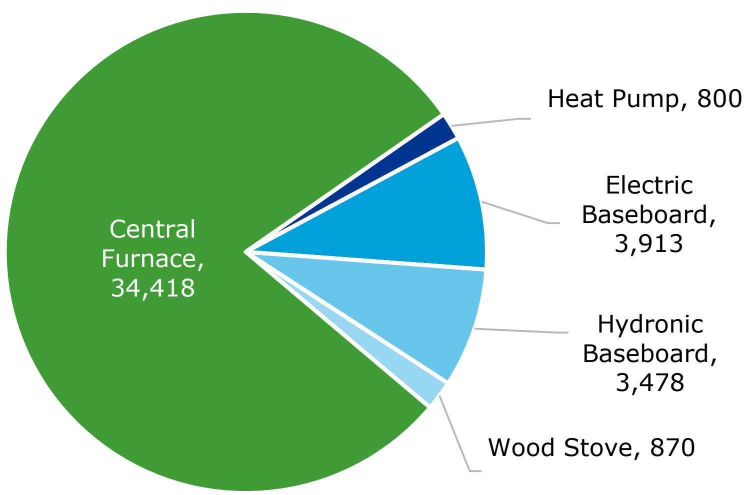
Figure 10. Number of permitted additions or remodels



2.2 Characterizing Boulder's existing residential heating & cooling systems

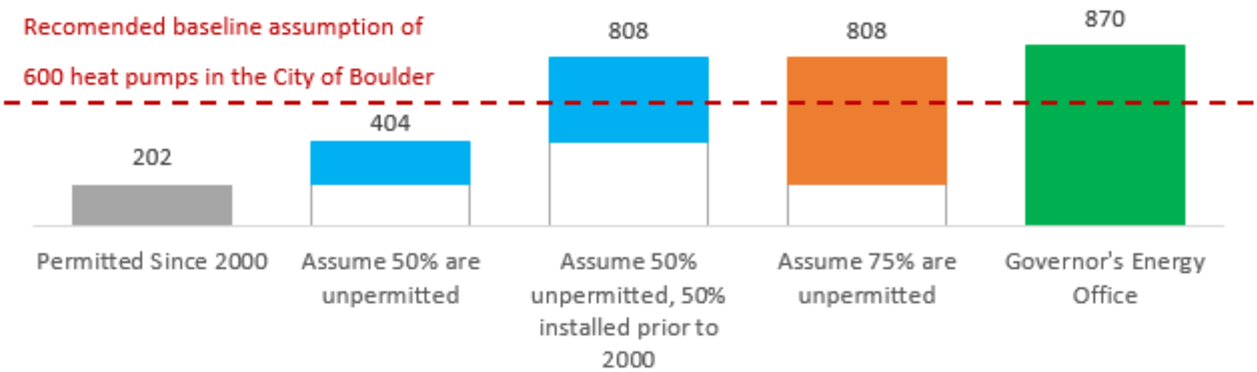
At almost 35,000 units, central furnaces (with natural gas fuel) make up the vast majority of systems in Boulder. At around a 2% market share, the saturation of heat pumps in the Boulder market is small, and likely surpassed by nearly every other space heating technology available. Figure 11shows the estimated number of residential heating systems in Boulder broken down by system type. Each system type will affect a different path to electrification.

Figure 11. Boulder heating system volume by type



Based on Radiant Labs research, 202 households have installed a permitted heat pump space heating system since 2000 (Figure 12). However, the number of HVAC permits pulled is much lower than would be expected given the useful life of the HVAC systems. A report by the governor's budget office estimates heat pump space heating saturation at two percent in the state of Colorado. Stakeholders from the Boulder working group determined 600 heat pumps to be a fair estimate of existing stock within City of Boulder homes as a median between permitted systems and the state survey.

Figure 12. Boulder HPSH 2017 baseline (number of homes with heat pumps)



Due to the low uptake ratio of water heater permits, estimating number of HPWH in Boulder homes is not possible. Since HPWH is such a new technology, it is assumed that less than 20 units exist across the city.

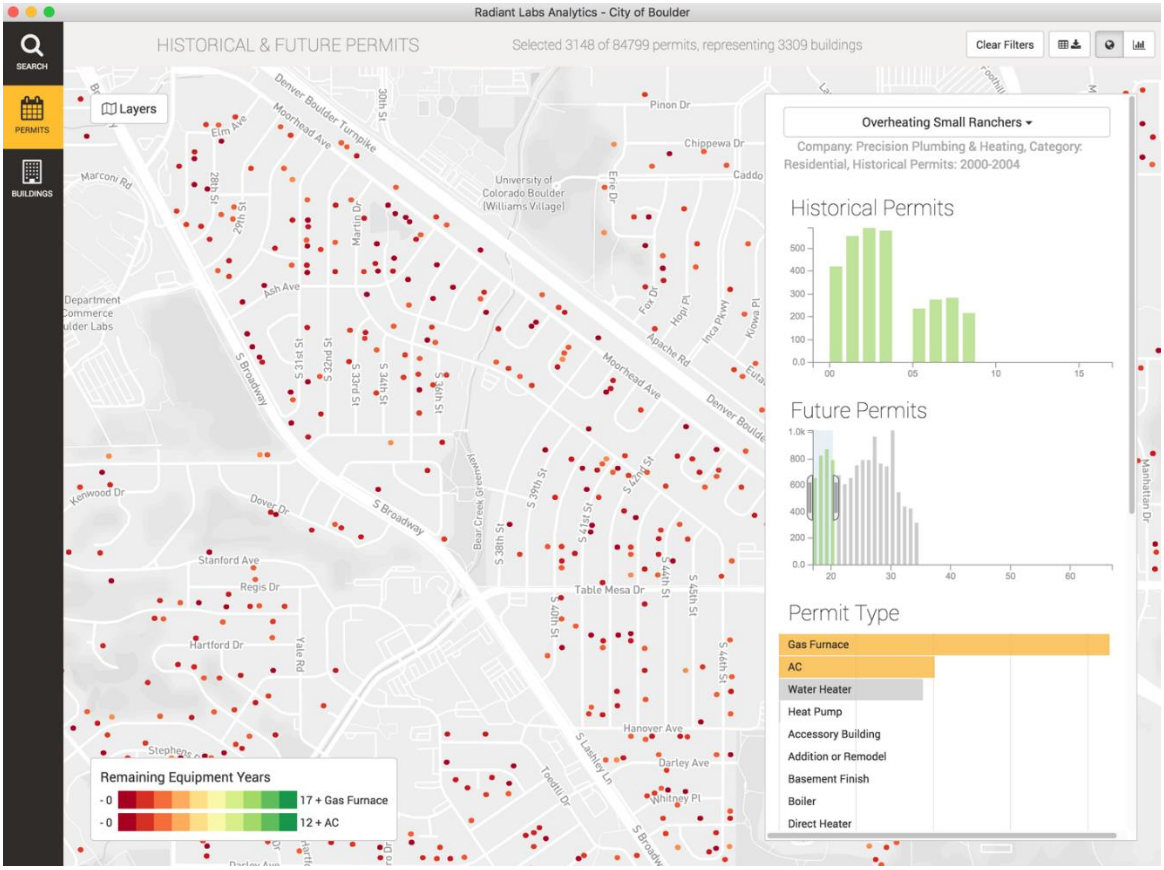
2.3 Customer segmentation

Customer profiles or archetypes have been developed for the top priority potential customers in Boulder based on building characteristics, demographics, and social indicator analysis. Radiant Labs has developed a tool for use by the city, which can be used for ongoing market segmentation/targeting, monitoring, and evaluation. The tool includes county assessor's data, permit data, building archetypes, census data, energy smart program data, as well as energy efficiency, solar PV, and other weatherization measure inputs. Radiant Lab's tool will be used to effectively target and generate demand in each customer segment.

2.3.1 Boulder early adopter cohorts

In Boulder, there are several early adopter archetypes, or cohorts, representing the profiles of consumers who would be likely to adopt heat pump technology. Many of these consumers are interested in energy efficiency, solar PV, electric vehicles and lack air conditioning. As temperatures in Boulder rise, demand grows for AC, which is a key intervention point to get ASHC technology into the home. Other key customer segments are likely to need a furnace or water heater replacement in the next five years. The map in Figure 13 shows an example of priority cohorts that the Radiant Labs tool can produce.

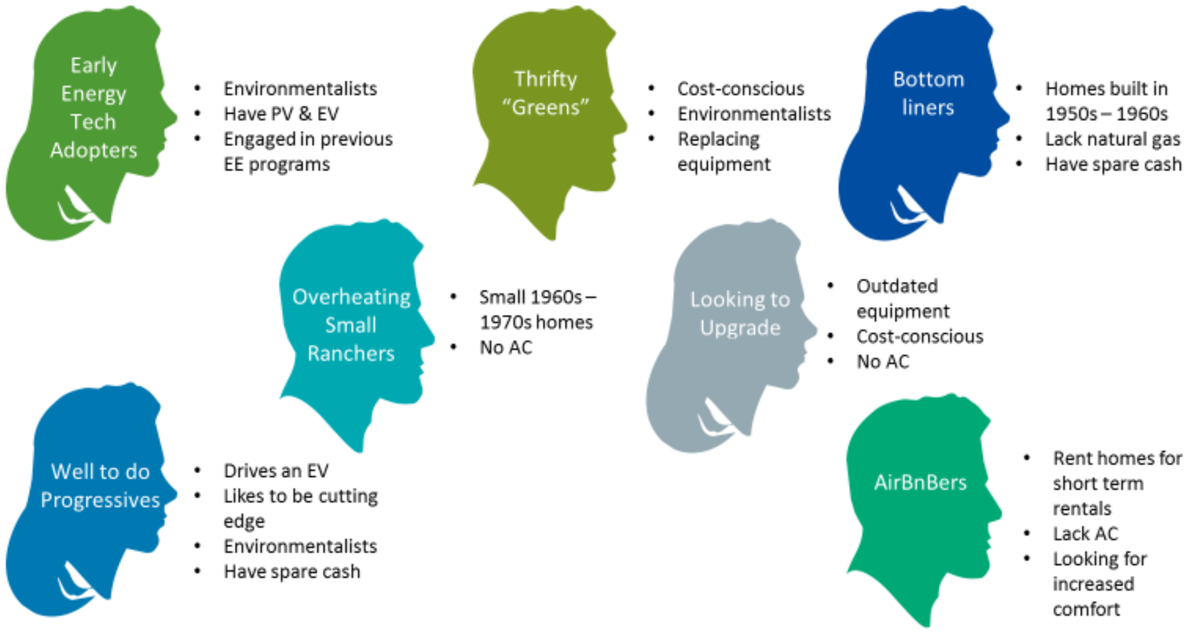
Figure 13. Sample map of furnaces to expire in next 5 years



Consumers who have previously participated in energy efficiency programs may be more open to adopting a new technology, particularly when there are incentives. Aside from those who care about the environment, early adopters may often be motived by cost or comfort concerns, either reducing heating costs in areas where natural gas is unavailable or replacing outdated and inefficient equipment. A survey of existing heat pump customers demonstrated a range of motivations for selecting heat pumps with the primary reasons as follows: efficiency, comfort, adding cooling, and, utilizing with solar PV. The existing customers are not representative of the broader market of average homeowners in Boulder; however, they provide insight into the mindset of early adopters. Figure 14 provides a snap shot of 7 potential early adopter archetypes that can be input (via filters) into the Radiant Lab tool. The table below the figure shows how many Boulder homes currently exist in each early adopter archetype.

The total of all these archetypes is 19,785 homes, with over half of those being the "well to do progressives" who (Have spare capital, replacing equipment) are in need of replacing AC or furnace in next five years, within census block where median income is greater than $81,000.

Figure 14. Early Adopter Cohorts



Early Energy Tech Adopters (Early movers in energy action) Criteria: Has Energy Smart upgrades, PV on the roof	**304 homes**
Overheating Small Ranchers (Small ranch houses built in the 60s-70s without AC) Criteria: Likely lacks AC, home under 2,500 sq ft, built in 1960s-1970s, owner-occupied	**3,309 homes**
Well-To-Do Progressives (Have spare capital, replacing equipment) Criteria: In need of replacing AC or furnace in next five years, within census block where median income is greater than $81,000	**11,047 homes**
Cashflow Positive Criteria: Identified in Radiant Labs to be cashflow positive with efficiency upgrades and full net-zero PV	**604 homes**
Thrifty "Greens" (Price conscious environmentalists with a broken AC unit) Criteria: Has Energy Smart upgrades, in need of replacing AC or furnace in next five years	**1,691 homes**
Landlords with Small Units Criteria: Home under 2,500 sq. ft., standard rental classification	**2,461 homes**
AirBnB Requiring Air Conditioning Criteria: Likely lacks AC, in need of replacing AC or furnace in next five years, short-term rental classification	**369 homes**

2.3.2 Iterative targeting refinement

Radiant Lab's also has an iterative adoption and refinement approach that helps an efficiency program regularly course correct. This process requires three major steps:

1. **Define a Cohort:**

Select a group of homes with common characteristics using the predefined archetype filters or any combination of filters that you plan to track over time, such as the archetypes named above. When that group of homes is ready to be tracked, save the chosen set of filters as a cohort. That will assign each home within the group a cohort ID, which will allow each house to be tracked over time as well as the aggregate performance of the entire cohort. The cohort characteristics will allow outreach and messaging to be tailored to the home. Then the entire cohort can be downloaded in CSV format, as presented in figure 16.

Figure 15. CSV data

Export Buildings Permits 2209 Records

PERMIT	ASSESSOR	OWNER	ADDRESS	DESC	TYPE
PMT2000-010...	#8725441	Peggy Smith	3003 VALMONT RD 124, Bould...	replace a residential forced air furnace .	Mechanical
PMT2000-030...	#0515943	Claire Broline	3153 9TH ST, Boulder, Colorad...	replace forced air furnace	Mechanical
PMT2000-039...	#0603897	Duane Dunn	1401 KALMIA AV, Boulder, Col...	replace a forced air furnace .	Mechanical
PMT2001-001...	#8728241	Dawn Stenman	4500 19TH ST 416, Boulder, Co...	replace forced air furnace .	Mechanical
PMT2001-001...	#8725737	David Keim Jesse W...	4500 19TH ST 494, Boulder, Co...	replace forced air furnace .	Mechanical
PMT2001-005...	#0606695	Velda Johnson	937 ROXWOOD LN, Boulder, Co...	replace forced air furnace in unit no 2	Mechanical
PMT2001-006...	#9999999	R Name	5630 ARAPAHOE 322, Boulder,...	unit 322 , replace furnace	Mechanical
PMT2001-007...	#0516150	Hospital Community	1810 ALPINE AV 1, Boulder, Co...	replacing a forced air furnace .	Mechanical

2. **Track home progress**:

In Colorado, all energy audits performed through Xcel Energy's subsidized audit program utilizing Snugg Pro (energy auditing software developed by Snugg Home, a sister company to Radiant Labs) to capture data and perform energy modeling. Participating contractors will utilize Snugg Pro to perform the necessary energy modeling to calculate system sizes, PV production requirements, and calculate the energy savings from the proposed improvements. This data will be used to create the formal proposal in the **homeowner roadmap tool** which shows complete home energy transition step by step through options in 4 categories: 1. Energy Efficiency, 2. Electrification of Heating and Cooling, 3. Solar PV, 4. Electric Vehicle

Once the work is completed, the actual improvements will be recorded by the contractor into Snugg Pro and a new energy model will be performed. The resulting modeled energy usage will be captured in the Radiant Labs software and stored with the original home data. If a household does not move forward with the upgrades a survey is conducted to find out the barriers and reasons for the inaction. This data will be recorded in the Radiant Labs database by an energy advisor or contractor.

3. Define and refine cohorts

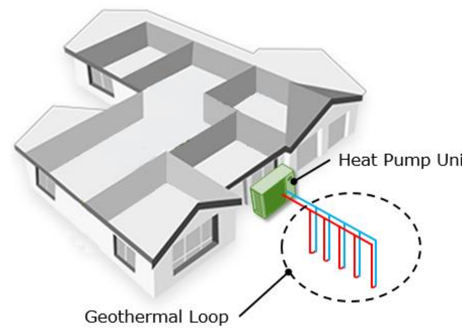
Improved pre- and post-retrofit data will facilitate the refinement of outreach and messaging strategies to be used. To refine cohorts the process is: 1. load the original cohort, 2. review the statistics on which homes got upgrades, 3. review any barriers to upgrades in that cohort for those who took no action, 4. adjust the filters to create a cohort with a better conversion rate by changing the filters to reflect the new data received.

Some cohort attributes which depend on market factors will change over time. Some of these factors include price per kWh, price per watt of PV, and carbon mix on the grid. It’s easy to add or remove homes from the cohort based on these updated market factors. Once this updated cohort is ready, it can be saved as a revision to the original cohort or added as a completely new cohort.

3 TECHNOLOGY SUMMARY

Heat pumps use the refrigeration cycle, run in reverse, to efficiently make heat without the requirement for on-site combustion of fossil fuel. A heat pump requires a heat sink from which to pull heat which is pumped into the space. In common residential applications, there are two basic options:

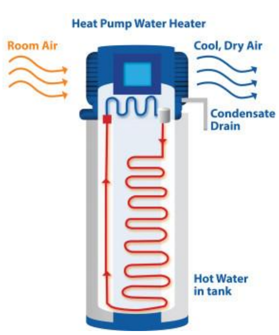
1. **Ground-source heat pumps:** Commonly called "geothermal," ground-source heat pumps utilize the consistent temperature of the earth to provide a source for heating and cooling of a home. This consistent temperature allows them to operate extremely efficiently, up to eight times as efficient as a gas-fired furnace. In certain applications, particularly those who desire extreme efficiency, there is no better choice. However, the installation is expensive. Holes are bored into the ground, up to 300 ft deep, and piping is inserted into the holes, which pumps a water-glycol solution to-and-from the heat pump unit. The large land requirements an expensive cost of boring make ground-source heat pumps unrealistic at scale for Boulder. Moreover, when geothermal loops reach end of useful life, the thousands of feet of plastic are abandoned in place, which is an environmental concern.



Ground-source Heat Pump

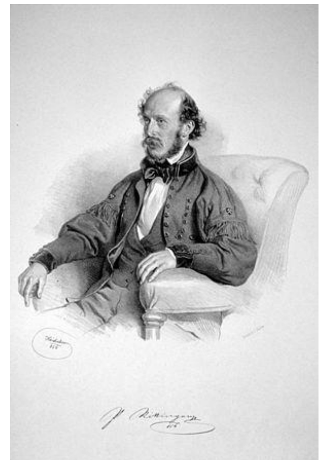
2. **Air-source heat pumps:** Air-Source Heat Pumps (ASHP) use the heat embodied in the outdoor air, which always contains some heat, as a source to heat the space or water. In cooling mode, heat is rejected from the building to the outdoors. Air-source heat pumps are three to four times as efficient as gas-fired equipment, are reasonably priced, and easy-to-install. The rest of this report will focus on air-source heat pump technology, which comes in two basic configurations:

Unitary systems: The entire system is housed in a single unit. The most common application for heat pump hot water heaters, this is less common in residential space heating and cooling.



Split systems: The "condensing unit" is installed outdoors to provide access to outdoor air, and houses the compressor and other equipment. Inside, a coil transfers heat to water heater or space conditioning system. If you have central air, it's probably a split system.

3.1 Air-source heating & cooling



Peter von Rittinger
Heat Pump Inventor
(Source: Wikipedia)

Heat pump space heating retrofits provide the biggest opportunity for carbon emissions reductions within Boulder homes. This will be even more apparent when Boulder's electricity becomes 100% renewable by 2030. With EVs starting to hit stride, space heating may well the biggest carbon emitter within Boulder City limits.

There is more than one way to skin a climate-destroying heating system. Electric furnaces, radiant heating systems, solar-hydronic, biomass combustion, and electric hydronic systems can all meet the goal of renewable heating. However, air-source heat pumps provide the most efficiency and cost-effectiveness within a package that is easy to install with technology which has been around for decades and is available today.

The first heat pump was invented in by Peter von Rittinger in 1857, and heat pump space heating systems have been widely used in the United States since the 1980s. Increases in efficiency and low-temperature heating performance which have occurred over the last decade have made the technology ripe for wide-scale implementation to reduce carbon emissions in both mild and cold climates.

3.2 Replacement versus displacement

Once 2030 hits, Boulder will need to ramp up gas meter elimination to meet their climate goals. However, in the interim, while technology is developing, not every therm of gas must be removed at once. In difficult installations, it might make sense to displace a large portion of gas usage with air source heating/cooling (ASHC) in one main living zone, as opposed to a full-scale fuel switch. Price of installations can escalate when several zones need unique fittings. Stating with one key zone will allow for displacement of most gas use, while also giving home owners the comfortable and safe experience of combustion free heating and cooling.

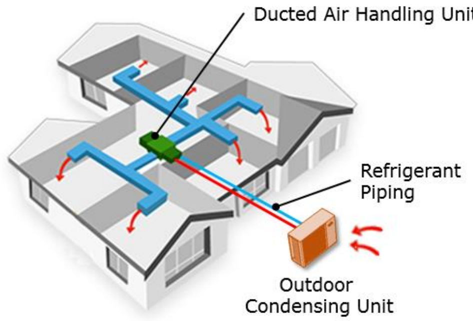
Examples when displacement might be preferable:

- **Single Zone Ductless in Heavily Used Zone:** If the primary need for comfort heating is a bedroom, or air conditioning is being added to a living room, a low-cost solution would be to install a single-zone ductless mini-split in that particular zone. This will enable high-efficiency electric heating or cooling in that zone at a low cost. Gas would still be burned to keep the home warm when guests are around or to ensure pipes don't freeze. But 50-80% of gas used for space heating can be offset.
- **Central Ducted System in Large Home with Gas Backup:** A standard residential gas furnace is sized at 80,000 BTU, but the largest central ducted HPSH is 60,000 BTU. In addition, HPSH capacity decreases slightly with ambient temperature depending on manufacturer. In a large home, on the coldest of nights, full electric replacement could mean requiring two central systems (doubling price) or an 80 A upgrade to the electric system ($2,000-$4,000.) The displacement scenario would maintain a single system by installing a heat pump A-coil attached to the existing furnace, and keep the gas connected to handle peak heating hours. Gas will likely be used for less than 10% of heating hours in this scenario. Costs for displacement versus replacement are explored later in this section.

3.3 Configurations – ducted or ductless

Air-source HPSH systems are available in ducted and ductless variants. The choice of which system to install is largely based on the preference of the homeowner and the existing system being replaced.

3.3.1 Ducted heat pump space heating



Ducted Heat Pump System

Ducted systems look identical to existing central air conditioning or central furnace systems. Refrigerant piping runs from the outdoor condensing unit to an "air handling unit" located indoors. From there, hot or cold air is blown throughout the home via ductwork which delivers air to each room via vents (e.g., grills, diffusers, registers, etc.).

Ducted systems are the simplest one-for-one replacement of existing central furnaces and air conditioners.

Example Ducted Variants

Pros:

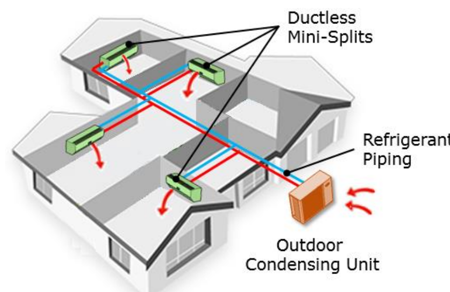
Directly replaces existing central air system

- Hidden out of view, like traditional "central air"
- Incorporating fresh, outside air is standard

Cons:

- Zoning requires more effort
- Slightly lower SEER than ductless systems

3.3.2 Ductless heat pump space heating



Ductless Heat Pump System

Ductless systems, often called "ductless mini-splits" are common in Asia-Pacific buildings, commercial buildings, and low-rise hotels. Since 2005, these systems have been gaining acceptance in the US market. Refrigerant piping runs from an outdoor condensing unit directly to units located in each room of the house. Ductless systems

Pros:

- Simple installation if home lacks ductwork Simple zoning
- People like to say "ductless mini-splits"

Example Ductless Variants

Cons:

- Americans are used to hidden units – "central air"
- Fresh, outside air requires separate system

3.3.3 Performance characteristics

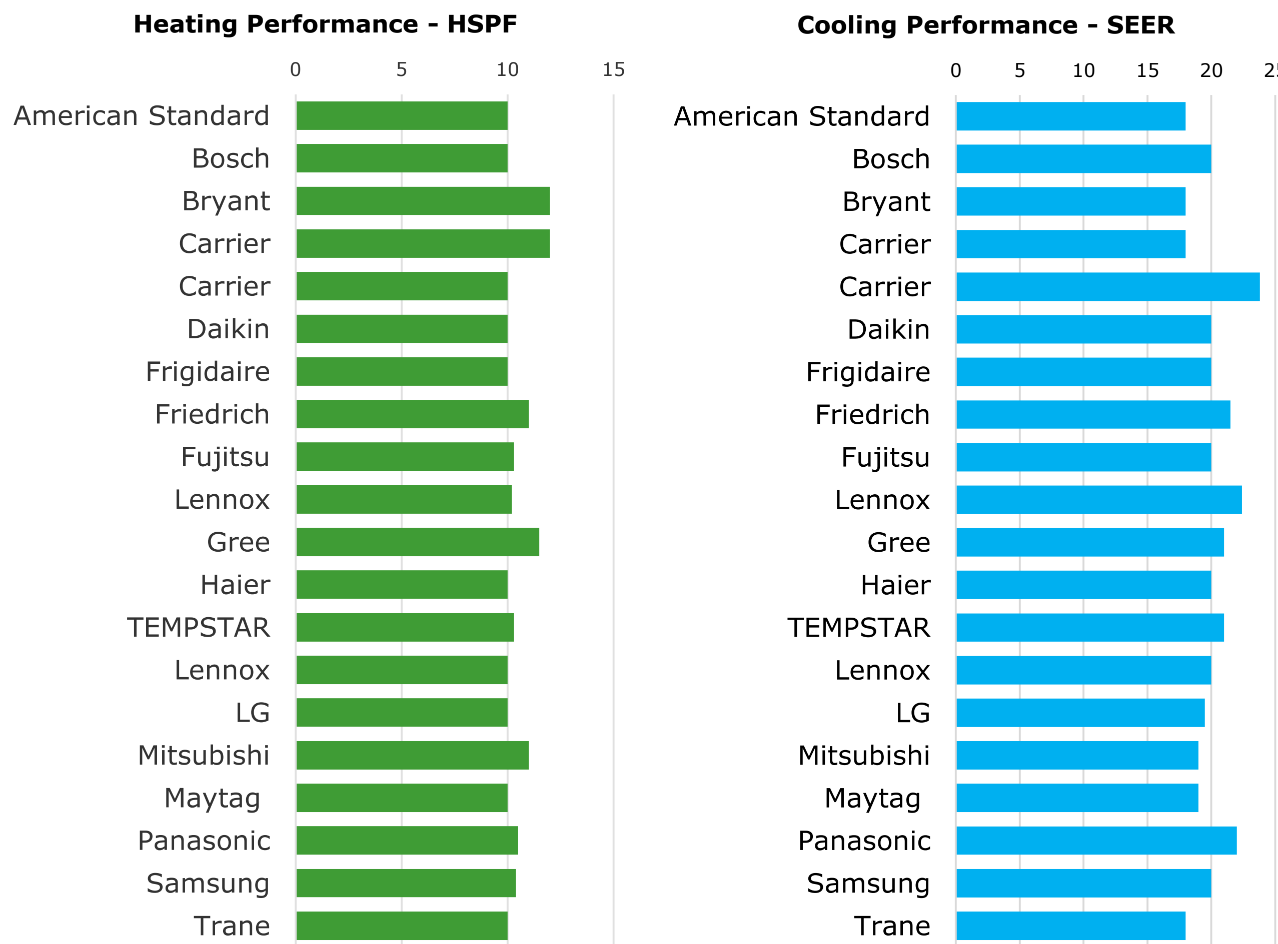
HPSH systems are three to four times more efficient than the space heating systems they will be replacing. The preference to utilize high-efficiency, inverter-driven units also means these are 25% more efficient at space cooling than the typical constant-speed systems found in the US housing stock.

The following variables are used to describe performance:

- **SEER** – The efficiency of central air conditioning systems is rated by a Seasonal Energy Efficiency Ratio (SEER). In general, the higher the SEER, the less electricity the system needs to do its job.[2]
- **HSPF** – The efficiency of heat pump systems is rated by Heating Seasonal Performance Factor (HSPF.) The higher, the better.
- **COP** – Coefficient of Performance (COP) is the ratio of energy created over energy used. This is the unit used by all countries on the metric system as well as most scientists.

The typical performance grouped by brand is provided in Figure 16.

Figure 16. Heating and cooling performance comparison



3.4 Cold climate analysis

While Boulder is well-known for snow-capped mountain hiking, locals know during chilly winter nights the mercury rarely drops below zero Fahrenheit. Even cold climate heat pumps can only perform to a certain temperature. Cut-off points for cold climate heat pump performance range from -4°F to -22°F. When

[2] http://www.ahrinet.org/Homeowners/Save-Energy/Seasonal-Energy-Efficiency-Ratio.aspx

temperatures drop below the cut-off, backup heat is required. This can either be in the form of traditional dirty, global warming, fossil fuel combustion such as natural gas furnaces, or with electric strip heaters specified within the unit. Electric strip heating has a cost premium of approximately $400, may require electrical circuit upgrades, and is only available in ducted systems.

Is backup heating critical to Boulder's RH&C pathway? As climate change has been warming the climate, the answer to this question is a resounding no. Consider the following cold weather trends shown in Table 1:

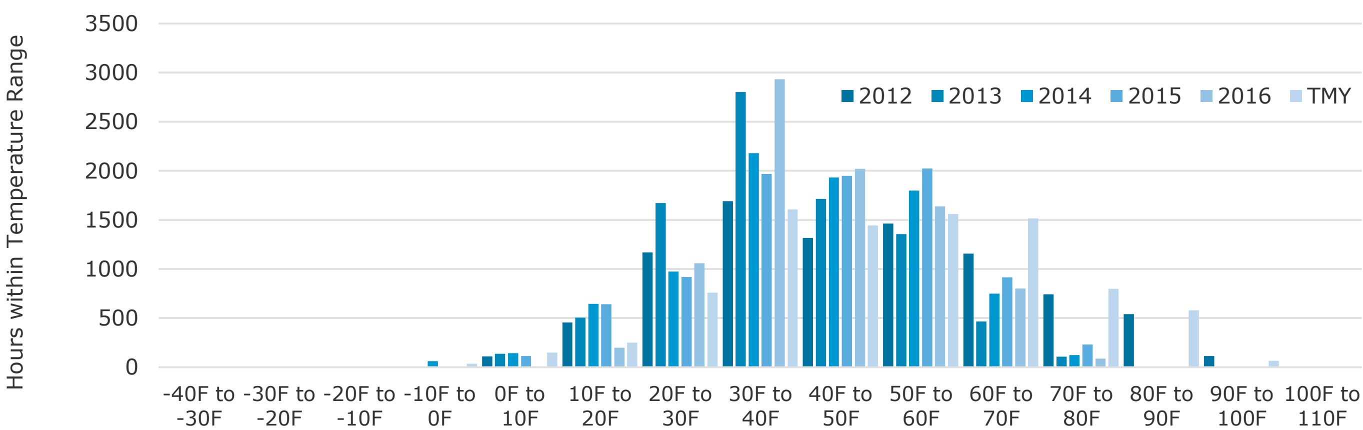
- The lowest temperature on record since 2012 is -5.8°F
- The ASHRAE Design Temperature, the nationally accepted standard for heating performance, in Boulder is 3.3°F to handle 99% of hours and -4.0°F to handle 99.6% of hours.

Table 1. Cold weather trends in Boulder

Year	2012	2013	2014	2015	2016	TMY
Minimum Recorded Temp	0.9°F	1.4°F	-5.8°F	3.2°F	8.6°F	-9.9°F
Hours Below Zero	0	0	60	0	0	37
Hours Below -5°F	0	0	7	0	0	7
Hours Below -10°F	0	0	0	0	0	0

The table and Figure 17 outline recent trends contrasted against the typical meteorological year (TMY). The weather trend here shows that global warming is leading to rising temperatures in Boulder, making ASHC more of an appropriate technology than ever before. In the past 4 years, there have been less than 10 hours of below zero temperature, thus, cold climate heat pumps are not a technical necessity.

Figure 17. Temperature BIN analysis – Boulder Municipal Airport



Given this weather data analysis, Boulder buildings are not confined to cold climate heat pump models, with the additional caveat that auxiliary heat (electric resistance) is offered as part of some HPSH system installations as another option to ease the fear of staying warm during those cold winter nights.

Auxiliary Heat

Most heat pump manufacturer offer a system with full electric resistance (strip heater) backup. Efficiency during electric resistance mode immediately drops to 100%. This is still more efficient than any gas-fired furnace, but can be expensive to operate compared to natural gas due to the outdated policies and subsidies that keep natural gas prices low.

3.5 ASHC retrofit costs

Capital Costs

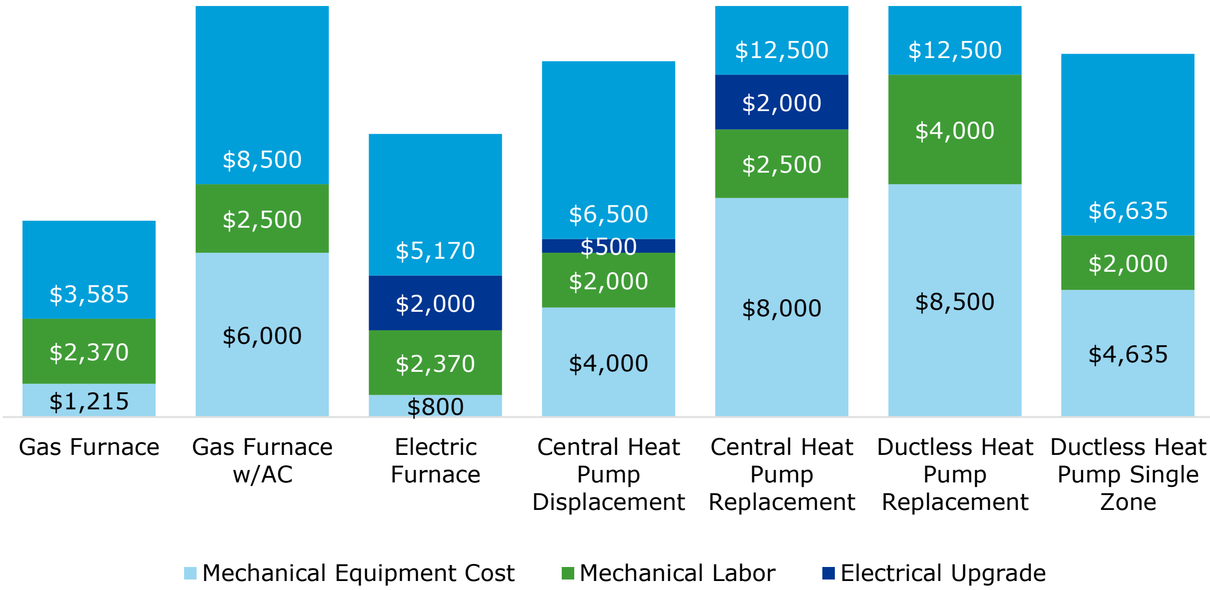
The capital cost of retrofitted an existing home with heat pump space heating is heavily dependent on the size and configuration of the existing home, as well as the decision on which type of system to install. While installation scenarios are limitless, Table 2 summarizes seven over-arching options a homeowner has when retrofitting or replacing HVAC equipment.

Table 2. Home space heating & cooling system comparison

	Installation Summary				Quality Enhancements			
System Type	Large Electrical Upgrade	New Outdoor Unit	Replace AHU	New Outdoor Unit	Zoned Solution	Aesthetically Identical	Zero Emissions Heating	Adds AC
Gas Furnace			✓	✓		✓		
Gas Furnace w/AC		✓	✓			✓		✓
Electric Furnace	✓		✓			✓	✓	
Central Heat Pump Displacement		✓				✓		✓
Central Heat Pump Replacement	✓	✓	✓			✓	✓	✓
Ductless Heat Pump Replacement		✓			✓		✓	✓
Ductless Heat Pump Single Zone		✓			✓			✓

Figure 18 outlines average capital costs of each replacement scenario based on information garnered from a variety of sources. In the United States, contractor pricing tends to be variable and is more based on what the contractor perceives a customer will pay, as opposed to a pre-determined cost. Additionally, each home has its own unique characteristics which may increase or decrease these cost estimates by 10%-20%. Note: gas furnace prices range based on efficiency. This chart uses the average Boulder furnace.

Figure 18. Home space heating and cooling system cost comparison



3.6 HPSH success stories

Boulder Zero Net Energy Homes

The volatility in the cost of natural gas prices can affect the cost parity of heat pumps. When paired with PV, heat pumps become a more cost-effective option, and the payback is reduced to approximately 4 years. Heat pumps have been very successful in Zero Net Energy homes in Boulder, with high owner satisfaction and comfort. Envelope efficiency is key to reducing the size of heat pump needed, which reduces upfront installation cost.

Northeast Energy Efficiency Alliance

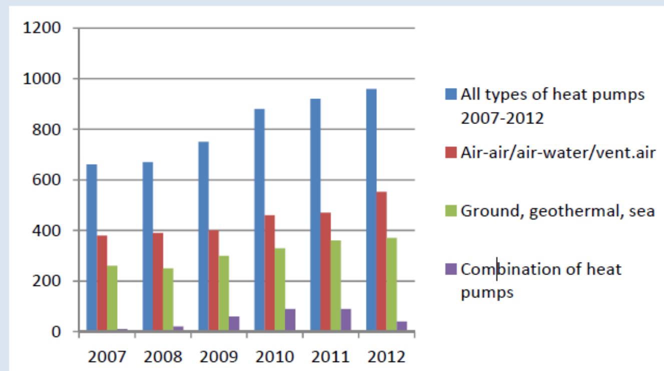
In 2013, the Northeast Energy Efficiency Partnership (NEEP) launched a market transformation initiative to accelerate the market adoption of residential ASHPs. The goal of this initiative is to convert 40% of households to heat pumps as their primary space heating system by 2030.

Emera Maine

Emera Maine implemented a heat pump pilot program targeting residential customers with high energy bills, who use oil, propane, electric resistance heat, or kerosene as their primary heating fuel. This program used marketing, contractor program training, participant referrals, contractor registration, on-bill financing, and rebates to remove barriers to customer adoption of heat pumps. Key findings from the pilot include: 1) Smaller homes with open floor plans were less likely to need supplemental heat; 2) Customers primary concerns include HP performance at low temperatures, reliability concerns, and initial investment costs.

Heat Pumps in Sweden

Beginning in the late 1970s, Sweden endorsed the technical and market development of heat pumps, which pushed the technology to become increasingly cheap and efficient. Due to this development, by 2012 nearly half of the almost 2 million single family homes in Sweden used some form of heat pump. Between 30%-50% of all energy used for heating in Sweden comes from heat pumps.



Number(x1000) of Swedish single family homes with some sort of heat pump (2007-2012)

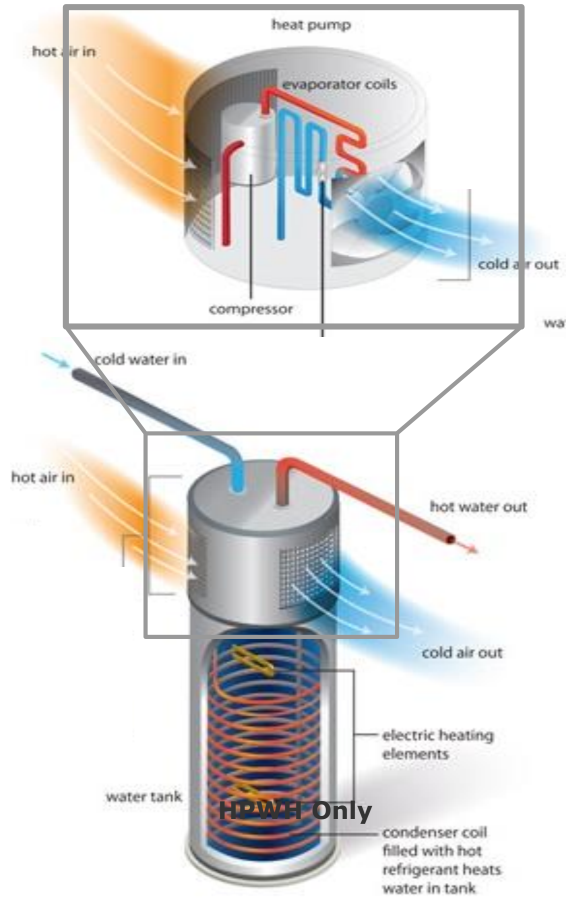
Ductless HP Cold Climate Performance Evaluation

A series of studies conducted by NEW, BPA, and NEEA of 20 homes assessed the performance of "cold climate" heat pumps with a rated capacity of 13,600 Btu/hr. The DHP excelled even in the coldest parts of the heating system, providing 100°F air to the occupants at a COP near 2. A billing analysis found an average savings of 3,000 kWh/yr at the NWE sites, 3,300 kWh/yr at the BPA Eastern Idaho sites, and 3,300 kWh/yr at the NEEA Eastern Idaho sites for an average savings of 3,241 kWh/yr. A direct COP measurement of DHP heat output and input at the site showed an even greater magnitude of savings, an average of 5,200 kWh/yr in all cold climate locations. The disparity in savings between methodologies is due to "takeback," where owners were running their thermostats warmer, which accounted for 40% of the heat produced.

3.7 Heat pump water heating

While HPSH has been utilized across the nation for decades, HPWH is a relatively new phenomenon. HPWH units have been available globally since the turn of the century, but have only been available in the United States since 2009. They are three to four times as efficient as their natural gas or standard electric counterparts. This ultra-high efficiency can off-set low natural gas costs which have been a result of the recent up-tick in fracking nationwide.

- HPWHs use the same basic technology as air source heat pumps, using electricity to transfer heat from the surrounding air to heat water in the tank. The image to the right outlines how heat is pumped into the water system via the vapor-compression cycle.
- If switching from gas, a new 30 A–40 A line must be run to the water heater. This requires adding an electrician to the job, which is normally done solely by a plumber. The City of Boulder should consider pre-qualifying teams so that this simple task can be done in emergency situations, which is typically when homeowners replace water heaters.



3.8 Configurations – unitary or split system

Unitary HPWH

- Unitary systems are far-and-away the most common type of HPHW heater with a variety of UL listed models available. They look markedly similar to the water heaters everyone is used to having in their home, and area relatively easy change.
- Spacing issues: Unitary HPWHs require air from which to draw heat. This can be provided one of two ways:
  1. 100 sq ft of closet space from which to draw heat, otherwise the room will get too cold and the system will not operate.
  2. A very small room can be outfitted with a simple louvered door to allow airflow as one would see when stacked washer-dryers are installed in a closet.

Split System HPWH

- Split system HPWH overcome the 100 sq ft closet space requirement by placing the compressor unit outside of the home and the tank indoors. At the time of the writing, Sanden is the only HPWH UL-listed for sale in the United States.
- The system has many benefits, including using CO_2 as a refrigerant. R-134A is used in most other HPWH systems. **Standard refrigerants such as R-134a contribute to ozone layer depletion and global warming when leakage occurs.** However, this new unit is more expensive than unitary systems.

Split System HPWH

3.9 HPWH performance comparison

HPWH performance characteristics are studied below. Information is based on ENERGY STAR® ratings and manufacturer data. Note that energy factors are increasing for this equipment every year, so the most recent equipment may have a higher rating.

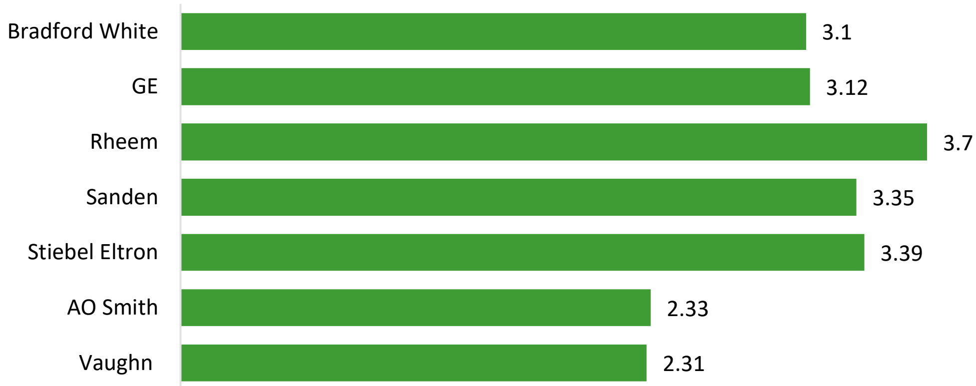
At the time of this writing, this list represents every ENERGY STAR listed HPHW unit. Note that some manufacturers provide options which are rebranded under a variety of names. These have been combined in Table 3.

Table 3. Heat Pump Comparison

Manufacturer	Model	Tank Size	Energy Factor* (from ENERGY STAR)	Refrigerant Type	Split or Packaged?	Energy Use per Year (EnergyStar)	Peak Power Draw
Bradford White	AEROTHERM: RE2H80R10B-1NCWT	80	3.1	R134a	Packaged	1,416 kWh/yr	4.6 kW
GE	Geospring GEH80DFEJSR	80	3.12	R134a	Packaged	1,407 kWh/yr	4.6 kW
Rheem	XE80T12Eh45U0	80	3.7	R134a	Packaged	1,792 kWh/yr	4.5 kW
Sanden	GUS-A45HPA	83	3.35	CO_2	Split	Not Listed	4.5 kW
Stiebel Eltron	Accelera 300 E	80	3.39	R134a	Packaged	1,289 kWh/yr	Not listed
AO Smith	PHPT 80 102	80	2.33	R134a	Packaged	1,591 kWh/yr	4.5 kW
Vaughn	S-80HPT (S80WHPT3838I)	80	2.31	R426A	Packaged	1,901 kWh/yr	3.8 kW

How these units perform based on energy factor are provided in Figure 19.

Figure 19. HPWH Energy Factor performance comparison

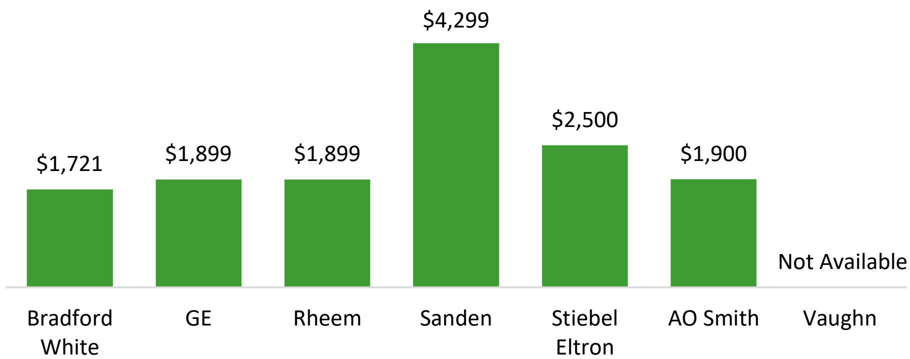


3.10 Water heating costs

Capital Costs

During research for this report, an analysis of every available HPWH manufacturer was performed to determine capital cost of equipment. The median price of a HPWH unit varies from $1,700-$4,300 with a median price of $1,900 (Figure 20).

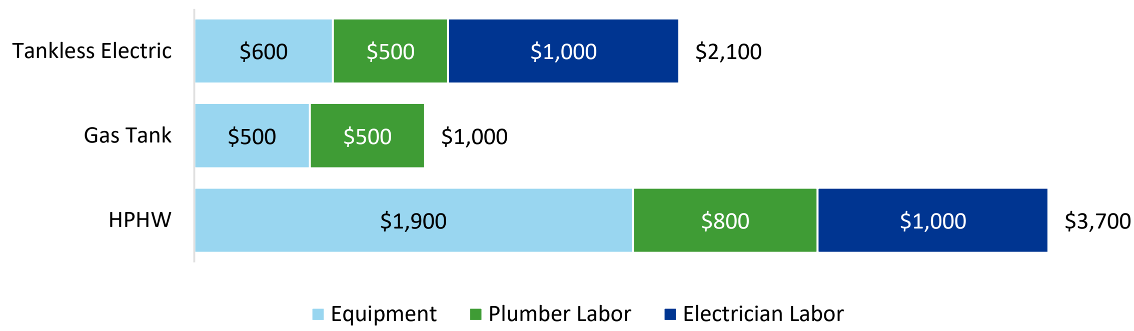
Figure 20. Heat pump hot water heaters – equipment cost[3]



When coupled with the cost of installation by a plumber ($800,) and the cost to run new electrical to the space ($1,000,) the total installed cost of a HPWH system is $3,700 (Figure 21). The table below compares this against replacement costs for tankless electric and gas tanks water heating systems.

[3] Costs collected via internet search by DNV GL Staff

Figure 21. Water heater retrofit costs



Due to the high cost of HPWH compared to gas furnaces, as well as the additional cost of electrician labor, determining how to overcome the cost difference is imperative. This will be discussed further in the "sizing our incentives" section.

3.11 HPWH success stories

SMUD

Under their Home Performance Program, SMUD offers a $1,000 incentive to customers replacing an existing electric resistance water heater with a Heat Pump Water Heater. A study conducted by ADM Associates, Inc. and SMUD looked at 22 customers who participated in the program to assess efficiency and savings. The study found the average energy use with electric resistance water heaters to be 2,004 kWh. The average energy use for the HPWH was 966 kWh per year resulting in 1,038 kWh in savings per year. Using an average of $0.1292/kWh, the average annual energy cost savings is $134. On average the cost of the HPWH was $1,118 and the installation cost was an average of $1,265. With the $1,000 incentive and the annual savings of $134, the simple payback is 3.6 years. Overall, all participants in the study reported being either satisfied or extremely satisfied with their HPWH.

Efficiency Maine

Efficiency Maine offers a Heat Pump Water Heater program with a $750 Distributor incentive for installers to offer a comparable price on 50 gallon HPWH for their clients. The incentive program has increased the sale of HPWH from 250 units per month to 900 per month.

Shifted Energy and Hawaiian Electric

Shifted Energy partnered with Hawaiian Electric to deploy 499 grid-interactive water heaters at a new multi-family housing complex on Oahu's west side, amounting to 2.5 MW of power potential. The heaters can be remotely controlled to meet grid service needs as well as ensure hot water for residents when they need it.

Glasgow Electric Plant Board (GEPB) Smart Energy Technologies Pilot

As part of the Smart Energy Technologies demonstration project, the GEPB installed smart heat pump hot water heaters in 306 targeted homes. In addition to HPWH, each home also has the following: Infotricity rate (different charges for on-peak and off-peak), Virtual Peaker Software, and Smart Thermostat

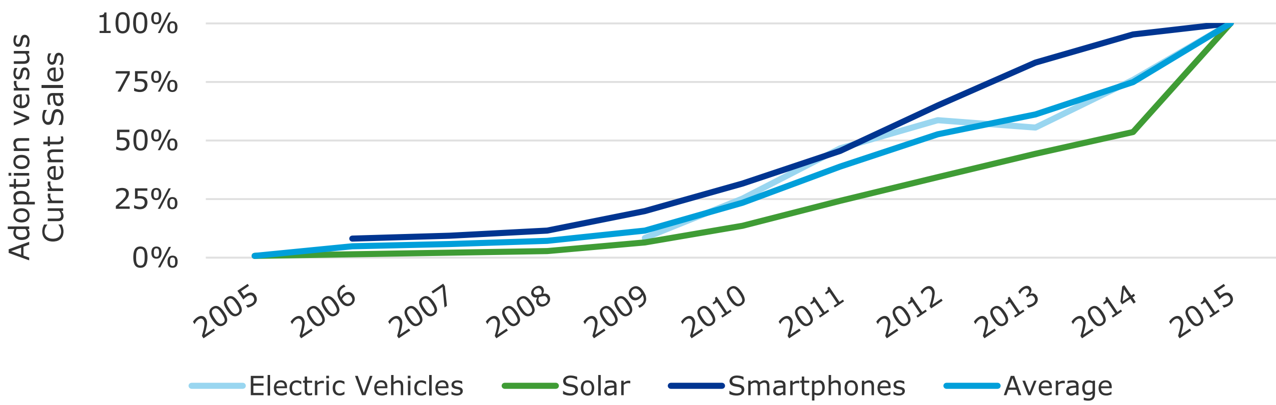
4 HEAT PUMP ADOPTION TARGETS IN BOULDER

4.1 New technology adoption curves and Boulder adoption targets

Programs targeted at switching constituents from natural gas to electric heating have only started in the past few years, with some states in the US still incentivizing fuel switching to natural gas! As such, the heat pump adoption curve displaying "what success looks like" is not available.

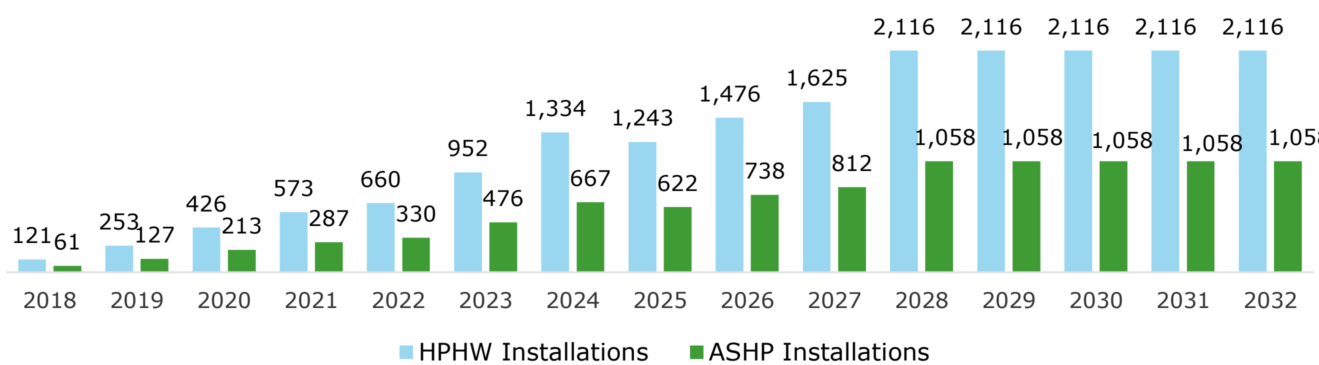
Instead, we have looked at other recent energy efficiency technology shifts to determine what viable targets will be for the first ten years of the program. Figure 22 below outlines the adoption curve of recent disruptive and green technologies.

Figure 22. Adoption rates of disruptive and green technology



Furnaces last 20 years. Therefore, if Boulder plans to eliminate gas as a space heating system by 2050, then every unit replaced from 2030 onward must be electrified. The target of electrifying every unit at the natural replacement timeline would result in the electrification of 2,116 water heaters and 1,058 space heaters per year. Working backwards from that goal and using the technology adoption curve methodology described previously, Figure 23 outlines the annual targets for number of systems electrified within the City of Boulder.

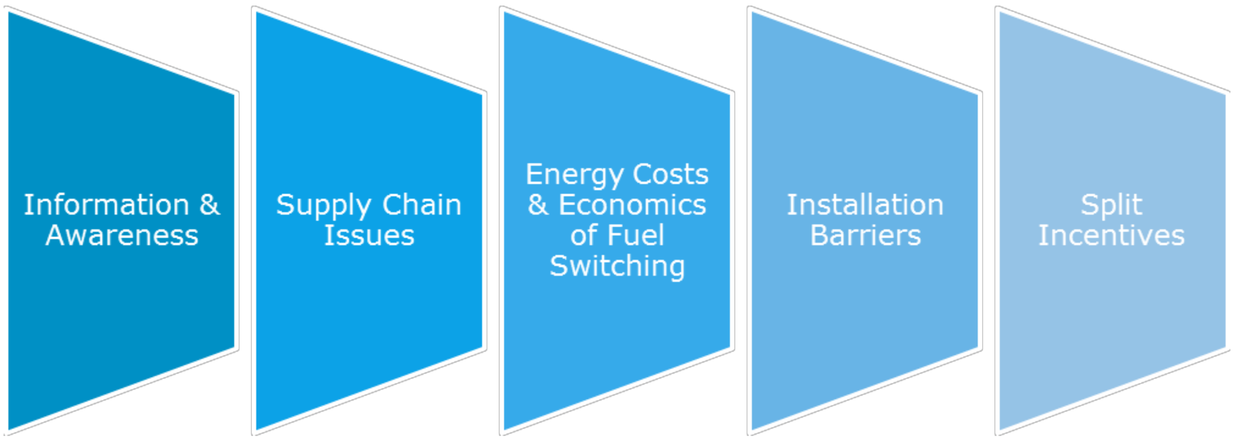
Figure 23. RH&C Installation Target by Year



5 ISSUES SHAPING AIR SOURCE HEATING & COOLING IMPLEMENTATION

The figure below highlights the five key barriers for adoption of heat pump technology. Each one is described in detail in the next sections.

Figure 24. Barriers to heat pump adoption



5.1 Information and awareness

One of the key barriers to heat pump adoption is a lack of awareness. Customers lack awareness of what options might exist outside of the gas-powered systems **and the general HVAC or plumbing installers** who will actually promote a cold climate heat pump for example over a traditional unit are few and far between. With the conditions of the current regulatory environment the reality is fuel switching is extremely tricky due to fossil fuel subsidies, the artificially low cost of carbon, thus the favoring of natural gas systems in both the contractors and consumers' minds.

5.1.1 City and state

Politically, there is a great deal of policy and awareness around overall **GHG emission reduction targets, economic development, and resilience and climate adaptation.** Yet there is no current connection between these overarching city goals and their connection to **thermal energy use.** How can we translate these city priorities into actions that decarbonize thermal energy use in Boulder? Certainly, more awareness and information around heat pump technology is needed. Heat pumps are an electrification and efficiency measure all in one but the word isn't out.

5.1.2 Contractors and installers

The residential HVAC industry is heavily localized, with a large, fragmented landscape of small HVAC contractors active throughout the city and surrounding areas. With thousands of small contracting and installing companies in the county, familiarity with energy efficiency and electrification strategies, programs and incentives can vary greatly. **Installers** motivations vary but often they work with distributors to get good deals and pass on savings to their customers, so tend to go with mainstream technologies. Manufacturers also rely on distributors to promote certain equipment. **See supply chain for more detail.**

Since it is the contractors who provide education, outreach and installation to end-use customers; it makes the most sense for the City to focus education and training campaigns on the midstream installers. To help raise awareness and ease the shift to heat pumps for the consumers, installers will need become personal energy transition advisors, seeing the connection to environmental, comfort and cost benefits. Of 17 local HVAC installers interviewed, not one mentioned heat pumps as an option until prompted.

5.1.3 Consumers

High rates of rentership and accompanying **split incentives** can limit the adoption of cost-effective energy technologies when costs are born by owners while benefits accrue to tenants. An effective communications strategy on dealing with the split incentive issue will be paramount. Most homeowners tend to **prioritize aesthetic improvements over energy-related improvements, or, make energy related purchases under duress when a system breaks.** When the home owner is evaluating opportunities for reducing energy consumption, they still often **lack awareness of or confidence in heat pump system performance.**

Consumer goals in Boulder most often include:

- Cost savings
- Building comfort
- Price stability
- Green/climate leadership / responsibility

Poor consumer awareness, a supply chain supporting older technology over new, and a lack of policy to catalyse market growth are all barriers and yet typical characteristics of a market in inception phase. Additionally, there is a perception that more electricity counts against efficiency. A mindset shift is needed to understand that fuel-switching from fossil fuels to electricity supports the city's decarbonization strategy.

5.2 Supply chain issues

Most actors within the residential HVAC supply chain use a two-step distribution model:

1. Manufacturers work with distributors to stock HVAC equipment
2. Contractors, who install the equipment, purchase HVAC equipment from distributors

The residential heat pump (and broader HVAC) supply chain summarized in Figure 25 is common across the United States. DIY installations are possible for HPWHs, though very uncommon for ASHPs, as most homeowners lack the technical ability, tools, and confidence to properly install HVAC systems. Electrification of HPWH does complicate the installation process as electricians and plumbers are then needed, thus DIY is less likely in future.

Figure 25. Heating and cooling supply chain

The relationships between the manufacturers, distributors and contractors is closely knit. Manufacturers rely on distributors to promote equipment and in some cases, recommend contractors for advanced certification. Contractors also work closely with distributors, and generally trust in distributor equipment recommendations. The contractors are the key touch point with the customers. They may be responsible for providing education and outreach to end-use customers as well as maintain quality and customers' satisfaction.[4]

Manufacturer accreditation is common throughout the heat pump industry, with requirements and benefits varying based on the manufacturer. Installers typically become accredited through participating in manufacturer trainings or third-party certifications, brand loyalty and marketing support, sales volume, customer services reviews/referral rate, and/or distributor nomination and typically receive a range of benefits, which may include: extended warranty, prominent placement on manufacturer website, literature and branding materials, access to marketing co-op funding, and/or financing discounts.[5]

Certifications also exist through various third-party organizations, including: North American Technician Excellence (NATE), Building Performance Institute (BPI), and the US Environmental Protection Agency (Section 608 Technician Certification).

[4] Bonneville Power Administration. (2016). HVAC Market Intelligence Report; Mitsubishi Diamond Contractor information.

[5] Murray, C. and Steiner, J. (2015). NYSERDA Residential Statewide Baseline Study – Volume 3: HVAC Market Assessment.

5.2.1 Boulder supply chain

The main supply chain manufacturers, distributors, and dealers/installers are listed below.

There are a wide variety of heat pump manufacturers offering products in the Boulder market. The most commonly installed systems in Boulder are Mitsubishi, Carrier, Lennox, LG, Rheem, Fujitsu, and Samsung. While Mitsubishi appears to be the most frequently installed, there are many options available in the area. In terms of cold climate options, NEEP certifies cold climate heat pumps from 17 different manufacturers.

Boulder has 3 main distributors: Johnstone Supply, Comfort Air, and J.H. Larson. There are many additional distributors in the surrounding areas.The supply chain analysis did not reveal any bottlenecks and the market has historically shown a great deal of demand flexibility.

In Boulder, there are 5 main heat pump installers: Save Home Heat, Boulder Metal Products, Inc., Precision Plumbing & Heating, Meyers Heating & Air Conditioning, and Timberline Mechanical Systems. The installers noted that the main models sold are Mitsubishi Mini-Splits and Lennox. The installers noted that most customers choosing heat pumps have already made their selection and are either adding supplement heat to a room, looking to reduce costs from electric baseboard heating, or looking to "go green."

Barriers to adoption include: awareness of heat pumps, as many consumers don't know about them, the initial cost, and the need to maintain supplemental heat systems. One installer noted that while the Mitsubishi Mini-Splits can continue providing heat at around -10°F, it stops being cost-effective, and they always recommend maintaining a backup heating system in case temperatures drop below -10°F. The installers did not note any maintenance issues with air-source heat pumps; however, one did identify a need to educate more technicians as the number of heat pumps in the area increase.

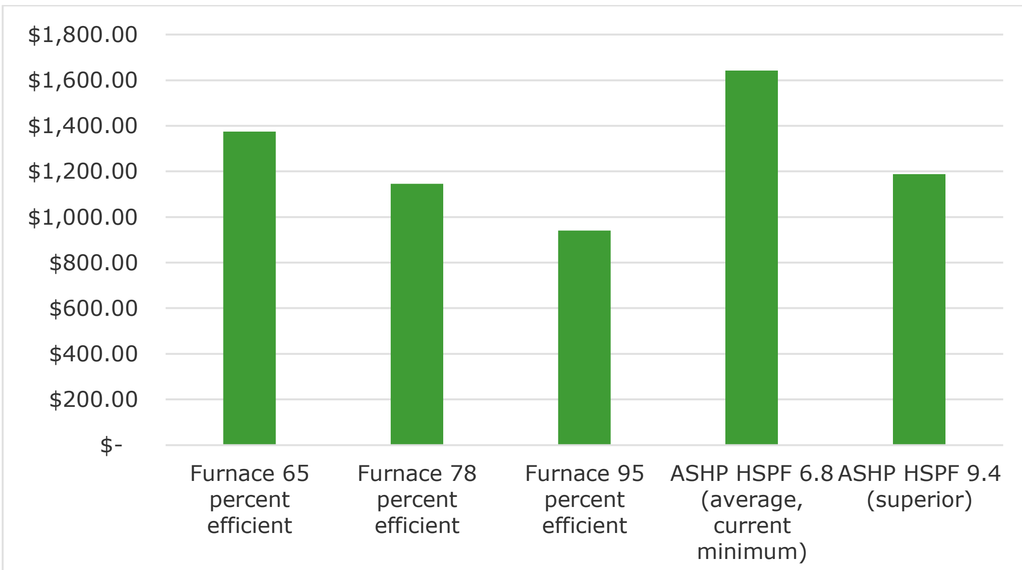
5.3 Economics of fuel switching

Significant economic barriers exist for adoption of heat pump technology. The economic barriers are driven by two key factors: high upfront costs of equipment and changes in annual operating costs, particularly when switching from natural gas to electric fuel types. Cities alone, due to limited influence, have trouble addressing the implications in operating costs when switching from natural gas to electricity (cost differential is rooted in artificially low price of Natural Gas); however, high upfront costs of equipment can be mitigated by cities with rebates and other programs.

The average natural gas price in Colorado is the lowest of any state, except North Dakota, which weakens the argument for fuel switching more here than in other states. The economic argument for switching from natural gas to electric sources depends not just on the cost of each fuel alone, but on the ratio of one to the other. Looking at this ratio can provide a useful “rule of thumb” for projected fuel operating costs when switching fuels. A higher ratio is better for electrification in this case, indicating more expensive natural gas and cheaper electricity. Using this ratio, Colorado ranks 47th out of the fifty states indicating a difficult case for ongoing fuel operating costs, even for efficient technologies like heat pumps.

Figure 26 provides a sample analysis comparing a range of natural gas furnaces and heat pumps shows the estimated annual costs for heating an average Boulder home (1,861 sq ft). This analysis assumes a natural gas cost of $0.78 per therm and 1$0.10 per kWh. Although heat pumps are more efficient, the high cost of electricity compared to natural gas makes fuel switching a barrier to implementation. This barrier is mitigated with a natural gas price of around $1/therm or when the system is paired with PV. A detailed financial analysis for HPWH can be found in Appendix A.

Figure 26. Gas furnace vs. HPSP annual cost comparison



5.4 Installation barriers

For ASHC installation configurations can vary greatly and costs can be significant, as seen in section 3 of this report. For HPWH, the installation barriers include needing an electrician and a plumber, as well as potential added electric panel capacity.

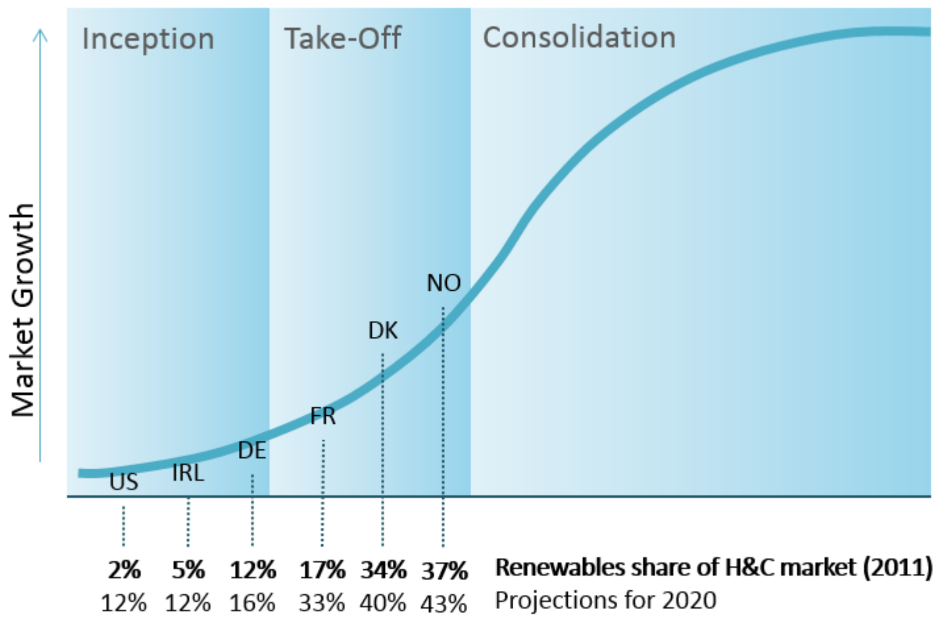
5.5 Split incentives

With approximately 50% (20,162 of the 42,165 housing units are owner occupied) of Boulder's housing stock being renter occupied, split incentives result as a barrier when dealing with household energy system upgrades. The owners are not motivated to upgrade to more efficient systems that may have a high upfront cost, as the benefit of reduced energy bills will only be for the renters. Even with incentives, motivation for the non-resident owners to spend on new systems lacks. On the other hand, tenants who are not paying their energy bill or pay a bill split between other tenants, creating a dissonance between energy use and costs, further distances the motivations to upgrade. A green lease agreement between renters and landlords can help bridge the split incentive issues.

6 OVERVIEW OF STRATEGIES

Strategies are designed to overcome barriers outlined in Section 5. The actions recommended for the city will be carried out in 3 phases, and will change as the market grows from inception (early adopter) phase, through take-off (early majority) and into consolidation (mainstream technology). Figure 27 shows the adoption curve and estimates of where various countries heating and cooling market penetration lies.

Figure 27. Adoption Curve for Heating and Cooling market



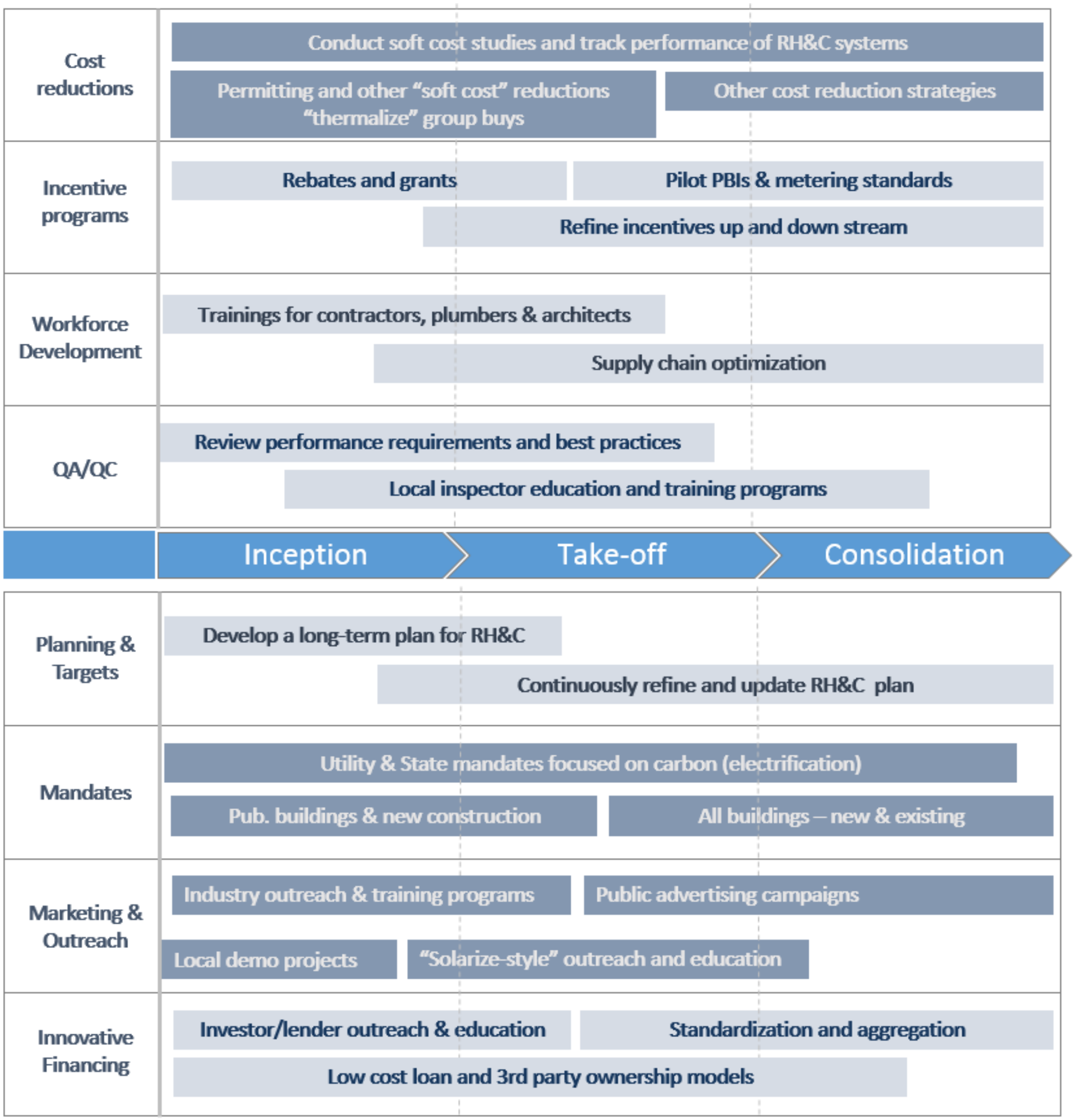
The three main strategy areas include:

1. Demand generation
2. Supply chain development
3. State and regional incentives and partnerships

For each of these areas, recommended strategies have been outlined. Figure 28 shows the Renewable Heating and Cooling Strategy roadmap with specific actions laid out over 3 phases of time: Inception, take off and consolidation into mainstream markets.

An example roadmap for the strategies for the City of Boulder is provided in figure 28.

Figure 28. RHC Strategies Roadmap



6.1 Strategy area 1: Demand generation

Objectives: Increase market demand for heat pumps and reduce soft costs

City Action Pathways: Demand generation depends on generating a desire for heat pumps on the consumer by increasing awareness of the benefits and breaking down the decision-making barriers systematically. Demand generation is most probably around the same customer segments that have been interested in Energy Smart Programs like energy efficiency/weatherization, and in solar PV and EVs.

6.1.1 Marketing & outreach

Actions:

- **Follow best practice on new technology outreach/marketing and behavior change programs.** Define value proposition for community and create targeted message campaign for each target group, along with pilot program launch. *It will be key to have incentives in place at this time to ease economic barrier.
- **Group purchasing campaigns-** use Group purchase discounts such as the Sunshares program which applies group discount for solar PV and Electric Vehicles.
- **Education and Training for contractors –** See Supply Chain Development
- **Innovation Program –** City to encourage clean electric technologies of all types through innovation hub, incubator, or formal public private partnerships.
- **Awareness Building -** To understand how to best build awareness in Boulder each consumer profile will need to be approached with their specific motivations in mind.
  - Consumers increasingly looking for efficient and safe options
  - Prevalence of inefficient heating systems in multifamily buildings
  - Customers claim HPs provide increased comfort, improved air quality, improved safety, increased home value, and lowered maintenance costs (NEEP, 2017)
  - Upon interviewing 20 residents who have done energy efficiency work through Energy Smart and own heat pumps the top motivations for the purchase decisions[6] were: Use with Solar PV/ to lower emissions, to Add AC; for Zonal control.

When this same Boulder sample of people were asked about the actual benefits of the heat pump systems were the following were the **top reasons: comfort, efficiency, lower bills, and quiet.**

Raising awareness at the consumer level with similar profiles of this sample would include speaking to their motivations to reduce emissions as well as to the benefits of the actual systems.

6.1.2 Planning and targets

See Section **4.1** for adoption target setting methodology.

In years 1-5, targets should be pursued by using the Radiant Labs tool and honing in on areas where heating/cooling/water systems are due to expire, as well as in areas where the top customer profiles reside, and where solar PV, EVs and energy efficiency are prevalent. Figure 29 lists the top building characteristics and social indicators evaluated to determine suitability of heat pumps.

[6] CU graduate student research, 2017

Figure 29. Building and Social Indicators of Heat Pump Suitability

Building Characteristics:

- **Building type**
- **Current heating fuel**
- **Access to gas heat**
- **Age of heating system**
- **Current cooling technology**
- **Building and lot size**
- **Current heat distribution equipment**

Social Indicators:

- **Home owner**
- **Income**
- **Education type**
- **Age**
- **Energy efficiency program participant**
- **EV owner**

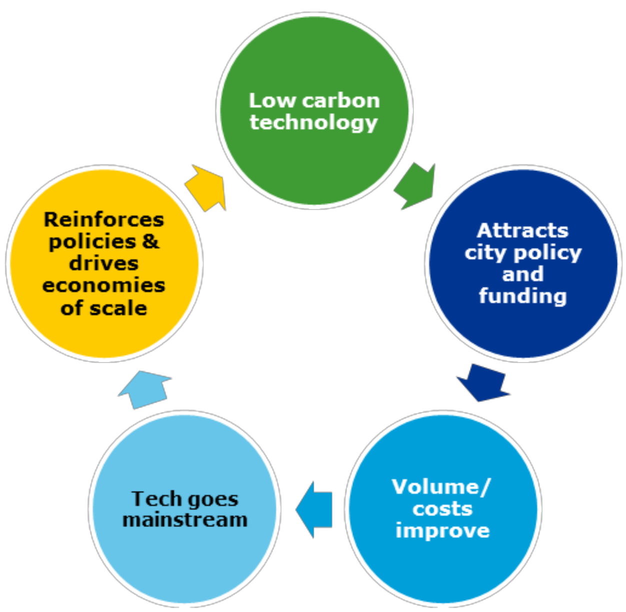
Actions:

- Set and adopt targets
- Use Radiant Labs tool to track progress and refine targets

6.1.3 Mandates

Mandates are a pivotal demand generator as well as financial catalyst that stimulates market growth for new technologies. The cycle of policy, financial markets and clean technologies is illustrated in Figure 30.

Figure 30. New technology policy and finance cycle



Actions:

- Begin with voluntary mandates and reach codes, and pilot programs for RHC, while continuing to advocate to change State Level policies and levies that continually subsidize natural gas. Provide plenty of recognition and rewards for early adopters, work pathway to mandatory codes such as electrify upon sale/lease turn over/etc.

6.2 Strategy area 2: Supply chain development strategies

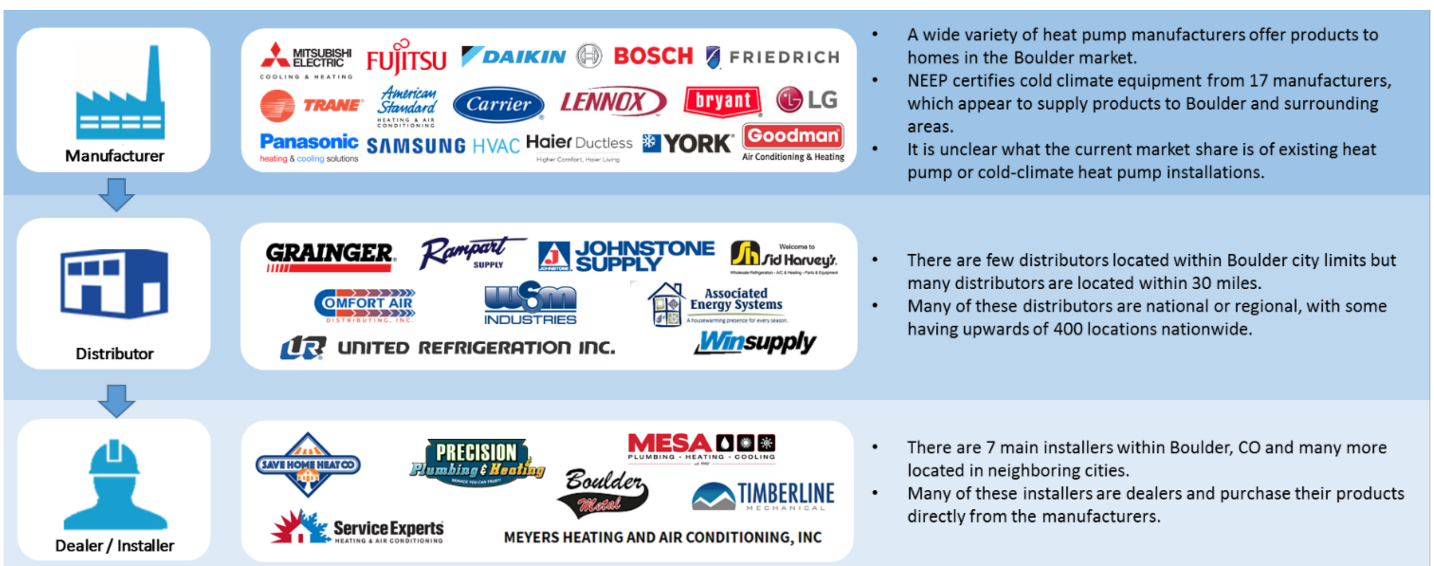
- **Targeted stakeholders**: Local conferences, distributors, manufacturers, and supporting industries
- **Objectives**: Improve installation quality, reduce soft costs, increase customer demand
- **City action pathways:** Training, certification, and workforce development program

6.2.1 Workforce development

The crux of demand generation lies with the contractors who install heat pumps, thus supply chain development is fundamentally a strategy for demand generation. The core supply-chain distributors are shown Figure 31.

Distributors will stock heat pump systems more if contractors are selling them frequently. Similarly, if contractors take time to educate consumers about the benefits of these efficient, non-fossil fuelled systems, including non-energy benefits (safety, costs, pollutants, noise, comfort), the demand for heat pumps will soar. Yet, contractors will need training and support to become the community's **energy transition advisors** who create demand on the customer side, and by increasing sales also encourage distributors to keep more heat pump systems in stock. Distributors play an important role in the appliance market and are a consolidated leverage point that can touch the wider local network and supply chain. Contractors will need to be trained in heat pump technology benefits, installations, financing options to create the market transformation needed in the thermal sector.

Figure 31. Core supply-chain actors in Boulder



Actions:

- Inventory and leverage existing trainings and training networks
- Develop new installer trainings or certification programs

- Develop and update lists of qualified installers
- Create a knowledge portal for the workforce to access technical, marketing, and training resources
- Conduct outreach and interviews to assess gaps in the supply chain

6.2.2 Training and certification program for contractors

Actions:

- Develop training and certification program for Contractors (with support of manufacturers/distributors) together with a rewards and recognition system. Coordinate incentives or offer 3rd party financing options- train contractors on financing options.
- Create a training tract for energy transition advisor – someone that can be on call to help community members who wish to electrify their energy use (get an EV, Solar, or Heat pumps). The household/personal transition is not easy so having help available to walk people through the various steps will greatly increase the number of people who make the leap. As part of training, set up a rewards system for number of installations as way to track installations.

6.2.3 Target design builders for new construction

Actions:

- Making a clear case for all electric new construction and supporting builders/developers in knowing about the benefits and best systems to install. Conduct Design competitions and get the community involved.

6.2.4 Existing buildings: Audits, certification programs and disclosure requirements

Measuring building/home performance and comparing against similar buildings presents building owners with tangible economic benefit of high-efficiency RHC equipment. The data can help building owners, managers and occupants make smarter energy use and administrative decisions.

Influence new construction market as soon as possible—focusing on ductless systems; and for existing buildings work with ducted and ductless options.

Actions:

- Develop benchmarking, audit, and retrofit program

6.2.5 Key city to distributer connection

Actions:

- Work with distributors to highlight ASHP and HPWH technology options, work with them to support their promotion (offer messaging and training support) and stocking of heat pumps.
- Leverage sales cycles – before winter or heat waves.
- Work with midstream incentives to alleviate high upfront costs.
- Share Data aggregation/segmentation results with distributor

6.2.6 Emergency replacement preparation

Distributor and contractor development actions are necessary to ensure that heat pump systems are in-stock so that when a system fails a natural gas system is not installed just because it is the only one on the truck/in stock. Most water heater replacements are emergency replacements, rather than planned, which means that more awareness and education is needed in the retail channel. Similarly, AC needs can arise up during a heat wave. The moment customers want to add air conditioning, this is a golden opportunity to switch heating and cooling system to a heat pump, as both loads can be met with one piece of equipment.

Actions:

- Create emergency replacement program and hotline, in partnership with suppliers

6.2.7 Market partnership strategies

- Partnerships are targeting addressing: Lack of customer awareness; Reduce customer acquisition costs; Increase interest in further supply chain development within industry

Actions:

- Develop QA/QC and certification program in collaboration with manufacturers
- Utility Partnerships- Agreements with the local utilities to coordinate efficiency program adoption and incentive mechanisms allows city planners make smarter decisions about energy efficiency goals.

6.3 Strategy area 3: State and regional incentives

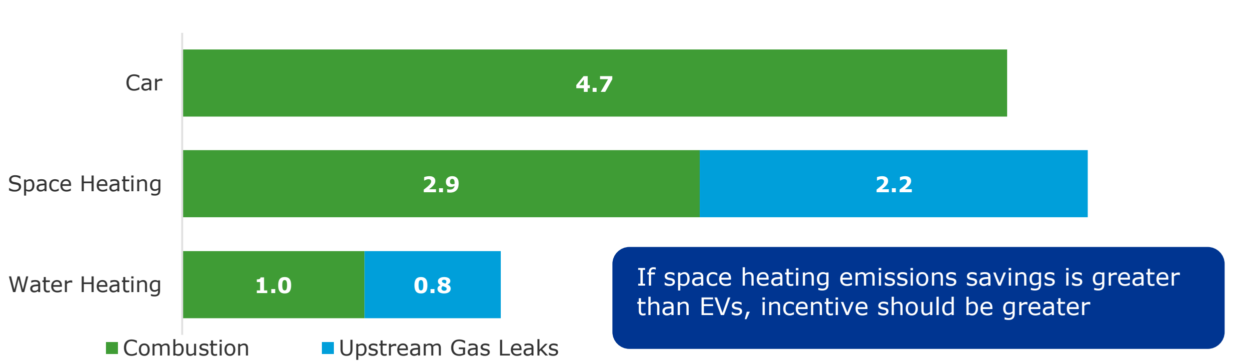
While Cities can put forth small scale incentive programs, it is only with State and Utility backing that incentives can move the critical masses to change energy prices to reflect carbon impacts, and policies that support renewable energy and electrification.

- **Targeted stakeholders:** State policymakers, regulators, and utilities
- **Objectives:** Establish long-term funding streams and policy support for heat pumps; access utility programs and resources
- **City action pathways:** Establish partnerships and stakeholder working groups, implement innovative financing programs, lobby at the state level.

6.3.1 Balanced incentives/rebate approach

Colorado currently has the highest electric vehicle incentive in the United States, at $5,000 per vehicle. In a 100% renewable future, the carbon emissions reductions potential of each electric vehicle is 4.7 metric tons (top green bar in Figure 32). The equivalent emissions reduction potential of electric space heating is 5.2 metric tons, with electric water heating at 1.4 metric tons. While thermal electrification at the home has a carbon emissions reduction potential 50% higher than that of vehicle electrification, the available incentives offered are 80% lower. If emissions are driving incentives, a balanced incentive program in Boulder/CO would offer $5,300 for electrification of space heating and $2,000 for hot water.

Figure 32. Emissions reduction potential of Boulder electrification strategies (MT CO_2e)



Actions:

- Regional Stakeholder Engagement: Boulder works with other Colorado Cities to advocate at the state level for a balanced incentives approach, based on electric vehicle rebate best practice. As with any successful HP incentives program, there are numerous pathways and methods deployed simultaneously, policy and program options evolve toward low carbon/renewable energy focus, while each stakeholder group (customers, industry representatives, and policy makers) coordinate to be able to move incentives/markets effectively.

  For example, **expanding on rebates** already offered by EnergySmart program (www.energysmartyes.com) and/or Efficiency Works (https://efficiencyworks.co/for-home/home-efficiency-audits/) as a starting point, or working to integrate heat pumps into the Home Repair Program that provides low-interest loans for health and safety repairs and energy conservation measures (up to $25K).

- Rebates at time of permit: Building permitting can use economic incentives as well, such as instituting a fee for new gas or oil hookups. Establish streamlined permitting and reduced fees for electric space heating equipment, or even adding a rebate at time of permitting to incentivize permit compliance and improved tracking.
- Along with the regional and state incentive advocacy, the city can align other actions such as permitting cost reduction, establishing/realigning incentives, training programs, and messaging with solar, efficiency, and green building efforts in the City.

6.3.2 Innovative financing strategies for electrification

Financing is essential to expand availability of capital to early heat pump adopters, lower cost of capital; reduce transaction costs, and time to access capital.

Direct cash incentive payments promote the adoption of high-efficiency equipment, while bonds, mortgage financing, loans, credit lines and tax incentives can bring projects with initial investment barriers needed financing to new technologies. To overcome economic hurdles of fuel switching technologies, amortizing funding mechanisms are particularly useful. Pricing must be consistent with or slightly better than borrowers could achieve borrowing directly in the market. Property Assessed Clean Energy programs or ESCOs have great promise in this regard.

Facing the cost versus the price of electricity – Electrification means the switching of one energy source (fossil fuel based) to clean electricity as a "fuel". Making sure that electricity is affordable is therefore a key concern to incentivize electrification. Electricity bills are unfairly and increasingly burdened with **policy related costs** from federal to state levies. This is further addressed in Section 7.

Actions:

- Developing low-cost loans and 3rd party ownership opportunities for heat-pumps will be key, non-policy related actions to financing.
- Institute PAYS model as a financing mechanism likened to on-bill financing, using a utility tariff approach to enable the utility to finance the purchases of heat pumps (http://cleanenergyworks.org/blog/pays-financing/)
- Establish guidelines for thermal energy metering (See: Renewable Thermal Alliance and Standardization Working Group[7])
- Pilot 3rd party ownership models like Green Mountain Power Heat Pump Leasing Program[8] (15-year lease, $42/month for single zone ductless mini-splits)
- Work with Green banks to deploy credit enhancements (loan guarantees)

6.3.3 Midstream vs. upstream incentives

Incentives strategies vary by jurisdiction but best practices indicate the top strategies to be:

1. **Putting Cash in Constituent Pockets:** Particularly the midstream incentive, meaning it goes to the installer/contractor or it is left up to them to decide if/how they want to pass the savings onto the end user.
   - The Efficiency Maine story for HPWHs (mentioned in case studies) is the best story: $750 incentive on a $250 price tag (cost competitive with NG systems) and the state plumbing inspector put a HPWH in his house to further proselytize the benefits.
   - Success story: $500 Visa Card given to contractors who install 5 heat pump systems from certain manufacturer.
2. **When You Replace Your Furnace, We'll Pay to Upgrade to Air Conditioning!**

Actions:

- Creating a city program that uses messaging and money to move consumer awareness and to act when system fails
- Work with manufacturers to get midstream incentives in installers pockets

6.3.4 Cost reductions

An important RHC Goal: Reduce manufacturing, installation, and administrative costs of heat pumps to make them more price competitive against conventional gas technology.

Many jurisdictions have developed a variety of strategies to address the upfront costs of equipment, including soft cost reductions through lead generation, increasing competition, or DIY options. Options also

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[7] http://cbey.yale.edu/programs-research/renewable-thermal-alliance
[8] http://products.greenmountainpower.com/product/ductless-heat-pump/

exist for reducing hard costs including bulk-buy deals and financial incentives. This has happened over decades in energy efficiency technologies, and best practice can be applied for the heat pumps as well.

Actions:

- Soft cost reduction through community procurement campaigns (e.g., thermalize)
- Tax abatements or local tax exemptions
- Fast track permitting processes
- Use Radiant Lab customer targeting and engagement tool to improve installing in clusters
- Standardize equipment specifications through incentives or industry supply chain outreach actions
- Provide technical assistance for large projects and improve information available for all projects

7 POLICY & PROGRAM RECOMMENDATIONS

Boulder is a sustainability leader and is driving toward renewable energy and becoming a carbon neutral city of the future. Carbon neutral construction and all electric codes will be necessary to get there. However, energy code awareness and compliance are difficult to administer and track in existing buildings, thus the existing building HP energy system conversions will rely heavily on the training and education strategies to ensure contractors are replacing old systems with heat pumps instead of like for like replacements. While codes can effectively change how with new structures are built.

Policy Objectives: Accelerate adoption of heat pumps through mandating use in buildings and establishing carve-out/obligation in state Renewable Portfolio Standards (RPS).

City action pathways summary:

- Establish "Leading by Example" requirements for thermal energy
- Establish building/energy code mandates (or local laws/amendments) for heat pumps (especially in new construction and major renovation)
- Develop ZNE building code requirements
- Advocate for thermal obligation in state RPS

7.1 Integration with Boulder energy codes

- Removing emissions from local heating in our buildings and cities, which traditionally run mostly on fossil fuels, can be enabled through energy codes. Appropriate, innovative policies enable these clean technologies to become cheaper, more flexible and bring more benefits to consumers faster.
- The additional energy policy costs will need to be spelled out, as they are currently added disproportionately to power bills (compared to gas or oil bills) making electricity more expensive to customers than fossil fuel alternatives.
- Policy enables financial investments by de-risking the perception for investors.
- Other factors which enable electrification, such as innovation and smart grids, can significantly increase the speed and benefits brought about by electrification. The current policy obstacles in these fields must therefore be addressed and removed simultaneously.
- The 2017 City of Boulder Energy Conservation Code (COBECC) is a great start. The COBECC outlines the minimum energy efficiency and conservation standards for new buildings and for additions and alterations to existing buildings to promote public health, safety, and welfare by requiring design and construction of buildings in the City of Boulder consistent with the city's energy, climate and sustainability goals adopted by City Council on December 6, 2016:
  - 80% reduction of the community's greenhouse gas emissions below 2005 levels by 2050
  - 100% renewable electricity by 2030 and ZNE buildings by 2031
  - Targets and tracking of heat pump programs is an essential component of the GHG reductions

Boulder has adopted increasingly aggressive energy codes and will continue on this path.

Energy codes relevant to Air Source Heat Pump systems:

- COBECC Sections R401.2.1 and R401.2.2.2 establish an Energy Rating Index (ERI) required for all new residential construction projects over 500 sf and residential construction projects adding more than 1,000 sf to existing homes.

- COBECC Section R401.2.3 outlines alteration or repair compliance requirements. For alterations or repairs with a valuation of less than 26% of assessed value of existing building, the homeowner must contact a qualified energy advisor, as defined by the city manager, receive an energy assessment, and discuss the construction project to learn how efficiency opportunities can be maximized. Projects with 26 to 50% of assessed value can choose the same requirement or comply with specific new construction requirements. Projects over 50% assessed value must follow all new construction requirements.
- COBECC Section R403.6 outlines mandatory "equipment sizing" for heating and cooling equipment
- 2012 IRC M23 outlines that all new construction is required to **be solar ready** including:
  - 40% of roof area designated for PV (no obstructions or shading)
  - Locate and provide space for future required electrical equipment (inverter and meter)
  - Install conduit from roof to future electrical equipment location
  - Main electrical panel shall have space for future solar
  - Structural live and dead loads included in roof design

7.2 City Permitting Process Upgrade

The permitting process can be utilized to provide rebates to contractors within and outside of the energy smart program, and additional information about the equipment being installed can be captured.

Radiant Labs tool parses and categorizes permits, companies, and owners using a combination of natural language processing, machine learning, and human-defined categorization criteria. When these permits are published monthly, all homes can be updated with the new improvement information, which also updates the cohort. This will track the date, equipment type, and equipment efficiency for what was is installed in each home.

For example, a contractor would typically write something like this in the permit description:

> *"Install a new ductless mini split and add wiring for the unit."*

To get the rebate for the equipment, the contractor simply needs to write the following instead:

> *"Install a new ductless mini split and add wiring for the unit. [Mitsubishi, Ductless, SEER: 12, HSPF:10.5]"*

For equipment such as water heaters, specs populate automatically based on the model number. Mini splits have multiple model numbers so some specs need to be listed.

The suggested permit process upgrade can flag new candidates for whole home upgrades. Contractors working outside of the Energy Smart program could take advantage of rebates for the types of equipment the city wants to subsidize. When those permits show up in the database system, they are then automatically flagged as great candidates to take other steps such as solar PV, efficiency, or an electric car.

7.3 State & Federal policy actions

To move toward a carbon neutral building stock, state and federal policy must be addressed.

State level: Advocate for thermal obligation in state RPS and work for state level tax on natural gas (and other fossil fuels); also for state level incentive deployment following solar PV and EV pathway. Work with the state on a performance-based incentive program and REC program.

Federal Level: Appoint a lobbyist to work on Boulder's behalf against natural gas subsidies, levies and outdated calculations that keep fossil fuel prices artificially low.

City actions:

- Work with other cities on national media campaigns
- Work through organizations like climate Mayors to create multi-city programs, bankable deals and group procurement opportunities
- Create Sate working group to collectively work with industry representatives and policy makers; follow energy efficiency and solar best practice on methods to deploy policy ad program options across stakeholder groups

City actions:

- Expand COBECC Section R401.2.3 that requires an energy advisor consult for certain projects into a free advisory service for energy efficiency improvements (such asNYC Retrofit Accelerator)
- Piggyback on solarize-style campaigns and solar requirements to include the benefits of electrification and solar PV power and readiness
- Integration of heat pumps into Home Repair Program that provides low-interest loans for health and safety repairs and energy conservation measures (up to $25K)

7.3.1 Carbon tax on natural gas

A carbon-based metric must be used to affectively address greenhouse gas emissions. Current energy based metrics are outdated and policies favouring natural gas cannot deliver full decarbonization. Taxes and levies are the major drivers of price increases in the power sector, and now is time is turn the tide toward true costs of carbon. A carbon tax on natural gas is a tool to lower consumption and fund electrification or power systems.

A carbon tax is a starting point for adjustment of the existing methodology used for calculating the primary energy factor, which should be calculated to include externalities and send accurate of the signals given to investors and decision-makers enabling them to select the best technologies in terms of economic and environmental sustainability. Even a small tax on Natural Gas that would make the price upward of $1/therm would make the cost/benefit analysis of heat pumps for many residents in Colorado a win for their bottom line and for future generations, as well as for the overall comfort and safety of their home.

8 PILOT PROJECT IMPLEMENTATION OVERVIEW

8.1 Renewable Energy Home Roadmap (Radiant Labs)

The City, using Radiant Labs tool and home roadmaps, and in partnership with heat pump manufacturers, will work to launch a pilot in 2018 including energy efficiency, solar PV, electric cars and electric heat pumps (space and water heating). The pilot hopes to leverage group buy purchases of ASHC and HPWHs through a multi-city collaborative.

8.1.1 Smarter grids and microgrid networks

An electricity grid which can integrate smart electric equipment intelligently and reward customers for intelligent use is a major enabler for the transformation of the energy system, and is becoming the business model of the future. The smart grid and smart meters can integrate behaviors and actions of all its users and can encourage consumers, to actively manage their energy demand, such as enabling them to shift their power consumption to times of lower prices. Technologies such as blockchain enable consumers of energy to become prosumers, also selling or benefiting from their efficiencies and excess energy. There is a a new use of grid enabled heat pump water heaters being used and smart grid storage. Shifted Energy deploys fleets of HPWHs as a networked virtual storage system; 1,000 water heaters can be managed as an equivalent to 3MWh of storage.

8.1.2 Strengthening supply through distributed energy resources, diversification and storage

Beyond the environmental benefits, electrifying thermal loads contributes to energy efficiency and increases security of supply, while creating affordable and responsive systems. Electrification combined with distributed energy resources allows for greater flexibility in selecting the energy source and thus strengthening security of supply.

8.1.3 Demand response

Being able to use electric vehicle batteries or electric appliances (e.g., water heaters) as flexible demand and as decentralized energy storage also brings additional benefits to customers of such products. On the one hand, they are no longer relying on fossil fuels and their volatile prices. The parallel development of demand response options for consumers makes electric solutions more valuable over fossil fuel alternatives. Electric solutions increase the potential to influence the bill with demand response, effectively giving more power to the end user.

City actions

- **Engagement between utilities and electric regulators** to assess long-standing policies and investment practices for fuel-switching, recoverable utility investments, etc.
- **Modification of retail rate designs to encourage electrification** for example, inclining block rate structures, electric space heating tariffs, time of use rates, etc.)
- **Assess new business models for utilities** to provide heating and cooling services such as new customer acquisition, financing programs, load management/balancing services

APPENDIX A HEAT PUMP WATER HEATER UPGRADE COST

Financial analysis of HPWH: By John Bratton and Mallika Jayaraman

Overview: The following memo outlines the energy and financial implications of upgrading a standard natural gas water heater (NGWH) to a highly efficient heat pump water heater (HPWH). The analysis looks primarily at the effect the switch on annual utility bills and net present value (NPV) for HPWHs of different efficiencies.

Methodology: This analysis used two calculators to examine changes in annual costs resulting from choosing a HPWH over a standard NGWH. The first calculator was developed by Carbon Free Palo Alto.[9] This calculator includes detailed financial assumptions, including default costs for installation labor, removal of the old water heater, and permitting. However, the energy use calculations are simplistic, using a per person estimate of energy needed to heat water annually adjusted by the number of people per household and the efficiency of the electric and natural gas water heating units. Therefore, calculations were checked against a second, internally developed calculator, which uses engineering calculations from Xcel Energy's 2017-2018 Demand Side Management Plan[10] to calculate changes in energy use. The two calculators provided fairly similar estimates on the change in utility bills with the installation of a HPWH, and always agreed on whether bills increased or decreased. As the savings or cost increases approached zero, the magnitude of difference between the two calculators also decreased. Net present values were calculated using the internal calculator, as it allowed application of a discount rate over the lifetime of the equipment. Carbon emissions reduction were calculated using the Carbon Free Palo Alto calculator.

The HPWH units examined were selected from the NEEA Advanced Water Heater Qualified Models[11] list (Table 4). One 50-gallon HPWH from each of the three dominant HPWH manufacturers was selected. The 50-gallon size was used because it is designed to serve a home of 2-3 people, and the average home size in Boulder is 2.42 people.[12] The lowest listed online price was used as the input for equipment cost.

Table 4. Heat pump water heater models and costs

Manufacturer	Energy Factor	Supplier	Cost
A.O. Smith HPTU 50 120	2.9	Global Industrial	$1,205
Bradford White RE2H50R10B-1NCWT	2.8	Not listed	N/A
Rheem PROPH50 T2 RH350 D	3.2	GP Conservation	$1,289

Calculations were run for both an older house scenario and a new house scenario, to capture the varying price of the required electrical upgrades. While the older house model requires both an electrical panel and

[9] Carbon Free Palo Alto. (2013). Electric vs. Gas Water Heating Costs Palo Alto [Excel workbook]. https://www.dropbox.com/sh/yint62e96ns1l2u/AAC425vtDceS99UflNmZlV6Aa/Electric%20vs.%20Gas%20Water%20Heating%20Costs%20Palo%20Alto%20%28v1%29.xlsx?dl=0.

[10] Xcel 2017/2018 Demand-side Management Plan, Proceeding No. 14A-057EG, pdf pg 394-395.

[11] NEEA. (2017). Advanced Water Heater Specification Qualified Products List for Heat Pump Water Heaters. http://neea.org/docs/default-source/advanced-water-heater-specification/qualified-products-list.pdf

[12] Boulder Economic Council. (2011). Demographic Profile Boulder, Colorado. https://www-static.bouldercolorado.gov/docs/boulder-demographic-profile-december-2011-1-201305151232.pdf. In the Palo Alto calculator, this estimate was rounded up to 3 to establish a conservative energy savings estimate.

circuit branch upgrade, costing a combined $1,950, the new house model only required the circuit branch upgrade, costing only $450. More information on this and other model assumptions can be found in Appendix A.

Findings:

- Without solar, none of the units have positive NPVs, although the highest efficiency unit installed in the new home almost breaks even. The total upfront cost of the HPWH in the newer home is $189 more expensive than the NGWH, considering labor costs and county and utility rebates (Table 2). In the older home, the price difference is much larger at $1,689, driven primarily by the $1,500 electric panel upgrade. This results in a much lower HPWH NPV for the older home.
- The annual utility bill savings for the two homes are the same, since the electrical upgrades were the only variables modified between the old and new home scenarios. For the highest efficiency unit (Rheem; EF =3.2), annual bill savings exist, but are relatively small. For the lower efficiency A.O Smith unit (EF = 2.9), the bill savings are even smaller, when switching to a HPWH. For the lowest efficiency of the three units (Bradford White, EF=2.8), annual bills actually increase by a small amount. Even with the high carbon energy mix of Colorado's electricity grid, carbon emissions are cut in half by the switch to the highest efficiency water heater.

Table 5. NPV and annual bill savings resulting from HPWH installation

Manufacturer	NPV Old Home (internal)	NPV New Home (internal)	Annual utility bill savings (Palo Alto)	Annual utility bill savings (internal)	CO2 savings in kg (Palo Alto)
A.O. Smith HPTU 50 120	($1,586.24)	($86.24)	$2.01	$2.37	12,709
Bradford White RE2H50R10B-1NCWT	N/A[a]	N/A[a]	($4.64)	($5.50)	12,211
Rheem PROPH50 T2 RH350 D	($1506.79)	($6.79)	$19.47	$23.02	14,016

[a] Value cannot be calculated because upfront cost is unknown

- In the new home, while the cost difference between the HPWH and the NGWH are not that large, particularly when considered over the lifetime of the equipment, we've learned from other program managers that customers can be very price sensitive when it comes to the upfront cost of these units[13]. However, it may be possible to overcome this price difference by highlighting better environmental performance or increased safety of these units over NGWHs.
- Another option to address the cost barriers to switching to a HPWH may be to install solar. Since solar provides a lower per kWh operating cost than the residential rate for electricity, installation of solar in conjunction with a HPWH can help make this a more cost-effective option. As shown below (Table 3), the addition of solar to cover the HPWH load makes all HPWH models cost-effective from a NPV standpoint in the new home, but not in the old home. However, solar installation does result in annual utility bill savings in both the old and new homes. Therefore, bundling these measures may make HPWHs a more compelling option for residential customers, particularly in customers with newer homes.

[13] Mills, J. (June 27, 2017). Personal Interview.

Table 6. NPV and annual bill savings resulting from HPWH switch with solar included

Manufacturer	NPV Old Home (internal)	NPV New Home (internal)	Annual utility bill savings (Palo Alto)	Annual utility bill savings (internal)
A.O. Smith HPTU 50 120	($859.78)	$640.22	$79.60	$94.13
Bradford White RE2H50R10B-1NCWT	N/A[a]	N/A[a]	$75.72	$89.55
Rheem PROPH50 T2 RH350 D	($848.43)	$651.57	$89.78	$106.18

[a] Value cannot be calculated because upfront cost is unknown

Rate structure impacts:

- Xcel Energy, the utility currently serving the City of Boulder, offers two main type of service: Residential General Service and Residential Demand Service. According to Xcel, customers with no gas service or with several large electric appliances may be better served by Residential Demand Service[14].
- For Residential General Service, which is the default for Xcel customers, Xcel implements a tiered rate structure, which takes effects between June 1st and September 30th. During these months, the first 500 kWh cost $0.05461 and all additional kWh cost $0.09902. Average monthly electricity consumption in Colorado is 706 kWh per household[15], so it is possible that adding a HPWH would result in additional kWh consumed in the second tier. This consumption results in an annual increase of $29, compared to a scenario in which all energy is consumed in the first tier, as modelled in the sections above. In the case of the non-solar installation, this increase in costs could be enough to offset any annual utility bill savings generated by the HPWH.
- The impact of residential demand service was not calculated; demand charges are determined based on the highest period of demand each month for the residential consumer. Insufficient data was available to determine what the baseline demand was and how HPWH installation would impact that demand. However, residential demand service may be a good option for customers with higher electric loads, because of installing several electrification measures.

Model assumptions:

- **Rebates:** $500 rebate from Boulder and $450 rebate from Xcel (see https://www.dropbox.com/s/ylfww3q5kiy3s47/Existing_incentives.xlsx?dl=0).
- **Energy costs:** Electric cost is $0.12/kWh and gas cost is $0.76/therm. If solar is installed, electric cost is $0.07/kWh (based on the Radiant Labs tool).
- **Soft costs:** Costs for labor ($400), removal and disposal of old water heater units ($80), and permits ($120) were drawn from the Carbon Free Palo Alto calculator. These costs were the same for both the HPWH and the NGWH.
- **Electrical upgrades:** There are two main upgrades that may be required for a HPWH installation. The first Is an electrical panel upgrade from 100A to 200A. This upgrade is only needed for older homes, as newer homes generally have sufficient electric panel capacity. This upgrade can range from $1000-$2000, depending on the complexity of the upgrade. The midpoint, $1500, was used for the older home upgrade calculation. The second upgrade required for HPWH installation is adding a 30A circuit branch.

[14] Xcel Energy. (2017). Colorado Residential Electric and natural gas rate schedule summaries. https://www.xcelenergy.com/staticfiles/xe/Regulatory/COResRates.pdf.

[15] Electricity Local. Boulder, CO Electricity Statistics. http://www.electricitylocal.com/states/colorado/boulder/.

The cost of this upgrade varies between $300-$600, depending on how far away the water heater is from the service panel. The midpoint of $450 was used for both older and newer home upgrades. Upgrade cost estimates obtained from Fuel Switch.

- **Engineering assumptions:** Default engineering assumptions were drawn from the Xcel 2017-2018 demand-side management plan (see https://www.dropbox.com/s/ojkjn04letg8ul5/HPWH%20calculator.xlsx?dl=0 for calculations)
- **Carbon emissions:** Colorado electricity emissions are 0.599 MT/MWh according to Xcel Energy. (2016). Energy and Carbon Emissions Reporting. https://www.xcelenergy.com/staticfiles/xe-responsive/Environment/Carbon/Carbon-Reduction-2016-Energy-and-Carbon-Summary.pdf
- **Discount rate:** The discount rate is 4.49%, which is the DOE's recommended discount rate for residential energy efficiency. From Dupuy, Max. (2015). "The Treatment of Discount Rates and Energy Efficiency Costs in EU Policy Scenarios." *Regulatory Assistance Project*. http://www.raponline.org/wp-content/uploads/2016/05/rap-discountratesee-2015-may.pdf.

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