The Energize Denver Renewable Heating and Cooling Plan – Technical Appendix

Resilient Existing Building and Homes

June 2021
APPENDIX A – STAKEHOLDER ENGAGEMENT METHODOLOGY AND DETAILED FINDINGS

Methodology

Two hundred and four community members were engaged through several outlets, allowing the opportunity for diverse voices to be heard, including:\(^1\)

- Under-resourced and people of color (POC) residential informational interviews.
- Under-resourced and POC residential online surveys.
- Six advisory group charettes.
- Two workforce roundtables.

Our approach was designed to introduce the very technical concept of electrification in an easily understandable way to community members while providing a forum to objectively collect data. We wanted to uncover knowledge and insights gained through life experience that might be missed in a purely technical and theoretical analysis. After hearing from community members, particularly those who could be impacted most by building policies, benefit most from solutions, and bear the greatest burden of climate change and its effects on public health, our goal was to design a better and more equitable building electrification implementation plan.

MOBILE HOME CONSIDERATIONS

We discussed including people who live in or rent mobile homes but ultimately decided that an electrification transition plan would not provide the most value to these residents. Energy Outreach Colorado’s (EOC) analysis showed that mobile homes comprise less than 1% of Denver’s under-resourced neighborhoods.\(^2\) Previous studies have shown that electrifying mobile homes can be difficult if not impossible due to space constraints and junction boxes. In addition, many mobile homes are being decimated for developers to benefit from the land value, displacing residents.

Our recommendation is to partner with affordable housing programs to find a suitable arrangement for displaced residents and to consider replacing current mobile homes with net zero emission modular homes. Today’s primary electrification strategy should focus on homes and buildings.

Feedback from Denver’s Stakeholders

UNDER-RESOURCED AND POC COMMUNITIES

Summary of Feedback

Gas appliances are most common. Results from the informational interviews showed that gas appliances are the most common. The online survey indicated higher electric adoption rates for dryers

\(^1\) Our original stakeholder engagement approach was modified to accommodate COVID-19 safety recommendations.

\(^2\) Analysis from EOC’s database.
and stoves, with a fairly equal breakdown between renters and homeowners. This is supported by our research.

**Most people are open to using electric space and water heating.** Most respondents were receptive to using electric heating and water heating if there were no cost increases relative to gas appliances. The positive environmental impact of making this switch appealed to people, and the primary concern was the additional upfront costs associated with electric equipment. Online respondents noted they would be more encouraged to use an air source heat pumps (ASHP) if it provided both space heating and cooling.

**There is not an overall preference for gas versus electric cooking.** Nearly all informational interview respondents indicated that they strongly prefer cooking with gas and view electricity as an inferior cooking source. However, homeowners and renters who responded to the online survey preferred electric stoves.

**Few homes have central air conditioning.** About 10% of our informational interview respondents and 50% of our online survey respondents stated that they have central air conditioning, while the majority of the households cool their homes with traditional fans, window units, and swamp coolers. Many of these units are not fully functional, however.

**Most people understand the primary benefits from using electric appliances.** Among the survey respondents, most homeowners and renters stated that electric appliances are safer to operate, better for indoor air quality, and cheaper to purchase than gas options. However, there was no consensus about which type of appliance was cheaper to run once purchased. Many were unaware that ASHPs also could provide space cooling.

**Emergency replacements are the primary reason for upgrades.** Overwhelmingly, respondents indicated that they only replace appliances when they break and cannot be fixed, supporting research findings.

Lacking access to credit compounds the frustration of emergency replacements.

**Many households have forgone gas or electricity because they could not afford their utility bills.** Even when including those who receive energy assistance, a majority of respondents still struggle to pay their utility bills.

**An overwhelming majority of renters do not have any control or say as to which appliances are installed in their homes.** Of those who would expect their landlord to intervene, 86% believe they have no say in what type of appliance would be installed.

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3 A gas perception study conducted by Consumer Research Associates titled “Healthier Colorado: Building Electrification” indicates that most of their surveyed respondents were not aware of the benefits of electric appliances. Our under-resourced respondents had been previously part of an energy efficiency program with EOC. Their exposure to energy efficiency may have helped them be more aware of the benefits of electrification than someone who had not participated in EOC's program.
Main Considerations for Transitioning Technology

Feedback received from under-resourced and POC household engagement tells us that the main considerations for replacing home appliances are (see Figure A1):

1. Safety.
2. Reliability and cost.

Safety was cited as the number one concern in both individual household calls and online surveys. Equipment reliability and cost vied for the second most important consideration by both groups surveyed. Respondents who provided feedback by phone noted energy efficiency as the next important consideration, while survey respondents noted impacts on health.

The feedback provided through our engagement supports findings from other organizations such as Greenlining Institute, which advocates for energy solutions that “… focus on health, affordability, safety, and access and THEN climate.”

In Denver’s case, equipment reliability should also be a key focus.

Other gas perception surveys conducted by Climate Nexus and Sierra Club show similar results with safety is the leading consideration followed by health impacts. Cost considerations are also near the top but are not the leading consideration when purchasing new equipment. ii, iii

Barriers to Change

There are multiple barriers to electrification for under-resourced and POC communities, including:

- **Economic barriers.** Many under-resourced households do not have easy access to capital and are unable to cover the upfront cost of new appliances. The energy burden is higher for these communities and adding another energy-related cost may be prohibitive.

- **Split incentive barriers.** Many under-resourced households are renters who do not have the authority or control when making new appliance purchase decisions. Accordingly, many of these homes are older and do not receive regular home upgrades. There are few incentives for landlords to invest in electrification when only the tenants benefit.

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ii This statement was recorded during a Building Decarbonization Coalition webinar. The Greenlining Institute was discussing their philosophy on equitable energy programs.
• **Regulatory barriers.** There is a lack of alignment between programs that focus on health, efficiency, and energy. Similarly, for those programs that do offer assistance, many require extensive paperwork, and the administrative burden prevents some from seeking the help they need.

• **Outreach barriers.** There is little public facing literature describing electrification and, when it is available, there tends to be a lack of culturally appropriate outreach materials. Many residents may be less connected with the latest technology and associated resources – including the workforce.

**Detailed Feedback from Informational Interviews**

A series of brief informational interviews in August and September of 2020 were held with community members who previously received support from one or more of EOC’s weatherization or home repair programs. The goal of these conversations was to understand:

- Common household appliances and fuel types.
- Resident concerns about household appliances (e.g., cost, efficiency, safety, etc.).
- Factors that drive decision-making when it comes time for appliance replacements.

Twenty-five households participated, and the majority (88%) were homeowners. Most respondents (76%) live in a single-family residence, while the remainder live in an apartment, townhouse, tri-plex, or condo.

**Appliance Details**

Most respondents indicated that they have some level of concern about their impact on the environment and air quality, and that it is important to maintain a comfortable indoor temperature. A slight majority (52%) noted that there is someone in their home with chronic respiratory health issues. Only 12% of respondents have central air conditioning in their homes; ceiling and/or box fans are the most common way respondents cool their home in the summer.

Gas-powered equipment was by far the most common for these households: 76% of respondents have a gas furnace, 80% have a gas water heater, 76% have a gas-powered dryer, and 52% use a gas cookstove.

**Key Takeaways**

Residents generally are aware of the types of appliances they have, the energy sources used to power those appliances, and the condition of their appliances. Many of the respondents (other than those currently using electric heaters or water heaters) were not familiar with electric appliances. Yet, most were open to using electric heating and water heating if there were no significant cost increases relative to gas appliances.

The positive environmental impact of making this switch appealed to multiple respondents. The primary concern was additional upfront costs; one respondent also noted a concern regarding whether their electrical panel could handle the additional load and another about how their home would be heated if there were a grid outage in the winter.

Respondents were asked about any concerns that they have regarding their current appliances and the condition of their homes in general. The main themes that popped up in responses included:

- Proper functioning of home cooling systems (if they had them).
- Leaky windows.
• Size of the electrical panel.
• Condition and reliability of stoves.
• The replacement cost of water heaters.
• General home condition due to age.

While many interviewees had received recent equipment replacements through EOC, several households noted poorly functioning gas stoves.

In a phone call, a respondent said that during an emergency replacement she could only find credit through the contractor. The contractor charged the homeowner $15,000 for a $6,000 replacement ($9,000 interest). Under-resourced homeowners with poor credit have limited options to purchase new equipment.

When it was time to replace equipment, many respondents noted that appliance safety was the most important decision-making criteria followed by appliance reliability, price, and energy efficiency.

Other factors included: size, durability, ease of install, availability of used appliances, and ability to get credit for the purchase. Overwhelmingly, respondents indicated that they only replace appliances when they break and cannot be fixed. Emergency replacements are the primary reason for upgrades; this supports research findings.

Next was investing in more energy-efficient equipment.

Surprisingly, home cooling was not frequently discussed, suggesting that many households are not aware of the simultaneous space heating and cooling benefits of residential heat pumps.

**Detailed Feedback from the Online Survey**

In November 2020, an online survey was sent out to community members who previously received support from one or more of EOC’s weatherization or home repair programs. The goal of this survey was to understand:

• Common household appliances and fuel types.
• Common perceptions about gas versus electric appliances.
• Challenges that are unique to renters versus homeowners.
• Factors that drive decision-making when it comes time for appliance replacements.

Sixty-one households participated, and the majority (66%) were renters. Most respondents (58%) lived in a single-family residence, while the remainder lived in an apartment, townhouse, tri-plex, or condo.

**Appliance Details**

Most renters and homeowners had gas-powered furnaces and water heaters: 67% of homeowners and 41% of renters had a gas furnace, and 72% of homeowners and 58% of renters had a gas water heater. Ninety percent of renters and 100% of homeowners had an electric powered dryer, and 89% of renters and 83% of homeowners used an electric cookstove.

Fifty percent of homeowners said they had central air conditioning. Of the homeowners, 78% had some form of air conditioning in the form of swamp coolers, window air conditioning units, or central air. However, 29% of those with air conditioning had units that somewhat or fully malfunction. For renters, 34% of respondents reported having central air conditioning, and 80% reported having some form of air conditioning.
conditioning (swamp coolers, window air conditioning units, or central air). Of those with some form of air conditioning, 36% had units that are partially or fully malfunctioning. Most homeowners also indicated that they would pay more for an appliance if it provided both heating and cooling (59%).

**Key Takeaways**

When asked about perceptions of gas versus electric appliances, most homeowners and renters stated that electric appliances are safer to operate, better for indoor air quality, and cheaper to purchase. However, there was no consensus about which type of appliance was cheaper to run once purchased. See Table A 1 for a detailed breakout of responses.

<table>
<thead>
<tr>
<th>Homeowners</th>
<th>Renters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safer to operate</td>
<td>Electric (85%)</td>
</tr>
<tr>
<td>Better for indoor air quality</td>
<td>Electric (86%)</td>
</tr>
<tr>
<td>Cheaper to purchase</td>
<td>Electric (56%)</td>
</tr>
<tr>
<td>Cheaper to run once installed</td>
<td>50/50 split</td>
</tr>
</tbody>
</table>

Both homeowners and renters had a strong preference for electric appliances, with the exception of water heaters for homeowners, where 60% preferred gas-powered water heaters, see Table A 2.

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Homeowners</th>
<th>Renters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Furnace</td>
<td>Electric (55%)</td>
<td>Electric (68%)</td>
</tr>
<tr>
<td>Water Heater</td>
<td>Gas (60%)</td>
<td>Electric (57%)</td>
</tr>
<tr>
<td>Dryer</td>
<td>Electric (100%)</td>
<td>Electric (86%)</td>
</tr>
<tr>
<td>Stove</td>
<td>Electric (77%)</td>
<td>Electric (55%)</td>
</tr>
</tbody>
</table>

**Renters**

For renters, 88% of respondents would expect their landlords to replace or repair an appliance if it stopped working. Of those who would expect their landlord to intervene, 86% believe they have NO say in what type of appliance would be installed.

When asked if they had ever forgone using gas or electricity because they could not afford their utility bill, 69% of respondents said yes. Including those who replied that they received energy assistance, 74% of respondents said they struggle to pay their utility bills. Regardless of whether a renter’s landlord would replace a broken appliance, renters agreed that the cost to buy and run an appliance and reliability were the most important qualities when choosing a replacement appliance. Energy efficiency was rated among the lowest of the priorities for the renters. For renters, 88% of respondents would expect their landlords to replace or repair an appliance if it stopped working. Of those who would expect their landlord to intervene, 86% believe they have no say in what type of appliance would be installed.

**Homeowners**
When asked if they had ever forgone using gas or electricity because they could not afford their utility bill, 33% of respondents said they had. All but one of those respondents also said they had gone without heat or hot water after an appliance stopped working because they could not afford the repair. Additionally, when asked how they would finance a replacement appliance if one broke down, 78% of respondents said they would not be able to afford to replace it or did not know how they would be able to afford a replacement. Of the remaining, 11% would take out a loan or borrow money from friends and family to replace it, and the other 11% had savings or cash on hand to cover a replacement.

Homeowners’ top priorities for qualities in replacement appliances were safety and price. The least important priority was the impact on indoor air quality. The majority of homeowners only replace their appliances when they fully stop working (89%) and would not (or are unsure if they would) be able to afford to replace appliances (89%). Homeowners also would pay more for an appliance if it made their home healthier (61%), was safer (59%), or was better for the environment (53%).

COMMUNITY REPRESENTATIVES

The first round of Advisory Group meetings were held with Denver’s stakeholders and potential partners in September of 2020, and a second round of meetings were in March of 2021. Each consisted of three separate groups: Public Health and Air Quality, Building Contractors, and Building Owners and Property Managers. These meetings solicited feedback on the primary barriers, opportunities, and values that should be considered when developing the implementation plan.

Primary Themes

- Approach electrification holistically; think of buildings as ecosystems. If managed appropriately, electrification can advance public health, equity, quality of life, and decarbonization.
- Carefully weigh the impacts of policies and incentives on under-resourced communities. Thoughtfully designed programs can avoid unintentionally increasing inequity and placing a disproportionate burden on Denver’s underrepresented and POC communities.
- Approach electrification program from different angles based on the market Denver is engaging. Different markets will require different messaging and different solutions.
- Support workforce development and training programs, particularly through official apprenticeships.
- Develop messaging and incentive programs that address some of the logistical and economic barriers of electrification; this is essential to successful program implementation.
Key Barriers

- Economic, particularly for under-resourced communities
  - The upfront costs to replace a fossil fuel system with a heat pump or heat pump water heater are high. The lowest first cost drives most decisions for commercial groups; electric equipment is generally not the lowest first cost.
    - Utility costs alone are likely to be higher with heat pumps, but you might see maintenance cost savings.
    - The cost to convert to sub-meters in master-metered MFU could be extremely high. Many are currently master-metered; this could be an issue with retrofits.
  - Under-resourced communities make choices regarding upgrade appliances in part based on credit and creditworthiness. There are frequent instances of predatory lending practices.
  - Market rate incentives are currently very low.
  - Xcel’s peak rates do not encourage electrification and gas is cheap.
  - Electrification may impact the profit margin of small businesses (e.g., restaurants).
  - Costs to upgrade to the newest codes are already expensive.
  - Many lenders do not like building electrification.
  - Capital costs are often passed on to tenants.
  - Steam costs are increasing, but it still may not make sense to go to electric.
  - Buildings turn over every five to seven years. The timeline for investments is short.
  - It is difficult to pay for upgrades when one is forced to be an early adopter through codes and the technology is not yet cost-effective.

- Logistical
  - There is a need to ensure that weatherization programs support making a home electric-ready.
  - Landlords may not necessarily reap the benefits of efficient electric appliances in rental units, making them less likely to invest (i.e., the split incentive issue).
  - Electric capacity in buildings could be insufficient, especially in under-resourced parts of Denver.
  - Electric resistance heat is very cheap to install; if Denver requires an electric transition, many may go to electric resistance heat (which is less efficient overall).
  - Contractors are super busy. It is hard to motivate them to do something new and unfamiliar.
  - Equipment is untested and may not last.
  - Xcel is already struggling and has rolling brownouts in Capital Hill and Speer Boulevard neighborhoods; the grid may not be able to support more electric demand.
  - Contractors may not be able to run ductwork in older homes.
  - Concerns about having to replace everything when going electric.
  - Many buildings are currently installing gas systems (particularly steam buildings). These systems last 20 to 25 years, so there is a need to act fast.
  - Restaurants will need new cookware for induction stoves.
  - An older building may not be able to handle the additional load.
  - Heating of recirculated water is very difficult.
  - There are space constraints in some buildings; contractors cannot physically get some equipment in the designated space.
  - Restaurants use gas kitchens and are very reluctant to change.
Educational

- Homeowners may be hesitant to take on a complex home improvement project. There is a need for an easy step-by-step process to guide residents to upgrade to electric equipment.
  - Customer education is key; contractors will not install equipment that the customer does not request.
- There is a lot of misinformation about a system’s ability to operate at low temperatures.
- Heat pumps must be installed correctly – a lot of contractors do not know how to install heat pumps. Poor installation and poor performance could blemish the entire industry transition.
- Contractors are often busy with installing and may not necessarily have the time for training on sales and quality installations for electric equipment.
- The contractor workforce is an aging workforce, and there is a lack of young people coming into the industry.
- Improved health and comfort benefits do not resonate with commercial owners.
- There is a tremendous need for education about the technology and the process of electrification, as well as the benefits.
- Switching technology causes fear for some people. Efficiency is seen as easier.
- Maintenance staff are underpaid, sometimes promoted from janitorial positions without building operation education.

Opportunities

- Improved public health
  - The indoor and outdoor air quality will be improved simultaneously as indoor gas appliances are eliminated and the grid becomes greener.
  - Better health is correlated with improved educational outcomes for children.
  - Widespread electrification will also reduce nitrous oxide (NOx) and volatile organic compounds (VOC), which will lead to lower levels of ozone.

- Better economics
  - Avoiding increasing costs due to stranded assets.
  - Opportunities for on-bill financing, which often makes home improvements more accessible to communities underserved by credit agencies or targeted by predatory lending practices.
  - C-PACE is a commercial financing option.
  - Considering programs that encourage property owners to try leasing technologies.
  - Grant programs to support upgrades are successful.
  - Tax incentives and midstream rebates are key.

- Advanced building policies
  - Electrification could be used to support the enforcement of regulations linked to habitability and warrantability.
  - There is an opportunity to connect with the state ordinance on what needs to be provided in a safe home. This in turn may influence landlords to improve the condition of homes that are occupied by underrepresented community members.

- Values-driven interests
  - Commercial customers are starting to look at their carbon impact and consider electrification options.
Customer satisfaction with heat pumps is high.

- **Further opportunities for the workforce**
  - Develop hands-on apprenticeships (not mentorships, which are unregulated and could pass on “old ways”). Once contractors are trained, they become advocates.
  - Support contractors and supply chains.

- **Regulatory pathways**
  - Codes drive change; the advancement of code is creating more demand.
  - Contractors suggested an all-electric ADU policy.

- **Additional approaches for consideration**
  - Wastewater heat could be an opportunity for downtown. There is a lot of waste heat in the system right now.
  - Thermal storage can help balance loads and ease the grid through the clean energy transition.
  - Electrification can lead to enhanced comfort because of the introduction of AC in buildings.

- **Education**
  - Installations are based on what is familiar and what the contractor recommends, and also offer training for building operators.
  - Need to facilitate trust between Xcel and building owners.
  - Expand education on the dangers and risks of gas.

- **Partnerships**
  - HOA management companies
  - Residential neighborhood organizations
  - Realtors
  - Home inspectors
  - Large building owners, not small ones
  - Pipefitters
  - Plumber unions

**LOCAL WORKFORCE AND LABOR**

**Key Findings**

- Recruitment opportunities should start as early as high school.
- Outreach helps make this occupation attractive to engage a younger workforce.
- Women and people of color should be going into schools doing recruitment. This allows diverse young people to see themselves in this workforce.
- Training programs should be affordable, appealing, and hands on.
- Training programs should be tailored for both new workforce and those about to exit the workforce.
- Apprenticeships and training are available, but it has been challenging to get the workforce to attend.
- More contractors and building managers need to be trained on sustainability so they can reference why this change is happening.
• Incentivizing and educating residents and building owners will be critical to increase demand, which will require the need for more jobs.
• Building owners will have to be on board to keep workforce in Denver.
• An easy to understand and effective licensing program would be beneficial.
• Keep in mind the different training and incentive needs for residential versus commercial.
• It will be critical to lay out a clear roadmap that breaks down what is coming. It was suggested to give five-, ten-, fifteen-, and twenty-year projections for planning and training purposes.
APPENDIX B – BUILDING STOCK AND TECHNOLOGY REPLACEMENTS METHODOLOGY

Our project team took the following steps to evaluate the impact of electrification on Denver’s building stock and recommend technology replacements.

1. Evaluated Denver’s building stock:
   a. Determined available data sources.
   b. Defined Denver’s building stock characteristics, including the building types and HVAC, water heating, and cooking equipment types.
   c. Defined the most common non-electric equipment currently used in the existing building stock.
   d. Identified the building types where the common equipment was used.
2. Modeled technology assessments:
   a. Determined the appropriate electric alternatives for the selected gas equipment.
   b. Developed and ran prototype energy models to correspond with each building type and selected equipment.

Using this procedure, the annual energy use by fuel type and electric peak demands were calculated to represent the scenarios both before and after electrification.

We then iterated our analysis to determine which technology options were most cost-effective.

Building Stock Analysis

DATA SOURCES

Several data sources were sought and reviewed for the existing building stock in Denver. Table B 1 lists the available data sources and characterizes the data carried by the source. Each source was evaluated to determine whether it was local to Denver and contained the building categories of interest, and what types of data it contained (energy, equipment densities, appliance types, etc.). As can be seen from Table B 1, there was no single data source that met each of these needs.

<table>
<thead>
<tr>
<th>Source</th>
<th>Denver Area Data</th>
<th>Large Set and Wide Variety of Buildings</th>
<th>Building Equipment, Appliances, Devices</th>
<th>Building Type</th>
<th>Building Construction</th>
<th>Energy Use by Fuel Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Housing Survey (AHS)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boiler &amp; Air Conditioning Permits</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
AHS and CBECS had the most relevant data for Denver and were used as the main data sources. Other sources were used to supplement the main sources. ResStock data was cross-referenced with AHS data to characterize the envelopes of homes. CBECS and RECS data were filtered for the Mountain Region and further into the Building America Climate Region 1. The RECS data were further filtered for metropolitan area residences. When gathering HVAC system types in CBECS, the INFOR database provided general verification that the HVAC systems appearing in CBECS were indeed used in Denver. For office buildings and warehouses, INFOR provided verification of HVAC systems for those specific building types.

Schools and hospitals were excluded as they are not under Denver’s jurisdiction. Industrial facilities and mobile homes were excluded due to the unique and specialized approaches needed to electrify these building types. The Convention Center, while a significant consumer of energy in Denver, was excluded, again because it is a single and unique building requiring specialized solutions.

**EQUIPMENT AND BUILDING TYPE**

Using the filtered data described above, Denver’s building stock was analyzed to determine:

1. The most common HVAC system types, water heating system types, and cooking appliance types.
2. The building types that consume the highest proportion of energy. Building type classification is further subdivided by the building vintage, which is a proxy for envelope (opaque and fenestration) performance, assumed to be better for newer buildings.

The analysis from step 1 provided information on the non-electric equipment to target for electrification. Using the data from step 2, the most common equipment types were mapped to building types that both used this equipment and also comprised a significant proportion of energy use in
Denver. This approach of targeting both frequency of systems and appliances, coupled with data on high energy-impact buildings, assures that the implementation plan will have a deep impact on Denver’s overall energy consumption.

**FUELS USED IN EQUIPMENT**

The most prevalent fuel sources were investigated to understand which end uses and which fuel types would provide the highest electrification benefit. Table B 2 contains the findings from the investigation.

*Table B 2: Distribution of fuels used in buildings by end use*

<table>
<thead>
<tr>
<th>Building Sector</th>
<th>End Use</th>
<th>Electricity</th>
<th>Non-electric</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Gas</td>
<td>Steam</td>
</tr>
<tr>
<td>Commercial (CBECS data)</td>
<td>Space heating</td>
<td>7%</td>
<td>88%</td>
</tr>
<tr>
<td></td>
<td>Water heating</td>
<td>30%</td>
<td>66%</td>
</tr>
<tr>
<td>Commercial (Energize Denver)</td>
<td>All</td>
<td>21%</td>
<td>71%</td>
</tr>
<tr>
<td>Multifamily (AHS data)</td>
<td>Space heating</td>
<td>36%</td>
<td>61%</td>
</tr>
<tr>
<td></td>
<td>Water heating</td>
<td>19%</td>
<td>79%</td>
</tr>
<tr>
<td></td>
<td>Cooking</td>
<td>79%</td>
<td>20%</td>
</tr>
<tr>
<td>Homes (AHS data)</td>
<td>Space heating</td>
<td>16%</td>
<td>81%</td>
</tr>
<tr>
<td></td>
<td>Water heating</td>
<td>13%</td>
<td>84%</td>
</tr>
<tr>
<td></td>
<td>Cooking</td>
<td>65%</td>
<td>34%</td>
</tr>
</tbody>
</table>

Based on the data, most of the cooking equipment in MFU is already fueled by electricity, and therefore this source was not selected for electrification. Because gas is the dominant non-electric fuel source, gas-based space heating and water heating equipment were chosen for representation in the final equipment selection. Steam is provided by a steam loop to several downtown buildings, comprising a significant portion of the consumption of non-electric fuels. Therefore, steam-based space and water heating were also chosen to be represented in the final equipment selection.

**HVAC, WATER HEATING, AND COOKING TYPOLOGY SELECTION**

The most common non-electric HVAC – water heating – and cooking equipment were considered for further evaluation in the analysis.

The HVAC and water heating system types were analyzed and compared to the portion of square footage covered by that equipment compared to all gas equipment. HVAC and water heating system types that had portions of square footage that were less than 2% compared to all gas equipment were not included because they had a diminishing impact on the analysis. The exception to this winnowing of the data was Denver’s steam loop; steam accounts for 10% of non-electric energy use in the Energize Denver database. The system selected to represent the steam loop was derived from INFOR data on large offices, as large offices comprised the largest portion of steam loop use.

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<sup>5</sup> Other fuels included propane, fuel oil, kerosene, wood, and other miscellaneous sources.
Gas cooking types were analyzed for MFU and homes. There are commercial cooking facilities in hotels using gas, but electrification of these was not considered in this analysis since commercial restaurants were not a chosen building typology.

Based on this analysis, the common HVAC, water heating, and cooking equipment were selected to target for electrification.

BUILDING TYPOLOGY SELECTION

As a next step in the analysis, the project team looked at which buildings used the selected equipment. The equipment was mapped to building types that both used the equipment and also comprised a large proportion of energy use in Denver. This approach, targeting common equipment coupled with high energy-impact buildings, assured that the analysis results would reflect a more accurate picture of Denver’s overall energy consumption.

To keep the number of permutations to a manageable level, the building stock was divided into “low” and “medium” envelope performance, respectively. This ensured that the energy analysis would more accurately represent the envelope performance and therefore energy use in Denver while keeping the number of building permutations manageable.

We assumed that equipment in the buildings such as lighting, electronic devices, and HVAC systems had been updated or replaced periodically. This meant that the vintage of the building did not represent the vintage of the equipment used in that building. To determine the age of the equipment in the buildings, it was assumed that modern equipment began to appear in the buildings in the mid-1970s and that equipment was replaced every eight to 15 years. Using this assumption, the average vintage of equipment was 2012. The performance of equipment was set at the International Energy Conservation Code for 2012, which was the acting standard for Denver in that year.

The building types and vintages that used the targeted systems and appliances were identified in the CBECS data. These building types were then cross-referenced in the Energize Denver database whenever possible to determine which of the building types had the largest energy impact. The portion of Energize Denver’s total non-electric energy consumption (i.e., gas plus steam) is given where available. The portion is only presented by building type and vintage because the Energize Denver database does not contain data on equipment types.

In some cases, we analyzed equipment in more than one building type. This accomplishes two goals:

1. The results of the analysis will better inform the overall impact on the grid because the energy use of targeted equipment will be characterized by multiple building characteristics that have significant energy use. For example, split systems with air-conditioning and furnaces are used in several building types. If only one building type was analyzed, this would not reflect the true impact on the grid.

2. The cost analysis of installation will be informed by the different demolition and installation constraints of buildings in which the equipment is installed.

By analyzing the buildings with the highest grid impact that used the targeted gas equipment, more than 56% of the non-electric commercial and MFU energy use of Denver could be accurately calculated.6 By

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6 This is the percentage exclusive of the energy use in buildings excluded from the analysis.
not calculating the remainder of the buildings some of the fidelity of the analysis to the actual energy use in Denver was lost. Some building types that use the targeted equipment may have different operating hours, insulation levels, or other characteristics that affect the timing and level of energy use.

However, it was not feasible to model all building types that use this equipment as there are over 50 building types in CBECS and over 75 building types in Energize Denver. To characterize even 75% of the energy use in these buildings, 27 building types would need to be analyzed. Aside from the long energy modeling run times for this number of buildings, research determining the envelope, form, occupancy schedules, and other relevant characteristics would need to be performed. Then this data would need to be input. These reasons limited the number of building types analyzed.

For homes, nearly 100% of the energy use was characterized because all building types of homes in this analysis were represented.

Technology Assessments

The following sections discuss the energy modeling methodology and electrification equipment selections. The primary all-electric option for space heating and water heating is some version of a standard heat pump.

ENERGY MODEL PROTOTYPES

Three scenarios were used to analyze the impact of electrification:

1. **Existing** – The performance of the existing building stock with existing equipment at their installed efficiency levels. This scenario informed the current demands on utilities and served as a baseline to measure changes to demands on the utilities.
2. **Like-for-like Replacement** – The performance of the existing building stock with equipment replaced with the same type of equipment but at current required minimum efficiencies. This scenario informed the cost proposition for building owners. It provided the energy cost baseline for comparison of life-cycle costs.
3. **Electrification** – The performance of the existing building stock with equipment replaced with electrification technologies. This scenario informed both the change in utility demands and the cost proposition for building owners from electrification.

To model these three scenarios, prototype energy models that were representative of the building types and equipment from the building stock analysis were created. These prototypes were based on the United States Department of Energy’s (DOE) Commercial Reference Buildings and Residential Prototype Buildings. The internal loads, equipment efficiencies, and insulation levels within the prototype model were modified to match the findings from the building stock analysis. These prototype energy models, along with the equipment discussed above, were used to characterize the gas, steam, and electric energy use of Denver buildings both before and after electrification.

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7 Over time, Denver’s building stock would evolve from a scenario 1 to a blend of scenarios 1 through 3 to, theoretically, only scenario 3. So, in addition to the needs of this analysis, all three scenarios could be used to map the evolution of utility impact and other pertinent metrics.
HVAC SYSTEMS

The first criteria used to select the electric HVAC systems was to search for technologies that had similar configurations as those in the existing building stock. This will generally result in the least changes during renovation, which results in lower installation costs. For example, if a split system heat pump\(^8\) replaced a split system air conditioner with a furnace, the heat pump system could likely use the same ductwork and other accessories.

The next step was to select the most efficient option and the appropriate efficiency level for each technology. Our selections, as well as the reasoning behind them, are listed below.

- **Heat pumps were selected wherever possible, as they are typically two to four times more efficient than electric resistance heating.**
  - Electric resistance heat was used to supplement compressor heating below 10° F. Cold-climate heat pumps (ccASHPs) are a subset of heat pumps specifically designed to operate in cold temperatures. They were considered in the analysis and may eventually be part of a layered incentive program. However, standard heat pumps were used in this analysis because they were found to produce nearly all the benefits of ccASHPs without the extra cost.

- **Water-loop heat-pump systems were generally chosen as replacements for systems that use high-capacity gas-fired boilers or steam.**
  - These hydronic systems often do not have efficient electric alternatives with similar configurations. Electric resistance boilers would result in high electric peak demands and much higher energy bills. Resources to accurately model and characterize the performance of heat pump boilers and heat recovery chillers were not found. Standard efficiency heat pumps with optimum start were selected for analysis for the remainder of the study.

- As the efficiency of technologies increases, the expected energy use and annual utility costs will decrease, but the upfront cost may increase (as compared to a standard, federal-minimum efficiency technology). We performed a preliminary analysis of HVAC systems to understand the impact that differences in efficiencies would make on energy use, energy cost, and grid impact. A preliminary analysis of different heat pump efficiency levels showed that standard heat pumps with optimum start generally had similar performance to ccASHPs. Larger units and rooftop units also could use optimum start, whereas ccASHPs are generally not available in sizes larger than 5 tons. Therefore, standard heat pumps with optimum start can be used in more building types than ccASHPs.

- The focus on standard heat pumps with optimum start does not preempt ccASHPs from incentives; it only indicates that they do not serve as the basis for this analysis.

WATER HEATING SYSTEMS

The process for determining the appropriate water heating and electrification technologies was similar to that used for HVAC systems, with the first criteria to search for technologies that had similar configurations as those in the existing building stock. For water heating, this corresponded to using central and individual storage and point-of-use (POU) water heaters where those configurations were

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\(^8\) A split system is one where the condenser is located outside, and the evaporator coils are located inside in a ducted system.
used in the existing building stock. Heat pumps are available for central and individual water heaters, and POU water heaters are electric resistance.

The design and operation of heat pump water heaters often differs from gas water heating systems. Typically, the storage tank is larger, and the heating capacity is lower. This has several advantages, including:

- Reducing overall hot water system cost because tanks are cheaper than heat pumps.
- Reducing building electrical service requirements including wiring, panels, and service.
- Reducing owner exposure to high peak demand charges.
- Reducing heat pump equipment short cycling.
- Serving hot water demand for longer during a power outage.

The disadvantage is that larger tanks require more space. Despite this disadvantage, the project team selected larger tanks for the analysis because of the significant list of advantages.

As compared to individual heat pump water heaters, central systems often use two tanks instead of a single, large tank. A group of primary tanks are heated by the heat pumps; these primary tanks feed a group of smaller tanks that maintain the temperature in a circulated hot water loop using electric resistance heating. This configuration optimizes the heat pump efficiency by operating the heat pumps in their optimum temperature range and was therefore used in the analysis.

Iterative Approach to Identify Cost-Effective Technology Replacements

ASSUMPTIONS

To find the most cost-effective solutions that approached operational cost parity, we evaluated additional technology replacement options. We used the following assumptions.

1. Heat pump compressor off at -4 degrees Fahrenheit for all runs, which is the EnergyPlus limit. Previous runs used 10 degrees Fahrenheit as the compressor cutoff for Standard heat pumps, 5 degrees Fahrenheit for ccASHPs and -4 degrees Fahrenheit for best-in-class ccASHPs.
2. Heating load versus heating coil size as shown in Table B 3.
4. Oversizing was optimized on maximum energy savings.
5. Original oversizing: 10%, 25%, and 50% showed increasing savings, so new ranges were evaluated.
6. Crankcase heater power for a single-family model was reduced from 200 Watt to 60 Watt.

Table B 3: Heating load versus heating coil size

<table>
<thead>
<tr>
<th>Building Type</th>
<th>HVAC serves</th>
<th>Heating Load [Btu/hr]</th>
<th>Base Heating Coil Size [Btu/hr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-family</td>
<td>Entire house</td>
<td>36,300</td>
<td>42,400</td>
</tr>
<tr>
<td>Small Office</td>
<td>Core of the building</td>
<td>14,500</td>
<td>19,100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>----------------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>Small Office</td>
<td>South perimeter</td>
<td>29,900</td>
<td>31,300</td>
</tr>
<tr>
<td>Small Office</td>
<td>East perimeter</td>
<td>19,200</td>
<td>20,100</td>
</tr>
<tr>
<td>Small Office</td>
<td>North perimeter</td>
<td>29,200</td>
<td>30,600</td>
</tr>
<tr>
<td>Small Office</td>
<td>West perimeter</td>
<td>19,200</td>
<td>20,300</td>
</tr>
</tbody>
</table>

**FINDINGS**

1. **Oversizing:**
   a. 75% oversizing is optimum for federal minimum.
   b. 50% oversizing optimum for ccASHPs because ccASHPs already have increased capacity at low temperatures.
   c. Oversizing did not result in significant improvement in savings.
   d. Oversizing for the Standard Split HP/NG supplement, which was used in the Small Office, has an optimum total energy savings at 40%, but cost may increase with all incremental increases in oversizing because gas heating is being incrementally replaced by electric heating.

2. **Ductless mini-splits:**
   a. When used with the existing furnace, they may have a decrease in peak electric load and cost compared to AC with furnace systems because they have less fan energy and a summer cooling peak that is lower than the winter heating peak of a heat pump during cold periods in Denver.

3. **Best-in-class:**
   a. Best-in-class split heat pumps have around 3.7% energy savings over standard split heat pumps.
   b. Best-in-class ccASHPs have around 1.9% energy savings over minimally compliant ccASHPs.
   c. Best-in-class ductless mini-split heat pumps have around 3.0% energy savings over standard ductless mini-split heat pumps.

4. **Compressor cutoff temperature:**
   a. Assuming a lower compressor cutoff temperature (-4 degrees Fahrenheit) increased the energy savings for all runs.
   b. The energy savings difference between Standard heat pumps with optimum start and ccASHPs remains about the same.
APPENDIX C – OPERATING AND CAPITAL COST METHODOLOGIES

Operating Cost Methodology

Hourly electricity and gas demands for prototype buildings were derived from the building simulations outlined in Appendix B. Building simulation results were provided on an hourly basis and differentiated by end use for each prototype building.

Each prototype building was simulated twice: once with typical gas-fueled equipment and once with electric equipment. First-year gas and electricity bills were calculated for both cases, enabling the calculation of net bill impacts associated with electrification. First-year electricity bills were calculated using Xcel’s existing TOU rates, and first-year gas bills were calculated using Xcel’s retail gas rates. Rates were specified by customer type; for example, residential prototype buildings were evaluated on residential rate tariffs.

For electricity rates, prototype buildings were matched with corresponding retail electricity tariffs based on Genability’s Electric Rate API\(^9\). Electric bills for residential prototype buildings were calculated using Xcel’s RE-TOU rates, shown in Table C 1. Electric bills for commercial prototype buildings were calculated using Xcel’s C rates, shown in Table C 2.

\textit{Table C 1: Xcel Energy residential TOU electricity rates}

<table>
<thead>
<tr>
<th>Xcel RE-TOU</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer On-Peak Energy per kWh</td>
<td>$0.2319</td>
</tr>
<tr>
<td>Summer Shoulder Energy per kWh</td>
<td>$0.1617</td>
</tr>
<tr>
<td>Summer Off-Peak Energy per kWh</td>
<td>$0.0914</td>
</tr>
<tr>
<td>Winter On-Peak Energy per kWh</td>
<td>$0.1493</td>
</tr>
<tr>
<td>Winter Shoulder Energy per kWh</td>
<td>$0.1203</td>
</tr>
<tr>
<td>Winter Off-Peak Energy per kWh</td>
<td>$0.0914</td>
</tr>
<tr>
<td>Service and Facility per Month</td>
<td>$5.58</td>
</tr>
</tbody>
</table>

\textit{Table C 2: Xcel Energy small commercial electricity rates}

<table>
<thead>
<tr>
<th>Xcel Small Commercial (C)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer Energy per kWh</td>
<td>$0.1311</td>
</tr>
<tr>
<td>Winter Energy per kWh</td>
<td>$0.0885</td>
</tr>
<tr>
<td>Service and Facility per Month</td>
<td>$10.71</td>
</tr>
</tbody>
</table>

Gas retail rates are based on tariffs from Xcel Energy’s website. These rates went into effect October 1, 2020.\(^10\) See Table C 3 and C 4.


Table C 3: Xcel Energy residential gas rates

<table>
<thead>
<tr>
<th>Xcel Energy Residential Gas Rates</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Usage Charge per therm</td>
<td>$0.52</td>
</tr>
<tr>
<td>Service and Facility per Month</td>
<td>$12.85</td>
</tr>
</tbody>
</table>

Table C 4: Xcel Energy commercial gas rates

<table>
<thead>
<tr>
<th>Xcel Energy Commercial Gas Rates</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Usage Charge per therm</td>
<td>$0.49</td>
</tr>
<tr>
<td>Service and Facility per Month</td>
<td>$44.56</td>
</tr>
</tbody>
</table>

Capital Cost Methodology

Capital costs for this project were developed by AECOM.

TOTAL PROJECT COST

Estimates used in this report reflect the complete project cost including any anticipated design and engineering expenses including any design or other consultants, as well as the cost of permits and fees. Cost estimates exclude any indirect cost/value impacts, such as lost revenue during construction activities, enhanced property value, etc. Costs related to hazardous materials, historic construction or finishes, deteriorated fabric, or other specialized conditions are also excluded.

Costs correspond to Q1 2021 and do not include escalation to the date of construction.

COST COMPONENTS

The estimates are built up from six components:

- **Demolition and Make Good.** This component includes all costs related to removal and disposal of existing equipment, including patching and repairing existing finishes. Management of hazardous materials, including any soot, combustion products, or asbestos insulation is excluded.
- **System Installation.** This component includes all costs related to installation of new equipment, including associated fittings and patching, and repairing existing finishes impacted by the installation.
- **Local Wiring.** This component includes all costs related to connecting power from the existing building wiring to the new main and terminal equipment, including any new breakers in existing panelboards.
- **Controls.** This component includes all costs related to replacing thermostats and other system controls.
- **Panelboard Upgrades.** This component includes all costs related to replacing or upsizing the building panelboards to accommodate increased loads. This cost only applies to the electrification systems. Panelboard upgrades are likely to be needed in the heating and cooling scenarios, particularly where electric resistance heating is used as a backup option. Panelboard
upgrades may be optimized in a broader electrification, combining electric vehicles, PV installations, battery, etc., in which case the cost can be shared across multiple projects.

- **New Service.** This component includes all costs related to upsizing the primary service from the utility infrastructure to the building. As with panelboard upgrades, this cost applies only to electrification, and may not be needed in all cases.

### COST VARIANCE

The costs are based on the prototypical models and the scopes used in the energy analysis for each of the building typologies. The actual building stock has a very wide variation of conditions, and costs will vary significantly in any single instance.

The largest drivers of variation include:

- Extent of demolition or making good required, including presence of hazardous materials.
- Extent of work required to accommodate replacement equipment. The estimates exclude building alterations which may be required to fit the new equipment, to bring spaces or clearances up to code, or to strengthen or expand access or path of travel.
- Extent of electrical upgrade work required.

### BACKUP HEATING

Retaining gas as a backup fuel could reduce the overall cost of the electrification. Dual fuel equipment is becoming more readily available and retaining gas would reduce the likelihood of increased electrical infrastructure costs.

### COST REPRESENTATION

The costs are based on adequate space for the required equipment being available at no cost to the project. In many cases, particularly for water heating, the electric option requires significantly more space, which may not be available in some existing buildings.

The costs also assume a mature market for the work scope, with adequate bid coverage and no premium for innovation or contractor learning.

### PROCUREMENT CONDITIONS

The estimates are based on the following procurement conditions:

- Work is undertaken as a single, stand-alone project, procured by an individual building owner, with no economy of scale for multiple projects under a single contract.
- Work is procured through conventional contracting methods for each building type, for example:
  - Single-family projects are undertaken by residential plumbing and HVAC contractors, solicited by the homeowner as a total package, with the contractor providing design and permitting services as part of the contract. The homeowner may solicit one or more bids, informally, and the contract is managed by the homeowner with no added consultants.
Small commercial and multifamily residential projects are undertaken by medium-sized plumbing and HVAC firms, also typically providing design and permitting as part of the contract. The property owner solicits formal proposals from multiple contractors. Management is by the property owner, with no added consultants.

Large commercial and multifamily residential projects are undertaken by major plumbing and MEP contractors, either acting as prime or under a specialized prime contractor. The project scopes will be defined by an engineering and design firm hired separately by the owner, and procurement through formal competitive bidding. Project oversight will be by owner’s design contractor. The owner’s consultants are included in the total project cost.

CONSTRUCTION CONDITIONS

The estimates are based on the following conditions of construction:

- Work is executed in a standard sequence and schedule, with no acceleration, overtime, or out-of-sequence work.
- The contractor has full access to the work areas at all times with no restrictions on working hours or service shutdown.
- Residential projects and small commercial will remain occupied during the execution of the work, and the contractor will work with the occupants to manage access, routine clean-up, security, and site management.
- Hotels will be active and occupied but work within hotel rooms will be in unoccupied (un-sold) rooms.
- Large commercial will be fully vacated during the work activities.
- The work areas are generally accessible, with adequate paths of travel and adequate clearance for work-around equipment. Hoisting, staging, and normally required access equipment is included in the estimate.
- The equipment to be removed and the supporting infrastructure is in good condition, with no requirement for additional repair.
- Work with hazardous materials is excluded.
- Work related to special (historic, architecturally significant, custom design) structures or finishes is excluded.
APPENDIX D – ELECTRIC GRID METHODOLOGY, CONSIDERATIONS, AND DETAILED FINDINGS

We developed hourly load shapes for space heating and space cooling in buildings, which reflect the largest sources of new electrified energy demands in most buildings. These load shapes are designed to estimate the diversity of potential building electrification demands across Denver, reflecting a mix of building types, technology types, and behavioral and operational considerations, while taking into account Denver’s specific climatic and temperature conditions. The E3 RESHAPE model (described in more detail below) is used to develop hourly space heating and space cooling load shapes that reflect weather, technology characteristics, and household behavior.

Residential and commercial space heating in Denver is currently dominated by gas furnaces and boilers. Displacing or supplementing these technologies with electric heat pumps is a key measure to decarbonize space heating and space cooling.

In this analysis, E3 considered three different ASHP technologies and one ground source heat pump (GSHP) technology. Specifications for the ASHP technologies are based on the cold climate air source heat pump (ccASHP) specification and product list from NEEP (the Northeast Energy Efficiency Partnership). The four technologies considered are described below, and their COPs relative to outdoor temperature are illustrated in Figure D 1 below.

- “Low ccASHP” – refers to the minimum product specification for NEEP’s ccASHP standard. It is important to note that this still describes a high-end appliance in today’s marketplace.
- “Mid ccASHP” – refers to a midrange ccASHP from the NEEP product list.
- “High ccASHP” – refers to the best ccASHP technologies in the NEEP product list.
- “GSHP” – refers to a ground source heat pump with a COP that is independent of outdoor air temperature.
The maximum capacity of an ASHP, i.e., the amount of heat it can produce, also declines as outdoor temperatures fall. ASHPs are generally sized to meet a building’s heat demands in most hours of the year but may require supplemental heat in the very coldest hours. This supplemental heat (or “backup heat”) can be provided by different heat sources and the details may have a large impact on winter peak loads. The grid impacts of building electrification, including potential impacts to overall system peak demands, will depend on how supplemental heating needs in the coldest hours of the year are met in buildings.

This supplemental heat (or “backup heat”) can be provided by different heat sources. Options include:

1) Minimizing supplemental heating needs with high-performance ccASHPs or geothermal heat pumps.

2) Electric resistance heat for supplemental heating needs.

3) ASHP with fuel backup, also known as a hybrid gas-electric heat pump or dual-fuel system.

In an ASHP with electric resistance backup, the heat pump includes an electric resistance heating element that activates automatically below a certain outdoor temperature. Alternatively, an ASHP with fuel backup describes an ASHP that is paired with a new or existing fuel-based appliance (this is also called a “hybrid heat pump” or a “dual-fuel system”). In a ducted central heating system, if an ASHP is installed in-line with a furnace, the two appliances will not operate simultaneously: in the coldest hours, the ASHP will shut off and all heating demands will be served by the backup heater. Conversely, if the ASHP is installed independent of the fuel-based heater, for example as a packaged terminal (“mini-split”) heater, then the ASHP and the fuel backup heater can run simultaneously.
From a system planning perspective, building electrification technology options that reduce winter peak electric heating needs may reduce electric grid upgrade costs. For example, GSHPs run at a high COP in cold hours, leading to relatively small peak impacts. For ASHPS, sizing larger heat pumps would reduce the amount of supplemental heat required in cold hours. Finally, fuel backup systems would reduce peak loads relative to ASHPs with electric resistance backup.

However, customers generally do not experience a strong economic signal to reduce electric peak demands, and instead will generally choose building technologies based on upfront capital cost or other factors. For example, GSHPs have a large upfront cost and are unlikely to see widespread adoption without incentives or customer education on the potential bill savings. Sizing decisions for ASHPS may be made by contractors hoping to reduce upfront cost, with little consideration of the costs of supplemental heat. The choice between electric resistance and fuel-based supplemental heat may depend on whether the customer has a functional fuel-based heater already installed. For customers with fuel backup, the choice of what hours to use the fuel backup may be tied to customer rates rather than a consideration of peak impacts to the grid.

RESHAPE METHODOLOGY

RESHAPE combines a set of characteristic buildings, many years of historical weather, and a physical model of heat pump operation. Building data comes from the Energy Information Administration (EIA) RECS and CBECS surveys, and weather data comes from NOAA’s North American Regional Reanalysis. A description of the RESHAPE model follows.

The first step in the RESHAPE model is developing a geographic sample of representative buildings. The model starts with a database of buildings from the EIA RECS and CBECS surveys, which includes ~1,000 residential buildings and ~250 commercial buildings in Denver. Next, the model creates a geographic sample of these buildings across Denver.

The second step in the RESHAPE model is using historical weather data to simulate hourly heating demands for each building. Weather data from 2019 is from NOAA’s North American Regional Reanalysis, enabling a representation of the weather conditions that may occur across Denver. The weather data is combined with data from the building surveys to simulate hourly heating for each building in the sample.

The third step in RESHAPE incorporates the heat pump technologies chosen in the adoption scenario and simulates heat pump operation for each building. As described above, a set of different heat pump technologies are adopted in residential and commercial buildings. These technologies are sampled into the different households in RESHAPE. Next, RESHAPE simulates the operation of these heat pumps (as well as supplemental heat) in order to calculate hourly space heating loads for each building. Finally, these loads are summed up to system-wide hourly space heating loads.

E3’s RESHAPE analysis was benchmarked against publicly available EIA data, and the aforementioned RECS and CBECS datasets along with Denver-specific data contributed by Xcel Energy. Xcel Colorado provided electric and gas load data for historic peak winter days in Colorado.
RESHAPE estimates the total heating service demand and water heating demand across Denver’s building stock independent of the heating technology type. The heating service demand is a measure of the total energy needed to heat buildings and to provide water heating within Denver. An illustration of this intermediate model output, for several representative winter days, is shown in Figure D 2. This figure illustrates the extent to which space heating demand dominates energy consumption in the winter, compared to water heating demand. It also shows the hourly timing of space and water heating in the winter. Space heating demand is highly correlated without outside air temperatures, as well as daytime hours, ramping up in the morning when people wake up, and dropping off at night as people go to sleep. Water heating service demand is highly correlated with shower and bathing schedules, showing smaller peaks in the morning hours and again in the evening.

![Figure D 2: Service demand for representative winter days](image)

The RESHAPE model translated the energy service demand for space heating and water heating (illustrated in the figure above) into estimates of hourly electricity demand. This translation step requires a number of assumptions about the electric heating equipment in use and the efficiency of the equipment and building shell. The tool is designed to easily allow sensitivity analysis around different technology input assumptions and building characteristics, without requiring re-running complex building simulations. Figure D 3 illustrates the electric demands for a sample scenario, using the energy service demands shown in Figure D 2 above. The electric demands associated with ASHP space heating loads peak at the same time as the energy service demand. The figure shows that wintertime electricity demands are both peaky and dominated by space heating loads, compared to the relatively small impact of electric air source water heating.
GRID IMPACT SCENARIOS

Several scenarios of grid impacts were evaluated assuming a diverse mix of heat pump technologies installed across Denver’s buildings. The five scenarios are defined as follows:

1. **Min ccASHP**: All heat pumps installed are consistent with the minimum performance required (COP > 1.75 @5 degrees Fahrenheit) to be listed on the NEEP Cold Climate Produce Specification.
2. **Min ccASHP + Shell**: Most buildings receive a deep shell retrofit, reducing annual statewide heat demand by 30% and cooling demand by 10%.
3. **High ccASHP**: All heat pumps installed are ccASHPs that are consistent with the highest performing units listed by NEEP (COP > 2.9 @5 degrees Fahrenheit).
4. **50% Hybrid**: Half of the heat pumps installed are hybrid systems that use either gaseous or liquid fuel backup as their source of supplemental heat. Half of the hybrid heat pumps are assumed to be centrally ducted and cannot run simultaneously with the backup system, while the other half are assumed to be mini-splits that can run simultaneously with the backup fuel system.
5. **Balanced**: Includes 15% high ccASHPs, 50% hybrid systems and the same shell improvements as the **Min ccASHP + Shell** scenario.

By evaluating this range of scenario assumptions, we can evaluate a broad range of potential future grid impacts, as each of these factors (heat pump efficiency, building shell efficiency and the use of hybrid or backup heating systems) will have an important impact on electricity demands.

The “Min ccASHP” scenario is consistent with the cold-climate heat pump technology characterization modeled by NORESCO’s building simulations. The “High ccASHP” scenario is consistent with NORESCO’s “best in class” high performance heat pump technology characterization. The building shell upgrade assumptions included in some of the scenarios above are consistent with the difference in building shell performance modeled by NORESCO between the “low envelope” and “medium envelope” performance cases.
APPENDIX E – CARBON EMISSION METHODOLOGY AND DETAILS

We developed emissions rates for gas and electricity usage in the city of Denver.

The gas emissions rate reflects the sum of two components: the carbon dioxide (CO₂) emissions resulting from the combustion of gas and the emissions corresponding to methane leakage from upstream (gas production) and downstream (gas delivery). As shown in Table E 1, methane leakage is calculated based on a 2.4% upstream methane leakage rate and a 0.5% downstream methane leakage rate, consistent with the Colorado GHG Reduction Roadmap. Carbon dioxide equivalent (CO₂e) emissions from methane leakage are calculated based on a 100-year global warming potential of 25 for methane. Accounting for leakage increases the emissions corresponding to gas usage in buildings by about 25% as compared to combustion only emissions.

We also developed annual average greenhouse gas emissions rates for electricity use in Denver, as shown in Figure E 1. These emissions rates are based on historical average emissions factors from Xcel Energy as well as Xcel Energy’s publicly stated emissions reduction targets. These targets are:

- 60% reductions below 2005 levels by 2026.
- 85% reductions by 2030.
- 100% reductions by 2050.

Table E 1: Retail gas emissions assumptions

<table>
<thead>
<tr>
<th>Retail NG Leakage Rate Calculation</th>
<th>Category</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volumes Delivered to Customers (EIA)</td>
<td>mcf</td>
<td></td>
<td>426,653</td>
</tr>
<tr>
<td>Downstream Leakage Rate (CDPHE)</td>
<td>%</td>
<td></td>
<td>0.50%</td>
</tr>
<tr>
<td>Gross Downstream Volume</td>
<td>mcf</td>
<td></td>
<td>428,797</td>
</tr>
<tr>
<td>Upstream Leakage Rate (CDPHE)</td>
<td>%</td>
<td></td>
<td>2.40%</td>
</tr>
<tr>
<td>Gross Upstream Volume</td>
<td>mcf</td>
<td></td>
<td>439,341</td>
</tr>
<tr>
<td>Total Leakage Rate</td>
<td>%</td>
<td></td>
<td>2.89%</td>
</tr>
</tbody>
</table>

12 CO GHG Reduction Roadmap Assumptions & Results, “Oil & Gas” worksheet. https://drive.google.com/file/d/1Ums5gH10yF6X1VvoyUvzPVBsDii4x2SD/view
13 EPA: https://www.epa.gov/ghgemissions/overview-greenhouse-gases#methane
The emissions rate was interpolated for years between stated targets. Note that the emissions rate reaches 0 in 2050, corresponding to the 100% emissions reduction target in that year.

![Figure E 1: Forecast annual emissions rate for Xcel Energy in Colorado](image)

**Refrigerant Emissions**

Prior work has shown that refrigerant leakage is likely to increase GHG emissions associated with the use of heat pumps. However, refrigerant leakage is also a source of GHG emissions from air conditioners, refrigerators, and freezers in homes and businesses. Thus, for existing buildings with air conditioning, building electrification is not expected to lead to a large increase in emissions due to refrigerant leakage. The refrigerant charge in an air conditioner is similar but not identical to a heat pump. There is currently not good data about the refrigerant leakage potential for the range of commercial heat pump technologies evaluated in this study. For this reason, GHG emissions from refrigerant leakage have not been included in this analysis.

Over the coming decades, new appliance standards for heat pumps and air conditioners may reduce these emissions by requiring the use of low-GWP refrigerants. These standards reflect an opportunity to further reduce GHG emissions in both mixed-fuel and electrified buildings.

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APPENDIX F – INCENTIVE BACKGROUND AND DESIGN

Incentives often take the form of monetary rebates, although programs that offer recognition or technical assistance (such as providing energy audits or contractor training) may also function as useful incentives. In general, incentives should be developed and structured in such a way that they can be stacked or layered (i.e., a given customer can benefit from multiple incentives) and should also address different steps throughout the process of electrification to make the transition as easy as possible for all involved.

Best Practices for Layering Incentives

Layering of incentives supports greater adoption of electrification technologies because it allows consumers to benefit from multiple resources that support the transition from both a financial and a technical perspective. An example of incentive layering may be an upstream discount to a distributor that is passed on to the customer, combined with a downstream discount to the customer to support either equipment purchases or necessary infrastructure (e.g., panel upgrades). Additional incentives to improve a building’s efficiency may be layered on top of the electrification-specific incentives.

The California Public Utilities Commission (CPUC) developed a proposal of recommendations on the best ways to layer incentives to support residential and commercial electrification. Their recommendations include: 18

- Ensure that incentives are available that touch different points of the electrification process.
- Coordinate available incentives across programs to reduce both appliance and installation cost.
- Establish incentives for each entity that are appropriate. For example, incentives from IOUs should support the utility’s efficiency and DSM efforts, while other entities may focus incentives on other steps in the process (e.g., energy audits, panel upgrades, etc.).
- Use incentives from entities that are not utilities – and specifically from local governments – to address specific local needs after considering utility- or state-level incentives that are available.
- Coordinate incentives across entities to ensure that market rate customers still pay for a portion of the appliance and installation costs. To the greatest degree possible, equity-based programs should cover 100% of costs for under-resourced households.
- Track incentives through a database where all program administrators report using the serial number of appliances. Benefits should be attributed to programs based on the share of total incentives that came from each program.
  - Track incentives for non-equipment project aspects (e.g., panel upgrades, installation costs, utility rate changes) and separately from appliance-specific incentives.
  - Develop an MOU between entities providing incentives to support appropriate tracking.

Incentivizing Energy versus Non-Energy Benefits

Often energy efficiency programs do not consider the full range of impacts that might result from the program, instead focusing only or primarily on direct energy and monetary impacts. For Investor-Owned Utilities (IOUs), including Xcel, the most common way to calculate cost-effectiveness for an energy efficiency program is the Total Resource Cost (TRC) test. This test compares the total cost of incentives,

18 See CPUC document R.19001-011 Phase II Staff Proposal.
administration costs, and customer contributions against the total avoided supply costs and non-resource impacts resulting from the program over the lifetime of the efficiency measure. Traditionally, this has been an insightful metric because it helps utilities focus on those measures that have the greatest potential to reduce energy use; utilities are required to reduce energy to demonstrate compliance with the state’s demand side management (DSM) requirements. Most often, non-energy benefits are not included in the TRC, leaving out many of the positive impacts of energy efficiency measures on households, businesses, and the wider community.

Currently, Colorado does not include public health, customer health and safety, or comfort in its cost-effectiveness test. Additionally, the social cost of carbon also is not effectively addressed in the TRC test for IOUs in Colorado. DSM metrics tend to quantify avoided therms or kilowatt hours rather than avoided carbon emissions. Integrating non-energy and non-monetary benefits into a revised TRC analysis, or developing a new method of program evaluation that accounts for these non-energy and non-monetary benefits may lead to an expansion of efficiency and energy programs and encourage Xcel to create further incentive programs that address the new metrics. EOC utilizes a modified TRC (mTRC) for income-qualified energy programs that the organization administers; this mTRC does account for overall community benefits and could be an example of how Xcel can begin to account for these benefits. According to a Settlement Agreement between Xcel, local cities, and program administrators, Xcel intends to provide mTRC ratios at the product level that will include the social cost of carbon and lifetime emissions reduction for electric portfolio options.

Figure F 1 illustrates the economic value assigned to various non-energy and non-monetary benefits that accrued to customers from a weatherization program in Massachusetts. This may provide a useful template when exploring how to quantify the non-energy impacts (NEIs) of energy and utility programs.

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19 See: https://www.xcelenergy.com/company/rates_and_regulations/filings/colorado_demand-side_management.
22 Based on conversations with Energy Outreach Colorado.
23 See: Microsoft Word - 20AL-XXXXE_DSMCA-E 2020_AFN Notice Exhibit 1_Final.doc (xcelenergy.com).
National Electrification Incentive Programs

Many states, local government entities, and utilities are creating incentives to drive the switch from gas-powered equipment to electrical alternatives. Figure F 2 outlines many of the most commonly utilized incentives currently offered throughout the country for electric space and water heating (note this is as of June 2020). Further details on incentive programs for existing buildings are provided in the text following the table.

The most frequent type of incentives are upstream rebates for manufacturers and distributors, downstream rebates for customers, and training and education programs for contractors. Programs that allow incentives to be layered or stacked and programs that aim to educate and promote electric heating technologies are also common. Less common are programs that provide bulk-purchase discounts for heat pump technologies or loaner equipment that allows consumers to test out induction stoves before they make the move to purchase one. Upstream rebate programs often include a requirement that the discount be passed on to the customer, as well as a certification or vetting of distributors and installers that are approved to receive the rebates.

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CALIFORNIA

- Upstream rebates, consumer education, and contractor training are available through the state’s Technology and Equipment for Clean Heating (TECH) program.
- HPWHs are incentivized through the state’s Self Generation Incentive Program.
- Downstream rebates for consumers purchasing electric equipment are available from local municipal utilities. Sacramento Municipal Utility District (SMUD) offers additional incentives up to $2,500 for electric panel and wiring upgrades needed to convert homes to all-electric.
- Induction cooktops can be loaned to prospective buyers for three weeks for free from the City of Palo Alto’s municipal utility. The city also provides a robust educational website.
- A proposed program from Southern California Edison (SCE) would provide free space and water heating and induction cooking equipment to homes with a high cooling load or that use propane or wood for space heating. A similar program is available in the San Joaquin Valley.
Fuel switching programs qualify as energy efficiency programs per state regulation. Various communities across the state have placed restrictions on installing new fossil fuel space-heating, water-heating, or cooking equipment.

**COLORADO**

- Education and outreach, active marketing, and financial incentives for heat pumps and HPWHs are available through the City of Boulder’s Comfort365 program. The city has partnered with Mitsubishi to offer additional incentives, marketing, and engagement of the company’s dealers and installers.26

**CONNECTICUT**

- Upstream rebates are available for ductless ASHPs from Energize CT; incentives are given to wholesale distributors, who must pass them on to customers. Only licensed contractors can receive incentives.
- Increased incentives are available from Eversource and the United Illuminating Company when installing insulation at the same time as a new heat pump is installed.

**MAINE**

- Incentives for heat pumps are available through Efficiency Maine Trust (EMT), Maine’s third-party energy efficiency program administrator; the largest involves rebates for ductless heat pumps, with higher incentives for low-income households. This program also has incentives for commercial customers, with rebates that can be applied to multiple zones if the commercial building requires multi-zone units.

**MASSACHUSETTS**

- Fuel optimization incentives are available through Massachusetts’ third-party program administrator (Mass Save). These are for households that decide to replace their central resistance heating system with heat pumps; a small businesses program is under development.
- Heat pump and integrated control training programs are available through Mass Save. Post-installation consumer education is also provided.
- GSHP incentives are available for residential customers, and a whole-house ASHP program is being piloted by Massachusetts Clean Energy Center (MassCEC).
- Alternative Energy Certificates (AECs), similar to renewable energy credits (RECs), are offered based on heat pump energy use through the Department of Energy Resources.

**NEW HAMPSHIRE**

- Incentives based on the total tons of heating/cooling that a system provides. Additional incentives are available for weatherization and whole-house electrification projects.

**NEW YORK**

- Downstream incentives for residential and commercial electric space and water heating are available through the Clean Heat: Statewide Heat Pump Program; the program is administered by

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26 Ibid.
the state’s electric utilities and ensures a common program structure across the state. Contractors are required to follow best practices in order to be eligible for participation.

- Prior to this, utilities offered their own incentives that could be combined with incentives from the New York State Energy Research and Development Authority (NYSERDA).

- Workforce development and training, consumer education and technical assistance, and technology innovation and demonstration programs and projects are funded through NYSERDA’s Clean Energy Fund. The program has set-asides for low- and moderate-income customers.

**RHODE ISLAND**

- Incentives from National Grid are available to customers whose current heating fuel is heating oil or propane. Additional incentives are available to customers whose existing heating fuel is electric when there is a 900 kilowatt hour/month difference between three winter months and the three lowest-usage months.

**OREGON**

- Programs to certify contractors as Master Installers and to enlist contractors to promote ductless ASHPs to customers are run by the Northwest Energy Efficiency Alliance in concert with local utilities.
- A limited-time group purchase program for ductless heat pumps is available for residential and commercial customers of the City of Ashland municipal utility.
- Loans for heat pumps are available from the Eugene Water and Electric Board.

**VERMONT**

- Incentives for ccASHPs and custom fuel-switching projects (for commercial/industrial customers) are offered by many of the state’s electric utilities.
  - Burlington Electric Department (BED) offers incentives for ccASHPs and has a network of heat pump installers. BED is also considering programs to support automatic integrated control options, tiered incentives, and financing options to encourage homes to weatherize before installing heat pumps.
- Midstream rebates for heat pumps are provided to wholesale distributors, who are required to pass the cost savings on to contractors in the form of an instant discount at the point of sale. Letters are sent to contractors’ customers informing them of the discount, which encourages contractors to pass the savings on to the customer. This program is administered by Efficiency Vermont.
- Programs that provide training, education, and promotion of heat pumps are under development by Efficiency Vermont.
- A comprehensive package of services including weatherization, heat pumps, and solar is available with support from Zero Energy Now, a program coordinated through Green Mountain Power and Efficiency Vermont.

**WASHINGTON**

- An energy performance standard specifically for large commercial buildings – including an incentive program for early adopters – is intended to drive efficiency and heat pumps installation; the program was developed by the state’s Department of Commerce. The standard applies to all commercial buildings larger than 50,000 square feet and will require them to conduct energy
benchmarking and create energy management plans, as the buildings will be mandated to prove they consume less energy than specified energy use intensity targets. The standard goes into effect as a voluntary program in 2021 and becomes mandatory in 2026.

**Current Incentives Available in Denver**

**GAPS IN INCENTIVES**

While there are many incentives available to Denver residents and businesses that support building electrification, there are some notable gaps to be filled:

- There are minimal upstream incentives specifically for heat pumps or HPWHs on either the residential or commercial side.
- There is no technical assistance or training for contractors, distributors, or consumers that is specific to heat pumps.
- There are no rebates for electric heating systems for commercial buildings.
- There is little ability to layer incentives beyond rebates and financing.

**TIMING AND TARGETING OF INCENTIVES**

In order to have the Denver community fully embrace electrification, incentives and programs need to be available to support adoption of this technology at every point of the product adoption curve. This means that there may be specific incentive programs and rewards available over the coming years that adjust and are modified as the technology is adopted more broadly.

Early incentives targeting the “enthusiasts” and “visionaries” seen in Figure F 3 may be most appropriate as downstream rebates for consumers, accompanied by a robust messaging and outreach program to educate these groups about the benefits of electrification.

Incentives that may be more effective in influencing the “pragmatists” and “conservatives” might include upstream incentives for distributors and training and certification programs for contractors installing the technology; this will ensure that consumers are being informed of the benefits of electrification at every touch point of the process of replacing their equipment.

“Skeptics” may be most impacted by both upstream and downstream incentives, as well as mandates that require electrification over time.
INCENTIVES AND EQUITY

While financial incentives that reduce the cost of a technology will inherently make it easier for consumers to adopt the technology, recent research and analysis indicate that, at their core, incentive programs generally do little to address issues of equity to ensure the most underserved members of the community benefit from the available services and resources. Researchers at the University of California determined that, “Incentive programs, even those that offer more generous payments to applicants that meet low-income requirements, are consistently underutilized by lower-income and minority cohorts due to financial barriers, limited awareness of such programs, and lower rates of property ownership.”

Research has shown that under-resourced communities use less energy overall than their higher-income neighbors; at the same time, service fees charged to all customers help to fund incentive-based programs, which often see much higher participation from higher-income customers.

Incentive programs are based on the priorities of the utilities and program administrators that are managing these programs; they generally are not co-created with the input and involvement of the whole community, including under-served populations. Incentive programs that provide financial rebates toward the cost of equipment purchase are a one-size-fits-all approach, and even those that target higher incentives for income-qualified populations tend to fall short of achieving their programmatic goals. An approach that comes from a standpoint of targeted universalism—where a common goal is achieved by providing different programs and resources to communities based on their needs—may be useful to apply in developing additional incentive programs that address the specific needs of under-resourced communities.

Denver is embarking on work with the Beneficial Electrification Institute (BEI) to determine what an equitable incentive program would look like for the Denver community; because this work is just getting started, the recommendations for incentive design shared below do not necessarily fully address how

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28 Ibid.
29 See https://belonging.berkeley.edu/targeteduniversalism.
incentives can be used to enhance equity. As Denver and BEI embark on this work, it is crucial that community-based organizations and representatives be engaged to determine what this program design will look like. Questions that should be addressed include:

- Who is in the most need in the community? What are their needs?
- What specific community programs currently exist that meet those needs?
- How does electrification address the needs?
- How can electrification be integrated into those existing programs?

By allowing for a collaborative process that is informed by community knowledge, Denver will be able to identify shared goals with the community and subsequently co-create programs that address community needs while also supporting Denver’s climate goals. This may result in changes to financial incentive levels that are available based on the consumer’s needs and income status, training programs that ensure that minority and women-owned businesses are able to benefit from the electrification transition, and programs that support bill payment for households that make the switch to electric and were previously supported through the Low-Income Home Energy Assistance Program (LIHEAP).  

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30 Based on conversations with staff at the Beneficial Electrification Institute


