MINNEAPOLIS 1–4 UNIT RESIDENTIAL WEATHERIZATION AND ELECTRIFICATION ROADMAP

Developed by Center for Energy and Environment

February 2023

Completed for: the City of Minneapolis

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Center for Energy and Environment

EXECUTIVE SUMMARY

Weatherizing and electrifying the City of Minneapolis' 88,441 1–4 unit residential homes offers a significant opportunity to meet the City's science-based carbon reduction goals (City of Minneapolis, 2021). Weatherization helps reduce energy load while electrification can facilitate the powering of home heating and appliances with clean energy.

To develop a path that would achieve City climate targets, we modeled weatherization and electrification scenarios through an iterative process involving City staff and external stakeholders. Analysis focused on market-ready electrification and weatherization measures with the greatest potential for greenhouse gas impacts, including air source heat pumps, induction stoves, electric vehicles, and insulation, among others. Stakeholders emphasized meeting climate goals and addressing equity as they helped guide assumptions included in the analysis around potential market efficiencies, utility rates, and where and how to target implementation.

Figure 1. Air source heat pump outdoor unit. Space heating electrification using cold climate air source heat pumps offers significant opportunity for home decarbonization.

The main takeaways from this project include the following.

- To meet the City's climate goals, whole home weatherization and electrification projects should begin in 2024 in approximately 4,400 homes, scaling and peaking to nearly 9,000 homes in 2029. Any delay in retrofits necessitates even more aggressive annual rates of project completions.
- The total upfront cost of weatherizing and electrifying these homes will be between $2.12 billion and $2.73 billion over the next 20 years. This is $1.06 billion to $1.24 billion above what will already be required for end-of-life equipment replacements, which we define as the upfront incremental cost. To meet the City's climate goals, the project work has an upfront incremental cost of around $77 million in 2024, scaling and peaking to over $200 million in 2029. The total, non-incremental per building cost averages to $30,900.
- This project work is a significant workforce development opportunity as Minneapolis will need a contractor workforce of nearly 1000 people in total to complete this work.
- Weatherization is the critical path to cost-effective electrification from an upfront cost and utility bill cost perspective.
- Approximately 75% of decarbonization potential stems from weatherization and space heating electrification.

- The oldest buildings are the least likely to have wall or attic insulation. These are best positioned for weatherization energy savings and are more likely to see utility bill savings upon electrification. A significant portion of homes in the Green Zones fall into this category.
- The median home completing electrification retrofits with weatherization and converting to those rates would see utility bill changes of -24% and 4% given today's available all-electric and dual fuel utility rates, respectively. Note: these numbers reflect the median. Actual impacts vary widely depending on the home. Scenarios using anticipated future rates similarly show utility bill benefits of weatherization and electrification, although the utility bill benefits are larger for the dual fuel scenario.
- Full electrification with weatherization would increase the peak power load required for this building set by over four times, which would affect the capability of existing utility distribution infrastructure, timelines for the distribution infrastructure upgrades to be able to accommodate such load growth, and future utility rates. Dual fuel and load control strategies can be significant hedges against these issues.
- Customer utility bills are estimated to be 25-70% lower by decarbonizing homes via electrification and weatherization compared with utilizing renewable natural gas.

The roadmap to meet the City's goals includes the following City investments.

- Launch a comprehensive weatherization and electrification pilot program to establish program processes and engage contractors.
- Prioritize investments in weatherization, first in the Green Zones and old, low-performing buildings throughout the city.
- Subsidize partial or full electrification in Green Zones as analysis shows utility bill cost advantages. The City should further encourage electrification in the remainder of the City in equipment end-of-life situations and when economically advantageous through outreach and education.

Beyond investments, the road for citywide weatherization and electrification will also necessitate the following leadership from the City.

- Advocate for increased weatherization and electrification incentives from both CenterPoint Energy and Xcel Energy.
- Advocate for Xcel Energy to build capacity to meet electrification goals.
- Participate in rate and policy discussions at the Public Utilities Commission to secure favorable rates and policies for electrification.
- Enhance City initiatives for electrification workforce development.
- Investigate and address barriers to electrification within existing City policies and procedures.
- Consider other electrification technologies for study.

The City of Minneapolis' climate goals are ambitious, but our analysis shows that they can be met with todays' weatherization and electrification technology. The goals can be achieved affordably from a utility bill perspective using today's and anticipated future all-electric and dual fuel utility rates. If the City moves quickly to make substantial upfront investments in weatherization and electrification, stand up appropriate programs, and engage with the utilities, meeting the City's decarbonization timeline in an equitable way is possible.

BACKGROUND

Over 70% of the climate pollution in Minneapolis stems from energy used in buildings. Reducing and decarbonizing the energy used in buildings is therefore key for any viable climate action plan.

Electricity and fossil (natural) gas are our two main energy sources. In our cold climate, most of buildings' annual energy use is for heating. Fossil gas currently supplies most of the energy used for heating because of the historically favorable economics compared to heating with electricity. However, electricity has a greater potential to become cleaner over time compared to fossil gas.

The electric grid is already rapidly decarbonizing as Xcel Energy increases its renewable energy generation and retires coal generation. Xcel Energy has committed to reduce carbon emissions for electricity generation 80% by 2030 and is required by Minnesota state law to achieve 100% carbon-free electricity generation by 2040 (State of Minnesota, 2023). Fossil gas, in comparison, has limited potential to decarbonize. Developments in renewable natural gas are not expected to achieve economically viable results, and technical constraints limit the use of alternative gases like hydrogen (Enegy Transitions Commission, 2018)((Sara, Esposito, & Tallackson, 2022).

The City of Minneapolis is now considering strategies to transition energy sources to electricity from fossil gas to maximize the potential for long-term decarbonization. This process is called electrification.

With 120,000 buildings in Minneapolis, where do we start?

The first step of the City's approach to decarbonizing building energy was to identify the building sector with most potential, given today's technology, to quickly electrify. Although heating is the primary driver of energy use in all Minneapolis buildings, the needs and equipment vary considerably by sector and building type. Commercial, industrial, and large multifamily building types have heating needs that are not well met by the electric heating technologies available today. By contrast, there are feasible technologies available to electrify heating in small (1-4 unit) residential buildings.

Definition: Upfront vs. Utility Bill Costs

In this paper, we define "upfront costs" as the cost to the property owner to contract with a professional to purchase, design, and install equipment. "Utility bill costs" or "bill costs" are the monthly operational energy costs incurred from using heating, water heating, appliances, and other equipment.

The second step was to identify a suitable electric heating technology that can economically meet our decarbonization goals. As costs are such a key factor, the modeling considered upfront costs, utility bill costs, and future energy rate implications.

We identified air source heat pumps (ASHPs) as the most promising technology to quickly scale heating electrification in one-to-four-unit residential buildings. ASHPs are air conditioners that can run in both directions to either heat or cool a building. Due to recent technological advancements, ASHPs can now provide heat to a home even when outdoor temperatures are well below freezing. Those that can provide heat below 0°F are called “cold climate” units (ccASHP) and are used for the majority of this analysis. ccASHPs are commercially available for one-to-four-unit residential buildings but are not well established in other building sectors.

There are additional advantages of focusing on electrifying one-to-four-unit residential buildings. Weatherization measures (insulation and air sealing) for one-to-four-unit residential buildings are widely available and deliver reliable energy savings. Additionally, other building functions that commonly use fossil gas, such as water heating, clothes drying, and cooking, can be transitioned to feasible electric options to save costs and promote health and safety.

For these reasons, this analysis focuses on how to electrify one-to-four-unit residential buildings with strategies revolving around ccASHP heating technology and weatherization measures.

METHODOLOGY

Overview

The analysis aimed to develop a feasible pathway to electrify the city's one-to-four-unit homes. We sought to create a set of measures and activities on a timeline with an upfront cost estimate that met the following criteria:

Achieve the City’s climate target and timeline in a way that advances equity, that uses existing technology, that can move forward in today’s regulatory environment, and that is scalable in the most cost-effective way possible for both upfront and utility bill costs.

The pathway development approach involved multiple modeling scenarios that were iterated via feedback provided through a stakeholder engagement process from September 2022 through December 2022.

Stakeholder Process

We engaged a City staff group and a community stakeholder group to develop the feasibility pathway. The City staff group comprised members whose work involves energy, sustainability, city planning, or residential buildings. The community stakeholder group consisted of members who could represent a diversity of concerns, perspectives, geographic areas, and lived experiences that would be relevant for any future electrification plan. These members included utility representatives, members of relevant City committees, energy experts, and community advocates. Lists of group members can be found in the Appendix.

We convened three two-hour workshops with each respective group for a total of six workshops. During each workshop, we presented modeling work and facilitated discussion. We refined and expanded our modeling and pathway design for each successive workshop based on the group's questions and interests. Workshop slides can also be found in the Appendix.

Modeling Analysis

The objective for modeling was to create a baseline model dataset representing the current state of all one-to-four-unit residential properties in the city of Minneapolis. This was done using a number City, federal, and utility data sources (Figure 2). Establishing this baseline dataset allowed us to run a variety of scenarios to determine upfront cost, utility bill cost, decarbonization impact, and workforce needs for various electrification measures. Further detail of the development of the baseline model is available in the Appendix.

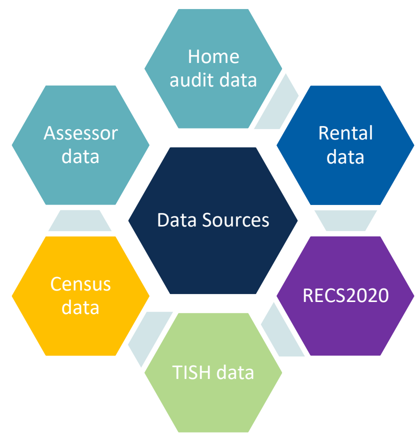

Figure 2. City, federal, and utility data sources used to create the baseline model.

Scenario models focused on the impacts of weatherization and electrification measures (Table 1). Weatherization measures were selected by how common they are implemented in weatherization and utility programs and their likelihood for savings. Electrification measures were chosen based on the ubiquity in Minneapolis homes and their potential impact to save greenhouse gas emissions.

Weatherization	Electrification
Wall insulation	Electric service upgrades including EV charging circuit to mid-tier Level 2, which is a 240V outlet
Attic insulation	Space heating systems • Furnace replaced with centrally ducted ccASHP • Boiler replaced with multi-split ccASHP
Air sealing	Domestic hot water replaced with heat pump water heater (HPWH)
Rim joist insulation	Clothes dryer replaced with heat pump clothes dryer (HPCD)
Ventilation	Cooking equipment replaced with induction ranges and electric ovens

Table 1. Measures used in model analyses.

Building Characteristics

There are 88,441 one-to-four-unit buildings and 102,788 individual units in Minneapolis (City of Minneapolis, 2022). Of those buildings, 13,877 are rental properties, comprising 22,296 rental units. The building stock is old, with most buildings built before the Great Depression. In terms of size, the buildings average around 2,400 ft^2 with a size distribution that aligns with the rest of the Twin Cities Metro.

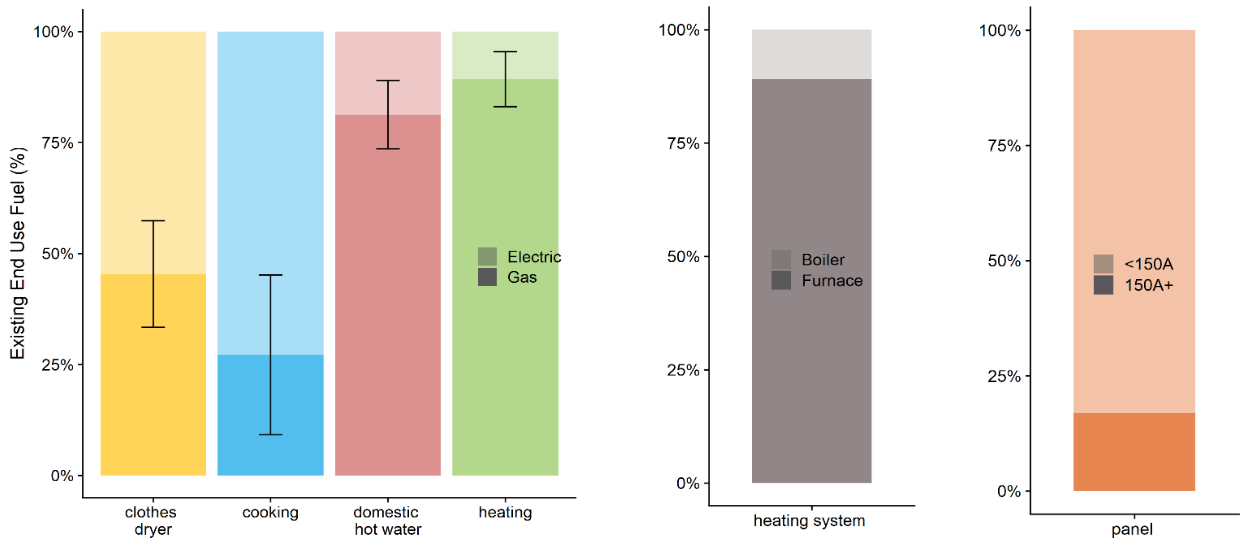

Figure 3. Existing energy end uses, fuel sources, and electric service panel capacity.

Minneapolis homes depend heavily on fossil gas for energy use as shown in Figure 3. About 90% use gas for space heating and 80% use gas for water heating. Roughly 45% and 25% use gas for clothes drying and cooking, respectively, although the accuracy confidence in these two percentages is lower. Most space heating, around 85%, is delivered by furnaces, while the remainder uses boiler systems. Lastly, less than 20% of these buildings have electric service of 150 Amps or greater. Powering heating, appliances, and other loads in a Minneapolis home requires significant electric load and therefore will likely require at least 150Amps of service.

46% of the buildings have inadequate wall insulation, as defined by having insulation values less than R8. Further, 56% of homes have inadequate attic insulation. Roof and attic geometry greatly impacts the insulation potential. We define the value of adequate insulation for unfinished attics as a minimum R50 and for finished attics with slanted ceilings as R21 or greater.

Definition: Dual fuel space heating

In a dual fuel system, a heat pump electrifies a home's heating in the spring, fall, and much of the winter. When outdoor air temperatures dip below a defined setpoint a gas furnace or boiler takes over to provide space heating. With a 5°F setpoint in Minneapolis, the electric heat pump provides approximately 80% of home heating in a year, while the gas equipment provides the remaining 20%. Dual fuel systems can be comprised of separate pieces of equipment (e.g., a legacy boiler and a new mini-split heat pump) or a singular combination heat pump and furnace device.

Modeling Iterations

Over the workshop series, we ran three rounds of model iterations. With each round, we received feedback from both stakeholder groups. The responses then informed the next round of modeling. Details of the various scenarios are listed in Table 2.

Scenario	Aim of Scenario
Round 1	
Full Electrification* (including weatherization)	Understand the upfront cost and utility bill costs of switching all mechanical systems including vehicles to electric power in the one-to-four-unit building stock. Understand the impact of weatherization on energy use, energy demand, upfront costs, and utility bill costs.
Grid Needs	Understand the impact of increasing electric load.
Pace of Implementation	Understand the number of building retrofits needed annually to meet the City's science-based climate target.
Labor Requirements	Understand the number of full-time staff in total needed by trade for electrification.
Round 2	
Dual Fuel Space Heating	Understand the impact on utility bill costs and emissions of dual fuel air source heat pumps when heat pumps are designed to meet 50% of the seasonal heating load (also known as 50% utilization; switchover temperature is at 25°F).
Utility Rates	Understand the impact of potential electric vs. gas rates.
Market Efficiencies	Understand the impact of market efficiencies by scaling manufacturing and installation of electrification measures including labor efficiencies.
Round 3	
Revised Dual Fuel Space Heating	Understand the impact on utility bill costs and emissions of dual fuel air source heat pumps, when designed to meet 80% of the heating load (also known as 80% utilization; switchover temperature is at 5°F).
Utility Rates	Understand the impact of refined electric and gas rates including renewable natural gas rates.
Market Efficiencies	Understand the impact of market efficiencies by scaling manufacturing and installation of electrification equipment minus labor efficiencies.
Pace and Strategy of Implementation	Understand the costs and opportunities of rolling out implementation based on geography and the emissions impact of delaying the pace of implementation (such as waiting to replace equipment on failure).

*Table 2. Scenarios evaluated and the goals of each in the three rounds of modeling. *Full electrification is also called "all-electric" in this report.*

RESULTS AND DISCUSSION

Stakeholder Feedback

Over the three workshops, we collected feedback from both City and external stakeholders. At workshop 1, we focused on understanding foundational values and areas of concern to guide the process. We asked why weatherizing and electrifying one-to-four-unit buildings in the city is important. Figure 4 shows a summary of their answers to the open-ended question. Overall, participants viewed home weatherization and electrification as an opportunity to improve in many areas, most prevalently in mitigating climate change, and supporting community equity, livability, and health.

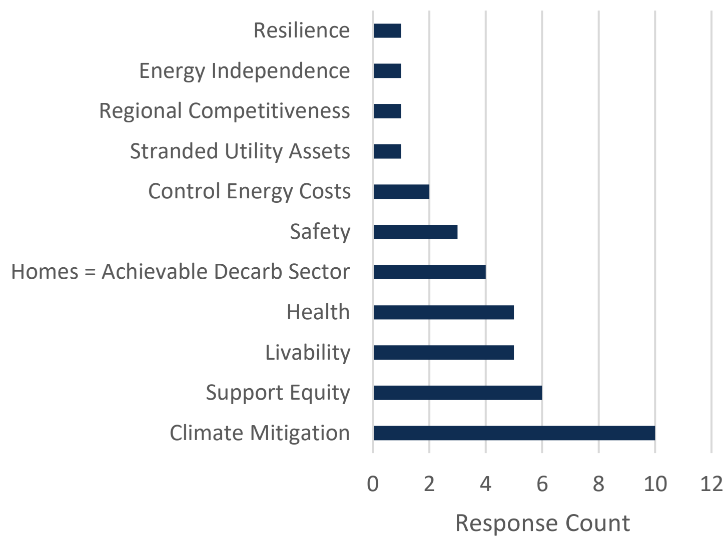

Figure 4. Prevalence of participant answers to the open-ended question: why is weatherization and electrification of 1-4 unit buildings important?

After viewing the first round of scenarios, participants were asked for their reactions to the modeling analysis and results. A major benefit that nearly all participants noted was a positive impact of weatherization on bill costs, energy load, and subsequent electrification upfront costs. Others also expressed surprise that total electrification of home energy was even technologically possible. Among concerns, upfront costs and bill costs garnered the strongest reaction.

This foundational feedback guided subsequent models to focus on maximizing climate mitigation on the timeline needed to meet the City's goals, controlling costs especially for disadvantaged areas of the city, and fine-tuning assumptions.

Upfront Costs

Over the approximately 20-year timeline in which decarbonization is needed to meet the City's climate goals, nearly all currently installed heating equipment and appliances will reach their end of life and will require replacement. As such, we modeled two electrification scenarios against a Baseline, which assumes replacement of like equipment (primarily gas equipment replaced with gas equipment) at the end of the equipment's life (Figure 5). The High Estimate scenario assumes no market efficiencies due to scaling, while the Low Estimate scenario assumes incremental equipment and soft cost improvements over time, similar to solar technology trends. No workforce efficiencies were included based on stakeholder feedback.

Stakeholders reasoned that current workforce insufficiency along with unfavorable workforce demographic trends counteract any typical labor efficiencies from market maturation.

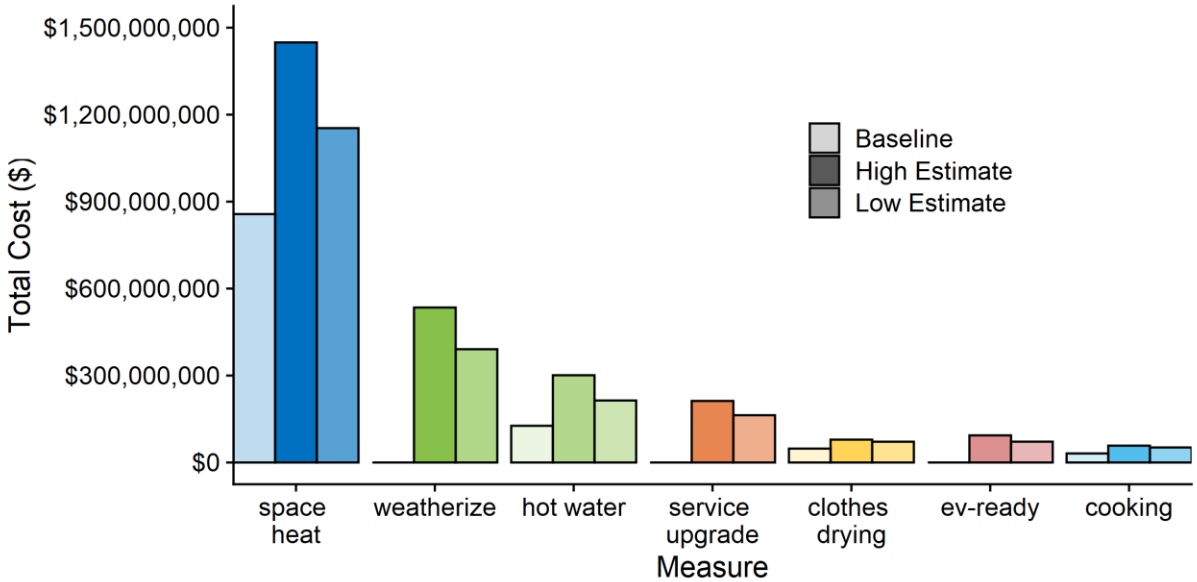

Figure 5. Low and High estimates of the total upfront cost of weatherizing and electrifying all 1-4 unit homes by measure compared to the Baseline, which is defined as the upfront cost to replace equipment with similar technology (primarily gas) at end of life. Given this, weatherization and EV-ready measures do not have a Baseline model. A detailed table is available in the Appendix.

We estimate the total upfront cost to weatherize and electrify the 88,441 buildings to range between $2.12 and 2.73 billion. This topline cost captures equipment and labor but does not include estimates for program administration. This compares to the approximate $1.06 billion upfront cost that will be needed to replace existing equipment at end of life with similar technology. As a result, the incremental upfront cost of weatherization and electrification is estimated to be between $1.06 billion and $1.67 billion.

Figure 5 shows the breakdown of measure costs for all buildings. ccASHP retrofits (“space heat”) command more than half the total cost at $1.15 billion to $1.45 billion. Weatherizing the building stock came in as the second highest total cost at $391 million to $535 million while the remaining measures total $575 million to $746 million combined. For context, the total upfront cost for the High scenario is equal to about 8% of the assessed value of the building stock. Divided across all buildings, the total upfront cost for the High scenario comes to an average of $30,900 per building and an average incremental upfront cost of $18,900 per building.

Home weatherization and electrification retrofit projects will need to be completed at a pace that meets the City’s science-based climate targets, described further in Sequencing and Pace of Implementation. The annual incremental upfront costs needed to complete retrofit projects per year is estimated in Figure 6 with costs starting around $77 million in 2024 and ramping up to over $200 million in 2029.

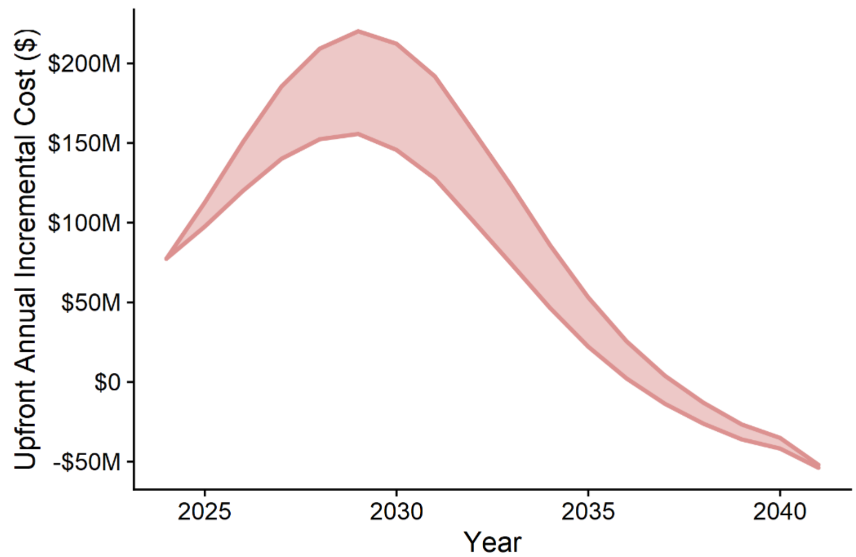

Figure 6. Estimated annual incremental upfront costs of weatherization and electrification projects needed to meet the City of Minneapolis' science-based climate emissions targets. The upper and lower bounds of the band represent the High and Low upfront cost scenarios in Figure 5.

Given the range of building ages, equipment, and percentage already retrofitted, results of modeling provided probability distributions of upfront costs for necessary equipment upgrades. These show the range of equipment upfront costs and the relative frequency that buildings would incur such costs. Figure 7 shows the range of measured upfront costs for the High scenario, which assumes no market efficiencies due to scaling. Important takeaways from this measure-level modeling are cost differences between measures as well as the extent that costs may range for an individual measure. Among all measures, heat pump clothes dryers and Level 2 electric vehicle chargers, the mid-tier charger providing 240 V, are the least expensive upfront measures. Space heating via a ccASHP has the highest measure-level upfront cost and a wide potential install cost distribution from $7,000 to over $20,000.

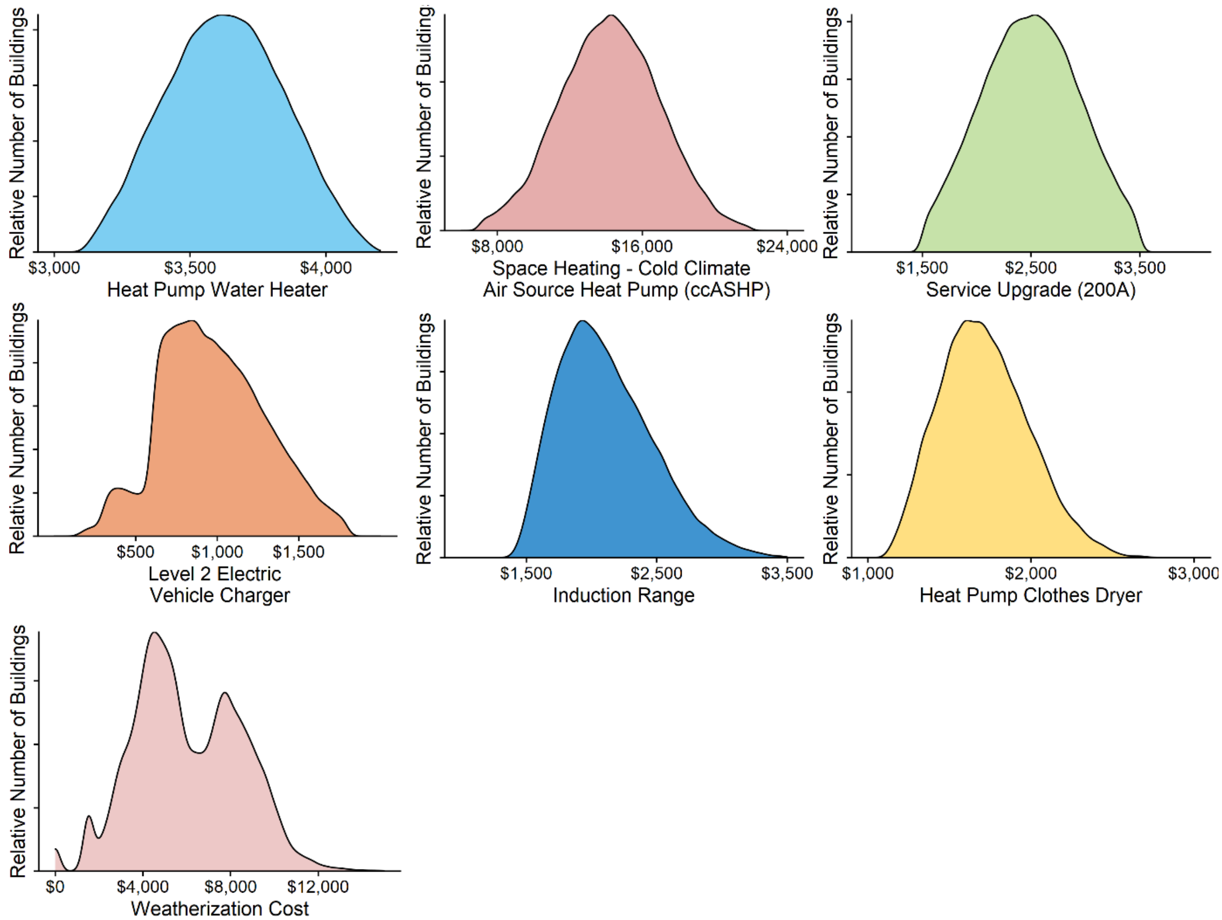

Figure 7. Distribution of upfront costs per measure for the Electrification High scenario, which assumes no cost reductions due to market efficiencies of scaling.

Utility Bill Costs

Weatherization Impact

Weatherization is a clear driver for energy savings. Most buildings achieve energy and utility cost savings from weatherization, although the impact varies. Here, we analyze scenarios keeping utility rates constant at the October 2022 fully loaded volumetric rates[1], with gas at $1.05/therm and electricity at $0.155/kwh. The full electrification with weatherization analysis

[1] The fully loaded volumetric rates are comprised of gas bill totals, including all riders, taxes, and fees, divided by the energy consumed. The price of fossil gas is passed directly through to customer bills and is driven by market forces. The volatility of this price made determining an appropriate "current" rate for analysis challenging. At the beginning of the process in September 2022, we used a 12-month average of $0.88/therm. The price of gas increased steadily through the workshop process such that the fully loaded volumetric rates surpassed $1.20/therm in January 2023. Given that the 12-month average of $0.88 did not fully reflect the global reality of gas supply due to forces such as the war in Ukraine, we reasoned that taking a rate of $1.05, which was the fully loaded volumetric rate in October 2022 when we held our first workshop was reasonable and even conservative to use as the "current" rate for analysis.

shows that median energy bills would only increase on average by 4% (or $120 per year). However, outcomes vary greatly across the building stock; 25% of customers will see more than $880/year in savings, 25% of customers will see increases of $580/year or more, and the remaining 50% of customers lie in between. Under 10% of customers would see no significant bill changes.

On the other hand, excluding weatherization from the full-electrification program, as shown in Figure 8, yields substantial bill increases for nearly all customers. Without weatherization, the average annual bill increase is $980 (34% above current), 75% of households would see annual costs increase by more than $600 (14% above current), and 25% of households would see bills increase by more than $1,310 (46% above current).

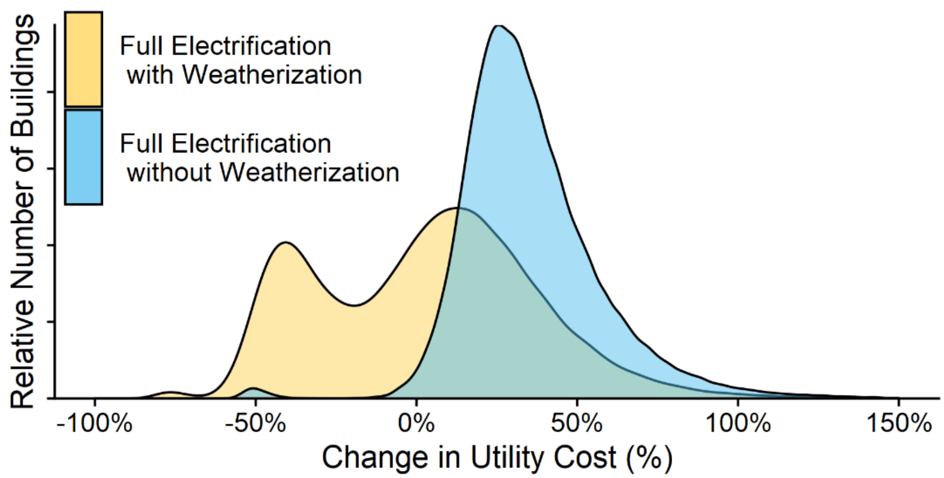

Figure 8. Distribution of buildings by the percent change of utility costs in scenarios with and without weatherization measures.

The disparity in outcomes is due to the very large energy savings offered by weatherization. In other words, the higher energy costs of electrification are mostly balanced by energy savings from weatherization. On top of these cost savings, weatherized homes have lower heat pump size requirements and enable heat pump systems to meet more annual space heating load. Recent work measuring heat pumps in the Northeast also suggests that heat pumps achieve higher performance in weatherized homes (Veilleux et al. 2022).

Weatherization is the critical path, providing large, cost-effective emissions savings regardless of heating equipment present. Approximately 75% of potential decarbonization savings come from weatherization and space heating electrification measures. Switching from gas to clean-energy-powered electric heat pump heating cuts emissions drastically, and weatherization is vital to ensuring the switch is cost-effective.

Building Age Impact

Low performing buildings have high energy loads and often no or low amounts of wall and attic insulation. Among the datasets, building age was the best predictor of low performing buildings; the older the building, the less likely the building has any or sufficient insulation. Analysis of electrification and weatherization of the building set found that the bill costs for older buildings were less likely to increase than that for newer buildings (Figure 9). This indicates that older buildings are more likely to benefit from weatherization and electrification. As building age data is much more readily available than information on insulation and air tightness, using building age as a proxy for savings potential could be a useful outreach strategy.

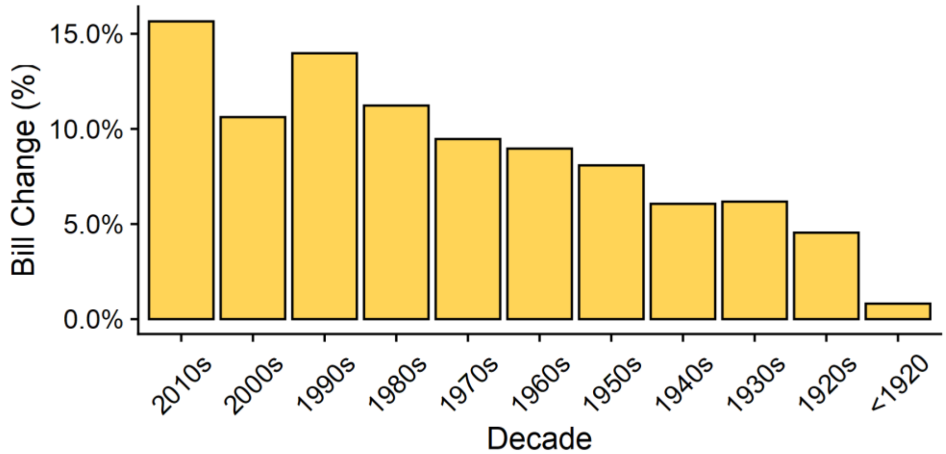

Figure 9. Utility bill cost impacts of full electrification and weatherization of buildings based on decade built using current standard electric and gas rates.

Geographic Impact

Historical development patterns have resulted in building differences across the city. Generally, older buildings are concentrated closer to downtown, while newer buildings are found toward the city border. Analysis of electrification and weatherization of the building set found trends in bill decreases or increases based on zip code. Zip codes immediately to the south of downtown, 55403-55407, show the greatest average opportunity for bill savings, while zip codes on the edges of the city show the greatest potential for bill increases (Figure *10*).

The City of Minneapolis has established Green Zones, which are areas of the city with high levels of environmental pollution and racial, political, and economic marginalization. Analysis of the Green Zone zip codes found an overlap of greater potential bill savings in the Southside Green Zone and a slight bill increase in the Northside Green Zone zip codes. The reason for this is unknown and should be explored further.

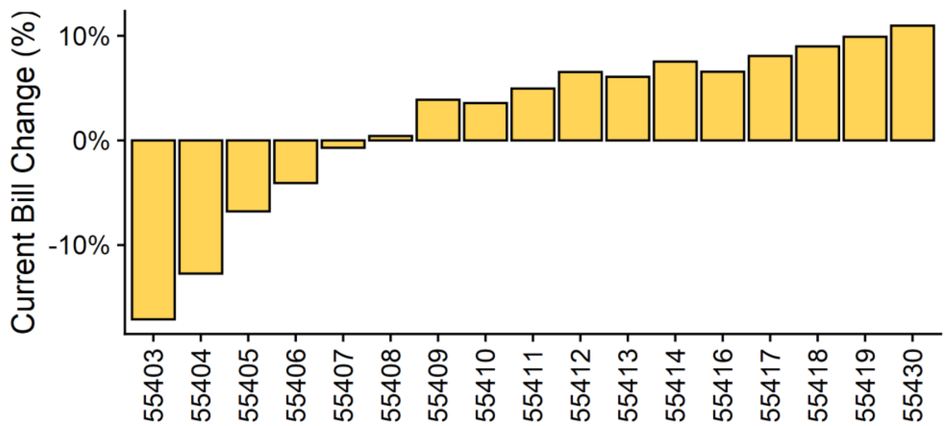

Figure 10. Utility bill cost impact of electrification and weatherization compared to current bills by zip code. Zip code locations can be referenced in Figure 11.

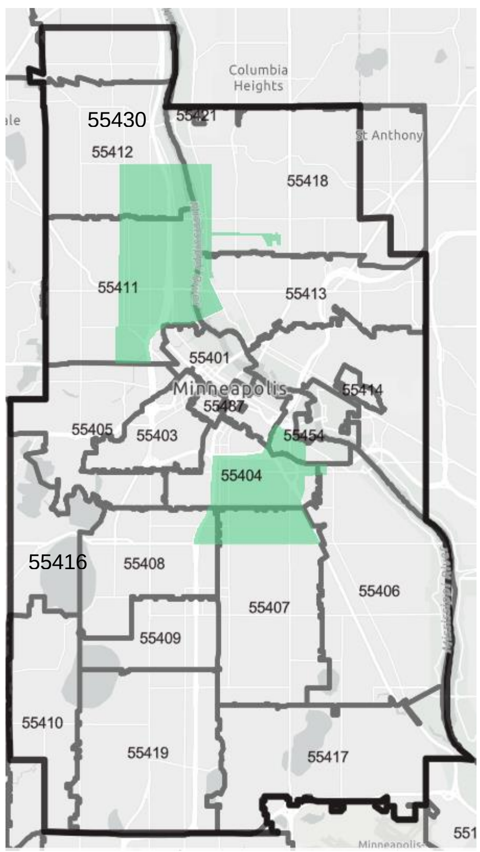

Figure 11. Map of Minneapolis zip code with Minneapolis Green Zones indicated with green shading.

Rate Impacts

We analyzed numerous scenarios using eight fully loaded volumetric rates, which are the bill totals, including all riders, taxes, and fees, divided by the energy consumed (Table 3, Table 4).

Given historical trends, gas rates are unlikely to be at the level of the Low rate in the future and are anticipated to increase, although the exact rate of increase is unknown. As another decarbonization pathway, we also examined the utility bill impacts of substituting all methane gas with sources of renewable gas. Future electric rates are based on the E21 Study, which assumed that rates would be designed to avoid super high electric demand and related need for significant infrastructure investments by relying on existing gas infrastructure for high winter peak (CEE & GPI, 2021).

Gas Rate Category	Cost / gas unit ($/therm)	Description
Current	$1.05	Gas rates as of October 2022
Future Low	$1.30	Reasonable future escalation given historical trends and volatility
Future High	$1.50	Reasonable future second escalation given historical trends and volatility
Renewable gas	$3.10	Cost of carbon-neutral natural gas (Nadel 2022)

Table 3. Fully loaded gas rates analyzed.

Electric Rate Category	Cost / electric unit ($/kwh)	Description
Current All-Electric	$0.11	Current Xcel Energy all-electric heat rate
Current Dual Fuel	$0.10	Current electric rate when using dual fuel
Current Standard	$0.15	Current standard electric rate with no discount for electric heat
Future Standard	$0.22	Future standard electric rates, assuming gas winter peak from the E21 Study (CEE & GPI, 2021)
Future All-Electric	$0.275	Future all-electric rate from the E21 Study (CEE & GPI, 2021)

Table 4. Fully loaded electric rates analyzed.

Current Rates

Analysis shows that weatherizing and electrifying today could be cost-effective from a utility bill perspective, although results vary significantly (Figure 12). The median home that is weatherized, converts all equipment to be powered by electricity, and utilizes the existing utility all-electric heating rate could see annual bill savings of 24%. Buildings on the all-electric heat rate benefit from the rate in the winter months but are on the standard rate for the rest of the year. For the median home, which is weatherized, has appliances converted to run on electricity, and space heating is converted to a dual fuel heat pump (at 80% electric utilization) using the dual fuel heating rate, annual utility savings are 4%.

It is important to recognize that outcomes remain highly variable even with special rates. All-electric rates bring savings to 84% of households, but 16% of households will still see net bill increases. Dual fuel rates bring savings to 59% of households, but 41% of customers will still see net bill increases. Figure 12 shows the wide distribution of possible outcomes.

At current costs, both dual fuel and all-electric pathways offer the majority of one-to-four-unit buildings in Minneapolis net savings on utility bills. Typically, dual fuel applications offer more savings than all-electric applications; however, due to recently high gas prices and additional savings when applying the electric heat rate to the existing electric load in the winter, all-electric systems currently offer the best opportunity. It's important to note that the current favorable all-electric and dual-fuel rates are not guaranteed in the future and will likely change.

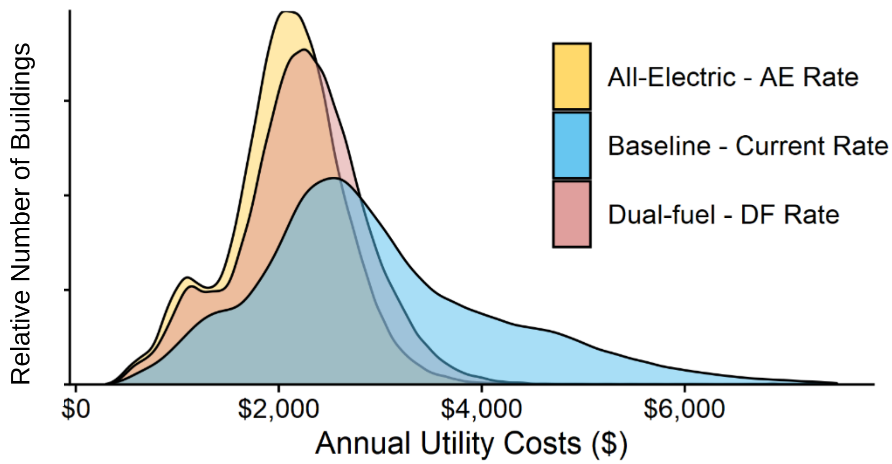

Figure 12. Annual utility costs for Minneapolis 1-4 unit buildings at the current rate compared to all-electric and dual fuel scenarios using 2022 utility rates. All-Electric and Duale-fuel scenarios assume the buildings have been weatherized.

Future Rates

Analysis of future rates similarly indicates potential benefits of weatherization and electrification retrofits. A baseline analysis examining an average home with gas equipment to a future scenario in which there is no weatherization or change to mechanical equipment shows median annual utility bill cost increases of 30% to 55% (Figure 13). Given no changes to the building stock, we would expect annual utility bills to rise.

If no equipment in homes is changed but the fuel used were renewable natural gas, there would be greenhouse gas emission savings. However, median annual utility bills would nearly triple compared to those today with an increase of 145% (Figure 14).

In the case of decarbonization via electrification retrofits, analysis shows an increase of 43% to 79% in median annual utility bill costs in the all-electric case compared to the baseline and a nearly neutral impact in the dual fuel case (at 80% electric utilization) with annual median bill changes ranging from 26% to 57% (Figure 15). The distributions show that outcomes vary by building. Dual fuel systems still offer more flexibility to achieve savings under different rate combinations. For example, dual fuel systems could be set up with a utilization rate that is economically optimal to give customers flexibility as rates change.

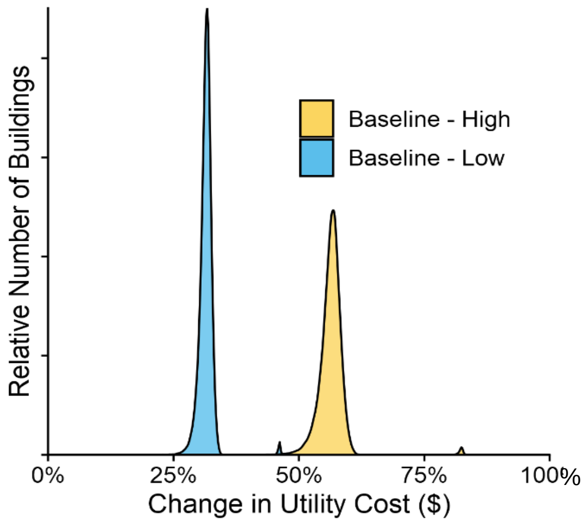

Figure 13. Baseline distributions of expected future utility bill using future standard rates of electric at $0.22 and gas at $1.30 and $1.50 for Low and High respectively. Assumes no weatherization or electrification. The true future distribution is expected to be equal to or lie between the "Baseline – High" and "Baseline – Low" curves.

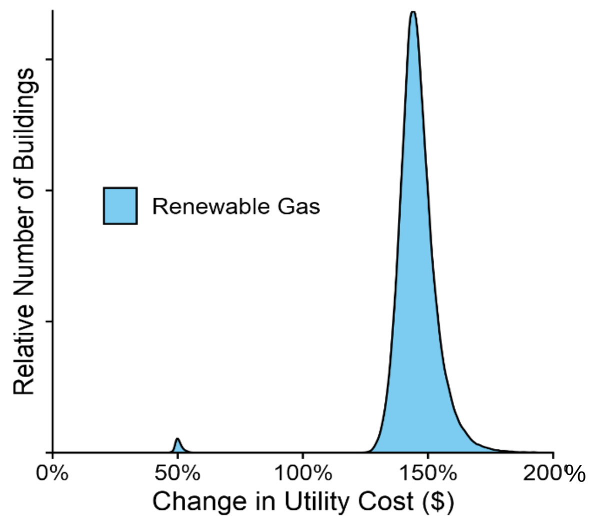

Figure 14. Distributions of expected future utility bill using future standard electric rate of $0.22 and renewable gas rates of $3.10. Assumes no weatherization or electrification.

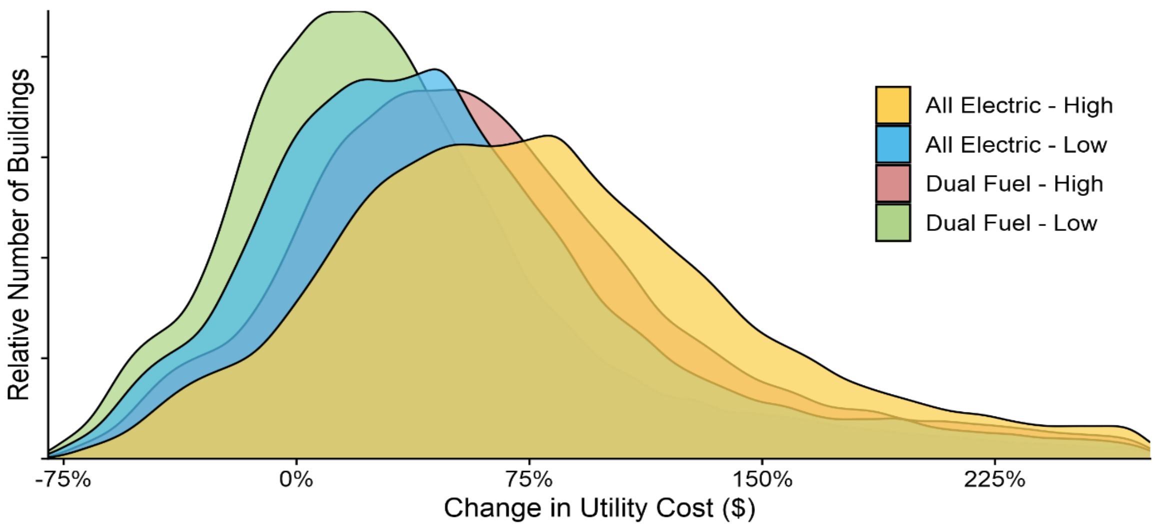

Figure 15. Distributions of expected future utility bill using future all-electric ($0.275) and dual fuel rates ($0.22) with Low and High gas rates ($1.30 and $1.50 respectively). Assumes weatherization and electrification with all-electric and dual fuel heating systems accordingly. The true future all-electric and dual fuel distribution is expected to be equal to or lie between each "Low" and "High" curve accordingly. The curves show that dual fuel rates could provide lower utility bill costs for more homes depending upon gas rates and overall can provide flexibility based on fuel source.

In summary, utility bill costs are expected to rise in the case of no intervention to the building set and in the case of a one-to-one replacement of fossil gas with renewable natural gas. All electric and dual fuel scenarios present opportunity for savings, although the distributions range greatly. In general, decarbonizing this building set through electrification and weatherization is estimated to be 25-70% less costly for customer utility bills than renewable natural gas. The operating costs of the all-electric case are 13% to 24% beyond anticipated increases in baseline bill costs, whereas the operating costs of the dual-fuel case is -4% to + 2% compared to the anticipated increases in baseline bill costs.

Grid Impact

A fully electrified scenario with weatherization of this building set would result in an estimated four times increase in electricity load compared to today's peak load (shown as "Electrified" in Figure 16). This scenario assumes electric resistance back-up heat. Framed another way, once approximately a quarter of these buildings electrify, the load is equal to current summer peak energy use. Today's grid, which is designed for summer peaking and a high availability of fossil gas, will likely fail to accommodate the doubling to tripling or more of volumetric electricity sales per customer. It will also likely fail to accommodate the tripling or more the potential peak load that is shifted from summer to winter.

There are a few ways to mitigate that increase. Critically, the highest power load situation occurs on a very cold winter morning when ccASHP equipment can provide the least heat to the building. The resulting draw on the backup heating source, electric resistance, is high not only due to the high heating need but also because the efficiency of electric resistance heating of near 100% is low compared to ccASHPs, which can be as high as 400%. A practical strategy to mitigate this issue is to use dual fuel systems for homes where ccASHPs cannot meet full heating loads. Additionally, employing load control strategies for EVs, hot water, and appliances allows customers to shift energy usage to non-peak times. Further advancements in ccASHP technologies to continue to operate at even lower temperatures may also contribute to reducing peak load.

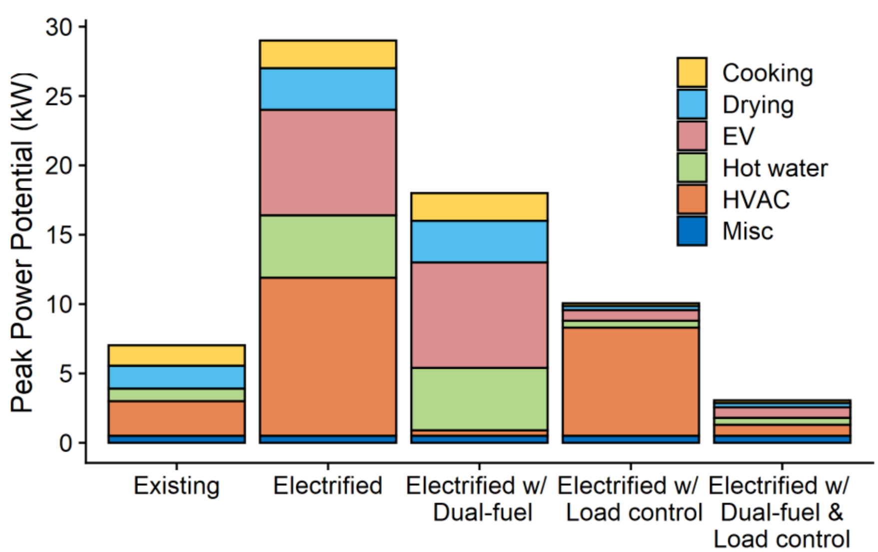

Figure 16. Total estimated peak power load of energy used by 1-4 unit buildings under various electrification scenarios compared to existing conditions.

Labor Requirements

Electrification and weatherization projects require a diverse workforce of weatherization technicians, electricians, plumbers, mechanical installers, and other general labor. The workforce required to do this would need to match the pace of retrofits to meet the City's science-based climate targets (Figure 17). Thus, the workers needed would change over time, peaking in 2029 at nearly 1000 people. The greatest worker requirement would be for weatherization, which peaks at over 300 workers, while the job area requiring the fewest workers would be in plumbing, which is only needed for heat pump water heaters.

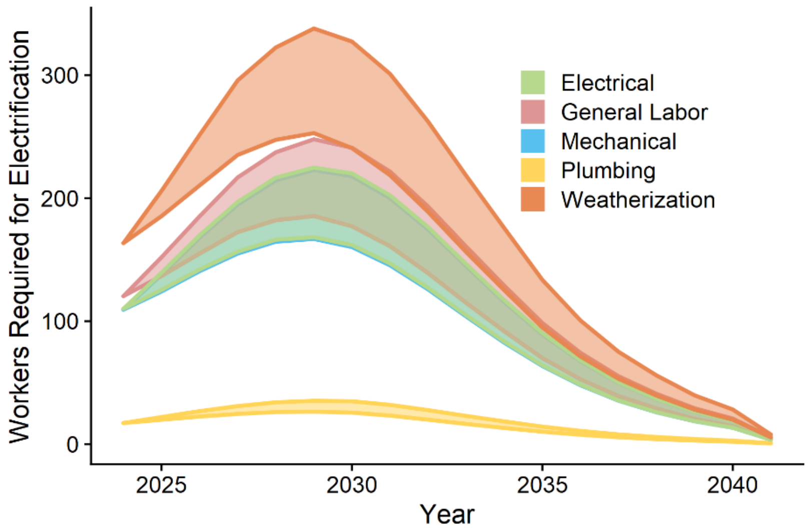

Figure 17. Annual workforce requirements for weatherizing and electrifying all 1-4 unit homes to meet the City's science-based climate target.

Electrification Emission Reduction by Measure

Due to Minneapolis' cold winters and resulting heavy heating load, weatherization and decarbonizing space heating generally represents 75% of the decarbonization opportunity in Minneapolis homes (Figure 18).

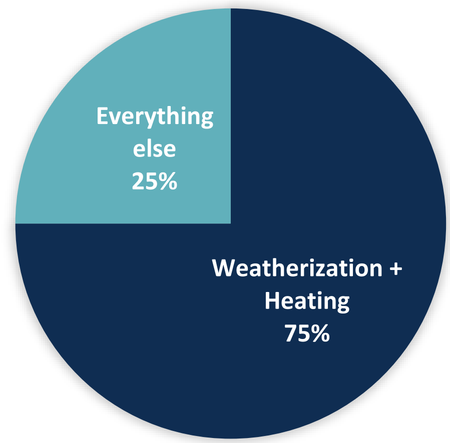

Figure 18. Simplified source breakdown of decarbonization opportunities.

Looking more closely, the relative impact of actual whole home decarbonization opportunities differ slightly between an all-electric retrofit scenario and a dual fuel scenario (Figure 19). The all-electric scenario replaces existing space heating equipment with ccASHPs with an electric resistance back-up heat source, which results in 55% of the scenario's climate emission reductions. The dual fuel scenario involves an ASHP retrofit that utilizes electricity 80% of the time and gas as a back-up system, resulting in 49% of the scenario's climate emission reductions. Weatherization accounts for a quarter of climate emission reductions, while heat pump water heaters and other appliances provide an additional 15% reduction. The remaining greenhouse gas emissions are assumed to stem from assorted garage, lawn, and other equipment as well as fireplaces and other fossil fuel burning devices. Ultimately, the all-electric scenario estimates a 95% greenhouse gas emission reduction, while the dual fuel scenrio shows approximately an 89% emission reduction.

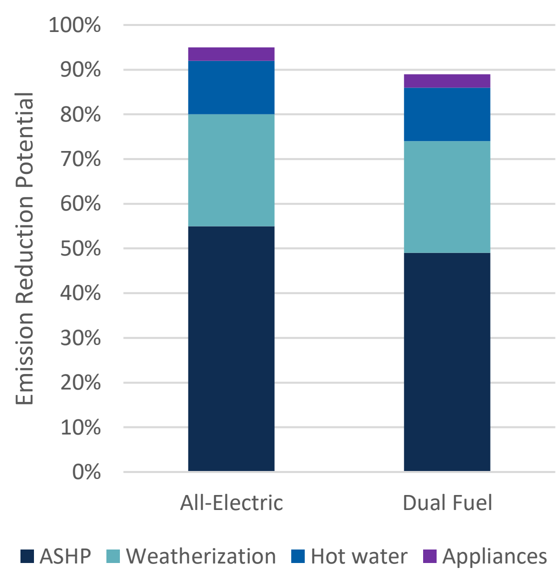

Figure 19. Breakdown of climate emissions reduction potential from all-electric and dual fuel retrofit scenarios by measure. The remaining emissions come stem from assorted fuel-using equipment such as garage, lawn, other equipment, and dual fuel heat pump system fossil gas use.

Sequencing and Pace of Implementation

Meeting the City's climate-based target as applied to residential buildings means following the negative S-curve with an inflection point in 2028 (Figure 20). This means that electrification projects must scale rapidly beginning with 4,400 homes in 2024 and peaking in 2029 at 9,000 before declining to less than 1,000 homes per year in 2039 (Figure 21).

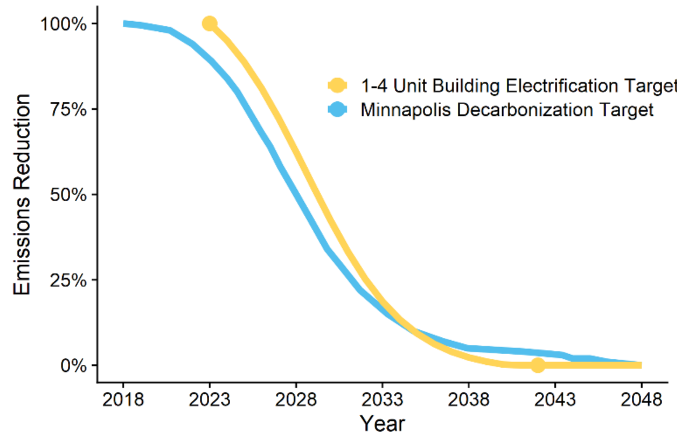

Figure 20. The pace of 1-4 unit electrification-related climate emissions modeled to match the City of Minneapolis' science-based climate emissions reduction target over time.

Figure 20 and Figure 21 assume an even distribution of retrofits in low and high performing buildings. However, as it is critical to maximize savings in the early years, targeting low performing buildings first could be a valuable strategy to stay on pace as retrofit programs and incentives ramp up. In fact, weatherizing and electrifying the 25% worst performing buildings could have up to eight times the impact as retrofitting the 25% best performing buildings.

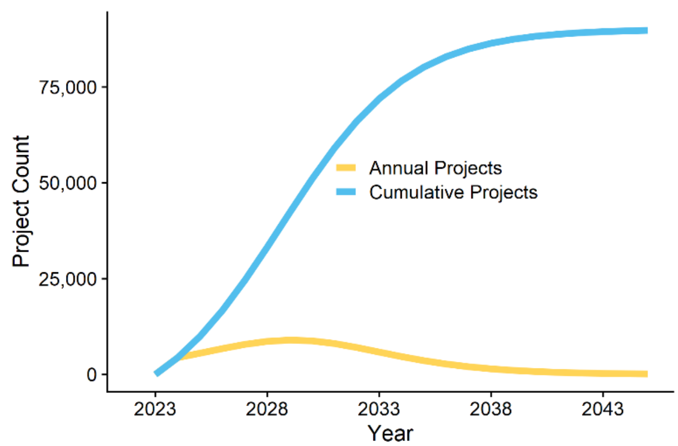

Figure 21.The annual and cumulative 1-4 unit whole home electrification and weatherization project count by year needed to match the City's science-based climate emissions reduction target.

Weatherization is the critical path to provide large emissions savings regardless of equipment. The savings are cost-effective and necessary to unlock all-electric heat pump space heating for most homes. However, a major challenge is that weatherization measures have the largest workforce requirements.

The high number of projects to be completed beginning in 2024 to keep the City on track can be daunting. One immediate strategy to consider is replacing equipment at end-of-life. This means replacing broken gas appliances with electric technologies and non-functioning air conditioning and furnace equipment with dual fuel heat pumps, which can be immediately operated cost-neutrally without special rates. Following this strategy alone would reduce climate emissions 80% by 2042. Although it is among the lowest cost decarbonization pathways and has the least sensitivity to workforce limitations, this strategy would miss the City's climate targets and result in cumulative emissions that are one and a half to two and a half times greater than original goals.

CONCLUSIONS AND RECOMMENDATIONS

Our modeling showed that it will cost between $2.12 billion and $2.73 billion to fully weatherize and electrify one-to-four-unit residential buildings in the city, which is incrementally $1.06 billion to $1.24 billion more than what will already be spent on routine end-of-life equipment replacements. These topline costs capture equipment and labor but do not include estimates for program implementation.

With such a high cost to fully weatherize and electrify one-to-four-unit residential buildings, stakeholder discussions focused on identifying the most valuable strategies, measures, and applications to prioritize. The clearest point of agreement among the stakeholder groups was that two measures would make the greatest difference in advancing the City's climate goal: addressing unmet weatherization needs and partially or fully electrifying space heating.

The stakeholder groups agreed that weatherization should be the priority of the two. Weatherization involves relatively low-cost measures that offer reliable energy savings and valuable non-energy benefits. And, importantly, it is more effective and affordable to electrify the space heating of a building that has already been weatherized. Beyond that, the stakeholder groups broadly coalesced around the following:

Recommendations for City Financial Investment

We recommend that the City prioritize financial investments in electrification and weatherization in the following order of importance.

1. **Implement a pilot.** The City should implement a pilot to set a programmatic foundation for future work, start building a base for contractor engagement and training, and consider additional opportunities like bulk equipment buys with manufacturers.
2. **Address weatherization opportunities in Green Zones.** Prioritizing work in Green Zones will have a greater impact on both climate and equity goals. Weatherization improvements to Green Zone buildings will net substantial energy savings because of the historical lack of investment in these areas.
3. **Address weatherization in the remainder of the city.** The city has a great number of older houses that are inadequately weatherized. Prioritizing the worst-performing buildings can provide big savings early on, which will be critical to maintain the decarbonization timeline and to gather resources to scale up programs.
4. **Subsidize partial or full electrification in Green Zones as analysis show utility bill cost advantages.** Transitioning to electric heating systems involves high upfront costs for middle-income and low-income residents. Where utility bills are likely to remain the same or decrease as a result of full electrification, the City should fully subsidize the costs of transitioning to electric heat pump heating equipment. When building analysis shows a risk of increased utility bills, the City should fully subsidize dual fuel heat pumps.
5. **Encourage electrification in the remainder of the city on equipment failure or end-of-life situations and when economically advantageous.** The City should provide education and outreach to encourage all residents to progressively electrify their homes,

especially at the time of equipment failure or end-of-life. For example, every replaced AC unit or furnace with similar equipment and not a heat pump is a missed opportunity and a 20-year sunk cost. The City can encourage dual fuel heating systems for residents or buildings that would not experience net benefits from fully transitioning to an electric heating system.

Additional Recommendations for City Initiatives

1. **Advocate for increased weatherization and electrification incentives from both CenterPoint Energy and Xcel Energy.** The City should actively participate in and take advantage of the Energy Conservation and Optimization Program and Natural Gas Innovation Act utility planning process to advocate for enhanced weatherization and electrification incentives.
2. **Advocate for Xcel Energy to build capacity to meet electrification goals.** The City should engage with the Clean Energy Partnership, Public Utilities Commission, and other relevant entities to advocate for increased capacity from Xcel Energy to meet future load demands from electrification.
3. **Participate in rate discussions at the PUC to secure favorable rates and policies for electrification.** Electricity rates will greatly impact how financially feasible it is for residents to electrify. The City should advocate for rate changes that make partial or full electrification viable or attractive to residents.
4. **Put City resources toward workforce development for weatherization and electrification.** The labor requirements for the modeled pace of implementation are high. The City should quantify the existing workforce and consider how to put resources toward expanding the workforce needed for electrification. The City should also advocate for utilities and the State to expand their efforts in workforce development.
5. **Investigate and address barriers to electrification within existing City policies and procedures, especially regarding replacing equipment on failure and at end-of-life.** The City can facilitate electrification by removing barriers and updating existing policies and procedures. Examples include promoting electrification in Time of Sale (also known as Truth-in-Sale-of-Housing) Energy Disclosure reports, modifying setback requirements, and adjusting permitting fees for gas versus electric equipment to drive further electrification.
6. **Consider other electrification technologies for study.** There were a variety of decarbonization suggestions and areas of interest brought up by group members that are not represented in the above recommendations and may warrant further exploration. Of note, neighborhood level geo-exchange systems and thermal storage were identified during the stakeholder process as measures for future study.

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APPENDIX

A.Workshop Participants

City Staff Group - Name and Department

- Alex Vollmer- Health Department- Lead and Healthy Homes
- Brad Ellis- Community Planning & Economic Development- Zoning and Enforcement
- Breanna Phelps- Construction Code Services
- Chris Droske- Energy Manager
- Dean Porter-Nelson- Health Department- Lead and Healthy Homes
- Dustin Brandt- Construction Management and Engineering
- Isaac Evans- Health Department- Sustainability Division
- Jason Wittenberg- Long Range Planning
- Kelly Muellman- Health Department- Sustainability Division, Green Zones Initiative
- Kevin Knase- Community Planning & Economic Development- Residential Real Estate Division
- Luke Hollenkamp- Health Department- Sustainability Division
- Mumtaz Anwar- Construction Code Services- Certified Building Official
- Murphy Sinsky- Regulatory Services- Community Engagement

Community Stakeholder Group- Name and Affiliation

- Akisha Everett- University of Minnesota
- Al Swintek- CenterPoint Energy
- Carmen Carruthers- Citizens Utility Board
- Daniel King- Xcel Energy
- Eduardo Cardena- Central Area Neighborhood Development Organization
- Elizabeth Turner- Precipitate Architecture
- Joseph Dammel- Fresh Energy
- Josh Martin- Xcel Energy
- Kat Knudson- CenterPoint Energy
- Marcus Mills- Black Visions Collective
- Maria McCoy- Institute for Local Self-Reliance
- Mary Britton- Prospect Park Neighborhood Association
- Nick Minderman- Xcel Energy
- Timothy Denherder-Thomas- Community Power

B. Baseline Model

To create a baseline building stock model estimating heating loads on Minnesota single-family buildings, we followed a process similar to a previous CEE research project (Quinnell and Genty 2022). The methodology duplicates one developed to analyze the technical and economic potential of energy efficiency upgrades in the national building stock (Wilson et al. 2017). Residential building data were pulled from over 2,000 records of home energy audits conducted in Minneapolis for utility energy efficiency programs as well as prior research project results (Edwards et al. 2013). Then, the sampled data was consolidated to build out a single dataset by re-coding categorical data for consistency, differentiating unknown data from zero values, and removing incomplete data and obviously incorrect data. A pair-wise correlation matrix (Pearson correlation coefficients) was produced to determine the correlation between each set of two parameters. Each variable was represented as an empirical probability distribution function. These distributions and their correlation data were sampled using a Latin Hyper Cube Sampling (LHS) approach to produce a representative dataset with the fewest samples while avoiding outliers (Millard 2013). This sampled modeled data was merged with City assessor data based on correlated characteristics to estimate the property characteristics of all Minneapolis one-to-four-unit buildings.

Heating and cooling loads were determined following ASHRAE residential heat balance method (ASHRAE 2021) using modeled home characteristics in the dataset. Annual loads are estimated as the sum of these load calculations for each hour below the balance point temperature of 65 °F for Minneapolis TMY3-2020 weather data (Sengupta et al. 2018). Annual loads are normalized to 8,000 heating degree days (HDD) based on an assessment of typical meteorological year3 (TMY3) data and NOAA hourly data for Minneapolis/St. Paul. Appliance energy loads were estimated from regional residential consumption survey data (DOE 2017).

To examine weatherization impacts, the model weatherizes existing building stock according to the criteria listed in Table 5. Potential weatherization measures include attic insulation, wall insulation, rim joist insulation, general air sealing efforts, and continuous exhaust ventilation.

Variable	Qualifying Criteria	Outcome
Air sealing	> 1.08 $CFM_{50}/ft.^2$	0.85 CFM_{50}
Wall insulation	< R-8	R-11 / 0.9 CFM_{50}
Attic insulation	< R-21* / R-50**	R-21* / R-50 and 0.9 CFM_{50}
Rim joist insulation	R < 4	R-10 / 0.95 CFM_{50}
Continuous exhaust ventilation	< 50% code ventilation served by infiltration	N/A

*Table 5. Weatherization Requirements and Outcomes. *R-21 is assumed the overall value (including bridging, knee walls, slants, peak, and open floor areas) for X.5 and X.75 style homes ** Open attic floors*

The baseline model was then modified to assess energy and cost impacts of the selected electrification measures. The measures (shown at right) were established in conjunction with the City based on market readiness, relative complexity, upfront cost, bill costs, and greenhouse gas emissions impact. While not all electrification measures were considered, those here are estimated to account for over 95% of fossil gas use in this building stock. We recognize that not all electrification technologies were evaluated and provide recommendations regarding that at the end of this report.

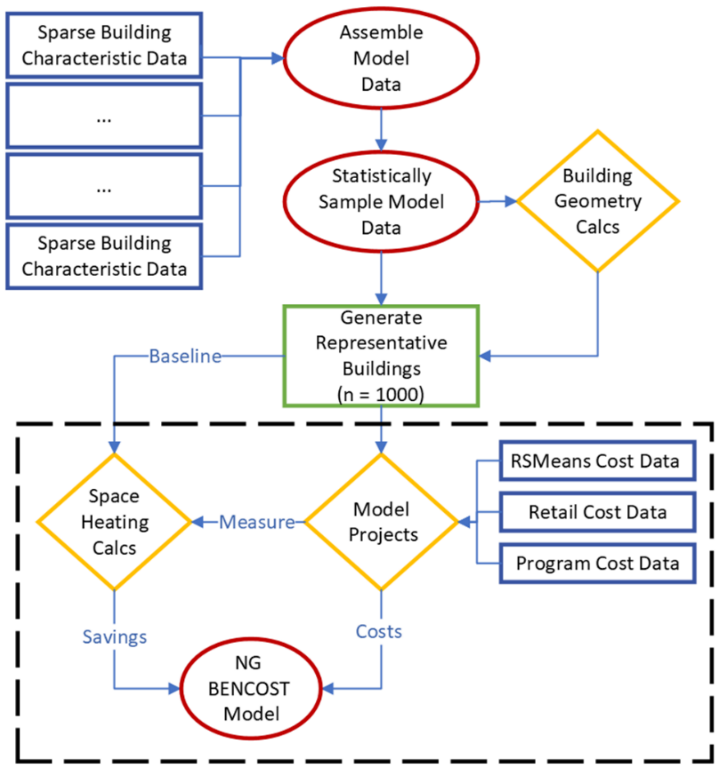


Figure 22. Modeling methodology.

Actual installation cost data from bids and contractor price lists used in utility and lending programs and 2022 retail data were used to estimate upfront costs for electrification measures on this building stock.

Figure 222 shows the various data and how they were used to create the full Minneapolis one-to-four-unit housing stock model dataset and initial measure impact analysis.

C.Upfront Cost Summary

	Baseline	High	Low
Space Heat	$857,000,000	$1,449,000,000	$1,154,000,000
Weatherization	-	$535,000,000	$391,000,000
Hot Water	$127,000,000	$302,000,000	$215,000,000
Service Upgrade	-	$213,000,000	$164,000,000
Clothes Drying	$48,000,000	$79,000,000	$72,000,000
Electric Vehicle - Ready	-	$94,000,000	$72,000,000
Cooking	$31,000,000	$58,000,000	$52,000,000
TOTAL	**$1,060,000,000**	**$2,730,000,000**	**$2,120,000,000**

Table 6. Low and High estimates of the total upfront cost of weatherizing and electrifying all 1-4 unit homes by measure compared to the Baseline, which is defined as the upfront cost to replace equipment with similar technology (primarily gas) at end of life.

D.Stakeholder Workshop Presentation Slides

Below are the slides used in the three rounds of workshops with the City staff group and external stakeholder group. This was an iterative process. Thus, each workshop and round of modeling informed the next and the final workshop informed the results reported in this roadmap. As such the information in these slides may not match exactly the results in this report.

City of Minneapolis Comprehensive Electrification Vision and Roadmap Workshop 1

2022.10.24

cee
Center for Energy and Environment

1

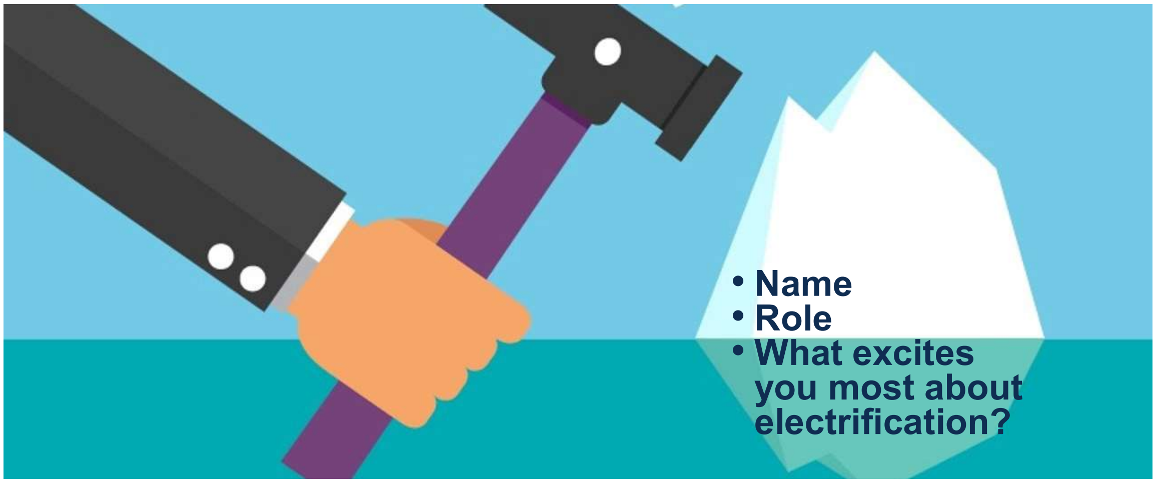
Agenda

Welcome and Intros
Background and Purpose
What is electrification? How do homes electrify?
- Break –
Electrifying all 1-4 unit homes: What does it take? Scenario 1
Discussion

cee

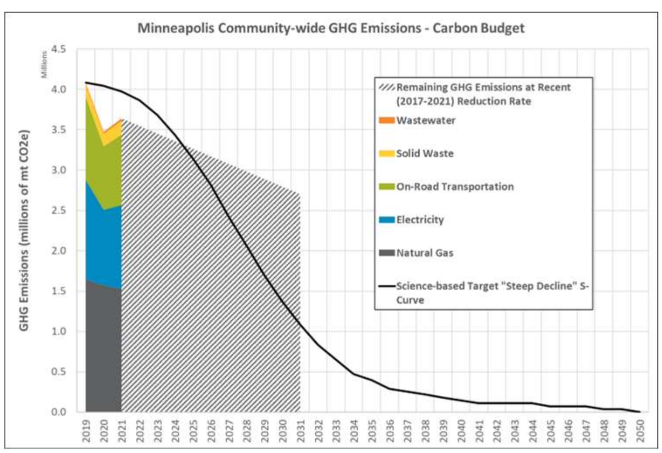
2

Introductions



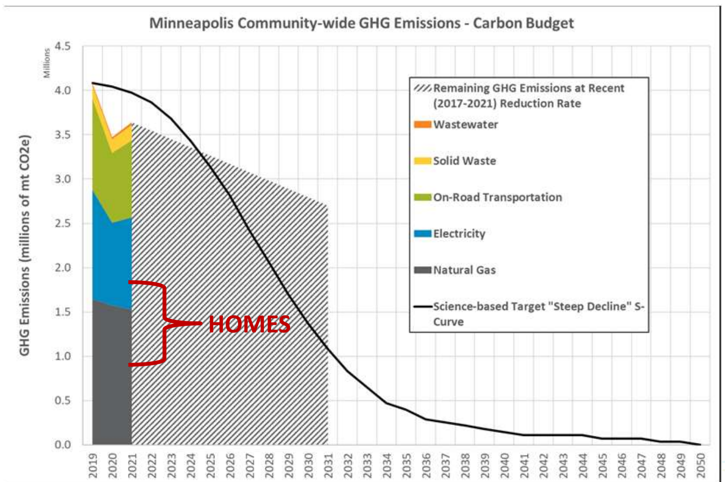
Why Home Electrification?

- Need to dramatically decrease GHG emissions in the 2020’s to meet Mpls Climate Goals



Why Home Electrification?

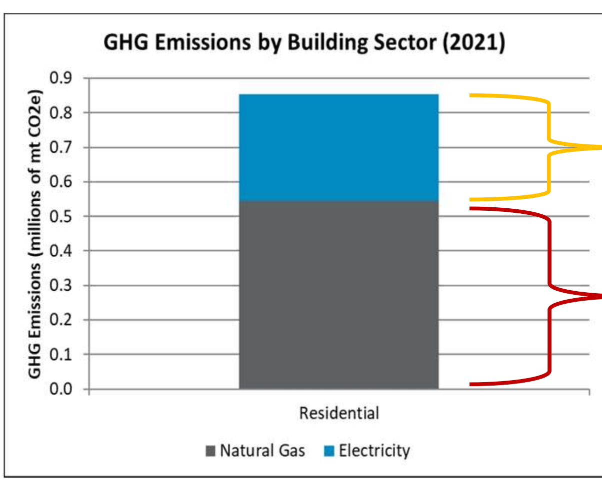
- Homes are 1/4 of City's overall emissions



5

Why Home Electrification?

- Need to Displace Natural Gas with Carbon-Free Electricity



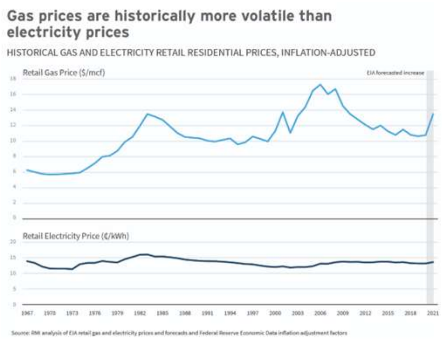
<u>ELECTRICITY</u>: Reducing to zero in Xcel's Carbon-free by 2050 Vision

<u>NATURAL GAS</u>: No current emissions-free alternative, so transition to carbon-free electricity

6

How Residents Benefit from Home Electrification

ENERGY COST STABILITY



INCREASED SAFETY

Homeowner's faulty water heater installation led to house explosion, fire that killed Hopkins couple

"A gas line was not reattached following the installation," a statement from the Fire Department read.

By Paul Walsh Star Tribune | AUGUST 10, 2022 — 2:45PM

RICHARD TSONG-TAATARII, STAR TRIBUNE

NATION

'Tragic loss': Carbon monoxide poisoning killed 7 people in Minnesota home, blood tests suggest

Ryan W. Miller and Joel Shannon USA TODAY

Published 12:00 a.m. ET Dec. 20, 2021 | Updated 7:26 p.m. ET Dec. 22, 2021

ENERGY COST SAVINGS, ASTHMA AND INDOOR AIR QUALITY, GEOPOLITICAL CONCERNS

7

Purpose of this group

Assist in creating a *Comprehensive Home Electrification and Energy Efficiency Vision and Roadmap*. (Deliverable to the Mpls Clean Energy Partnership)

A. Explore housing data, information on technologies, upfront and operating cost data, workforce needs, existing energy program information, and more to understand the full cost for electrifying 1-4 unit buildings and how best to roll out efficiency and electrification measures throughout the city.
B. Identify opportunities to align City policies and programs to streamline and encourage home energy efficiency and electrification.

Also provides single-family housing strategies to the in-progress update to the City's Climate Equity Plan

8

9

Inspiration

Ithaca NY: $150M and counting

SEPTEMBER 28TH, 2021 | 51:39 | E15

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EPISODE DETAILS / **TRANSCRIPT**

Introduction

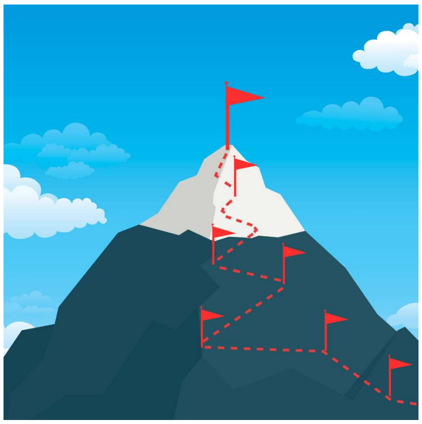
Abby Finis 00:02

Cities produce more than sixty percent of global greenhouse gas emissions. Big cities get a lot of attention, but most household emissions in the US actually come from communities outside urban cores, making them critical players in climate mitigation and climate justice. City Climate Corner explores how these small- and mid-sized cities are tackling climate change and moving toward an equitable and sustainable future.

cee
Center for Energy and Environment

10

Goals for the vision and roadmap



- Estimate the scale of the **cost** and **workforce** to weatherize and electrify all 1-4 unit buildings
- Identify the barriers and potential solutions to implementation (incl. existing resources)
- Devise a probable pathway

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What is electrification?
How do homes electrify?

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Electrification?

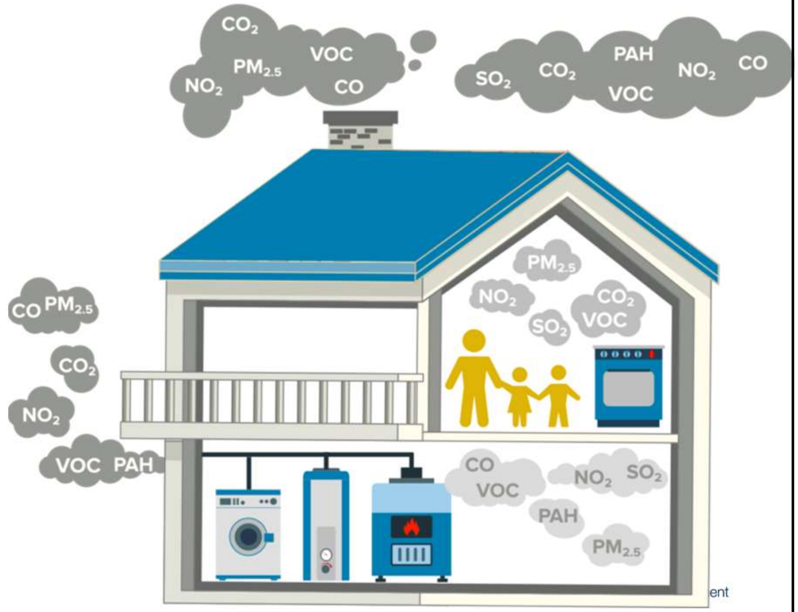

Image source: Fresh Energy: https://fresh-energy.org/whats-up-with-natural-gas-in-my-home

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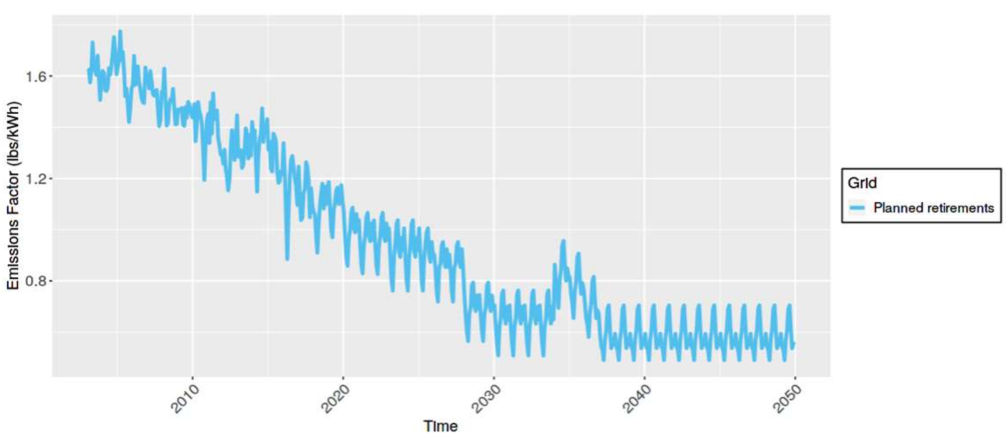
But that electricity isn't clean?



Shown above are pounds of CO_2 equivalent emissions produced to use 1 kWh of energy. Statewide emissions change over time depending on which assets are retired, when they are retired, and what they are replaced with.

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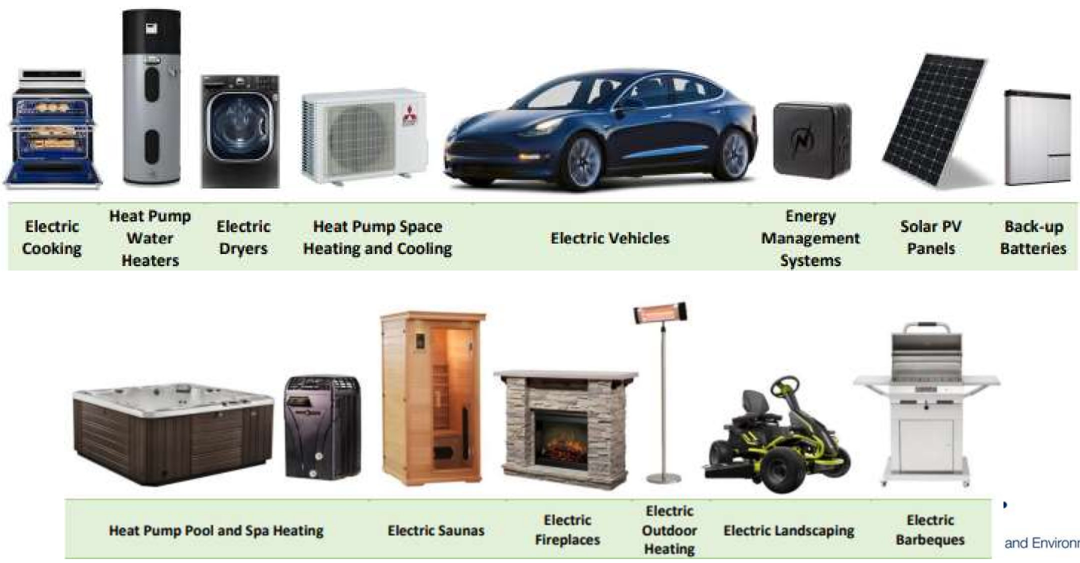
All-Electric Retrofits of Single-Family Homes



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Home Heating Systems

- Combustion furnace/boiler ~80 – 98% efficient
  - Constant efficiency and capacity
- Electric resistance furnace/boiler/baseboard ~100% efficient
  - Constant efficiency and capacity
- Air Source Heat Pump ~100 to 650% efficient
  - Variable efficiency and capacity
  - Both proportional to outside air temperature

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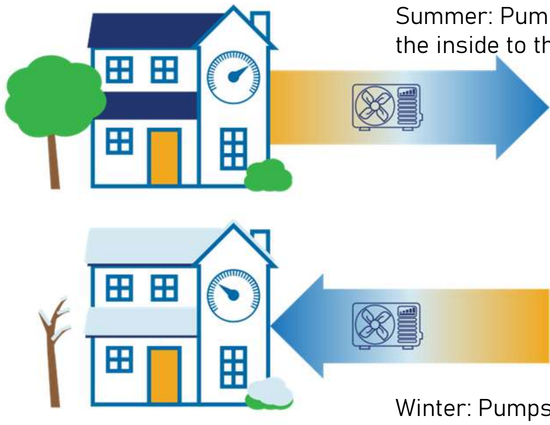
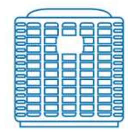
What is a heat pump?



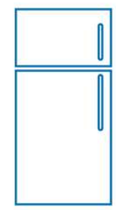
Summer: Pumps heat from the inside to the outside

Winter: Pumps heat from the outside to the inside

Same technology as:



Air Conditioner



Refrigerator

Types of Heat Pumps

- Residential Heat Pumps
  - Minisplit heat pumps
  - Multi-split heat pumps
  - Centrally ducted heat pumps
  - Dual-fuel heat pumps
  - Air-to-water heat pumps
  - Ground source heat pumps
- Commercial Heat Pumps
  - VRF heat pumps
  - Ground source heat pumps
  - PTAC heat pumps
  - RTU heat pumps
- Other heat pumps
  - High temperature heat pumps
  - Heat pump water heaters
  - Automotive heat pumps

Hot Water Heaters

- Combustion systems
  - Systems with tanks ~53% – 60% efficient
  - Instant hot water heaters ~80 – 95%
- Electric resistance
  - Systems with tanks ~90% – 95% efficient
  - Instant hot water heaters ~ 98%+
- Heat Pump water heaters (tank only)
  - Rated efficiencies of ~225 – 425%
  - Actual efficiencies of ~130– 220%
  - Hybrid with electrical resistance

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Heat Pump Water Heaters

- From electric resistance:
  - Very easy 'box in' replacement
  - Caveat: many folks with electric water heat are on utility programs that use the existing electric water heater
  - Will cut cost of water heating by 40% to 70%
- From natural gas (tank):
  - Additional work (cap gas line, run new 240V circuit)
  - May yield bill savings, but most likely to break even ±$30/yr

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Beneficial Electrification is in MN Statute (ECO)

- Goal: transition from carbon intensive fossil fuels to less carbon intensive electric alternative
  - Net reduction in lifetime carbon emissions
  - Net reduction in source energy use
  - Net reduction in fuel-neutral customer energy costs
  - No increase in coincident peak electricity demand

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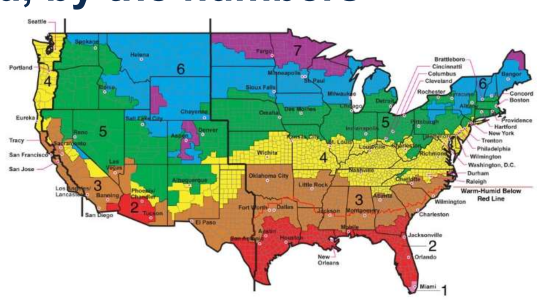
It's very cold, by the numbers



Location	Winter design temp (°F)	TMY3 HDD	Longest sustained period below design temperature
Thief River Falls (NW)	-22	9,700	16 hr
Duluth (NE)	-17	9,000	9 hr
Minneapolis / St. Paul (SE)	**-11**	**8,400**	**47 hr**
Worthington (SW)	-11	7,700	19 hr

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How buildings use energy slide section

- Efficiency first
- Importance of building envelope/weatherization
- We know how to do this (WAP)
- Scaling opportunities

- Ending point: 70-80% of blame is on heating; majority of focus should be on heating

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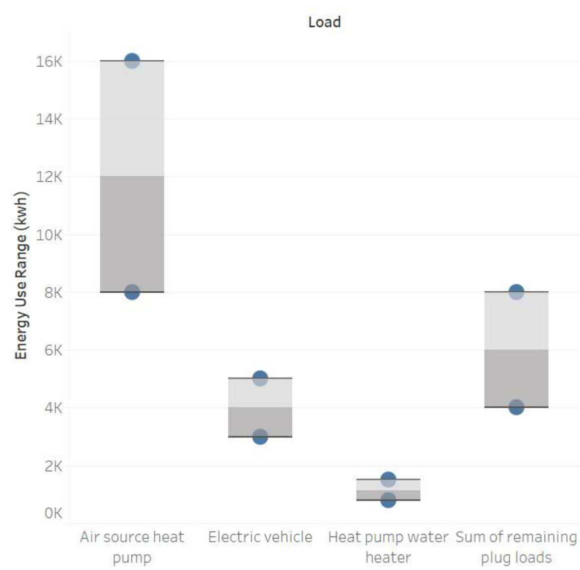
Building Decarbonization

- Consumer facing aspects of decarbonization are building and transportation electrification
  - Displace natural gas, propane, and gasoline with electricity

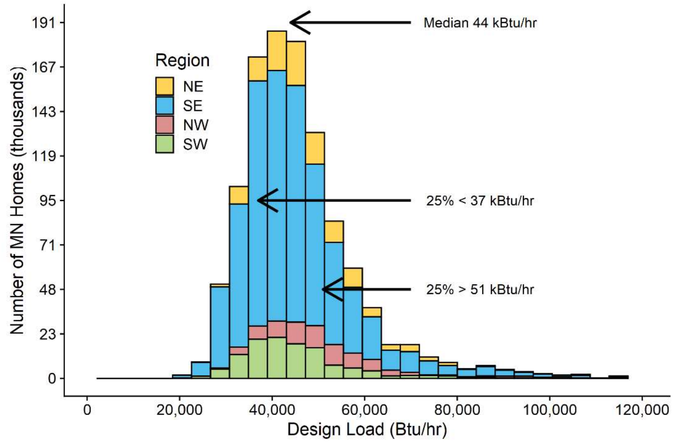
- Nationally, about 40% of home energy goes to space heating
  - In MN homes, its double that about 70 to 80%

- An all-electric home:



But we built homes well over the last century

- Minnesota homes built <1990
- Space heating loads are less than commonly believed
- But still must meet these loads or more at peak winter conditions ≤11 °F



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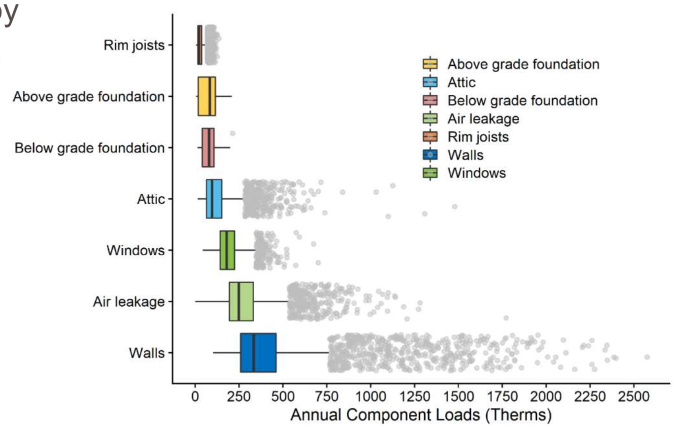
Energy use for heating is still high

- Annual space heating loads by building envelope component
- Walls and air leakage drive space heating requirements
- Note the large number of outliers particularly for attics, air leakage, and walls



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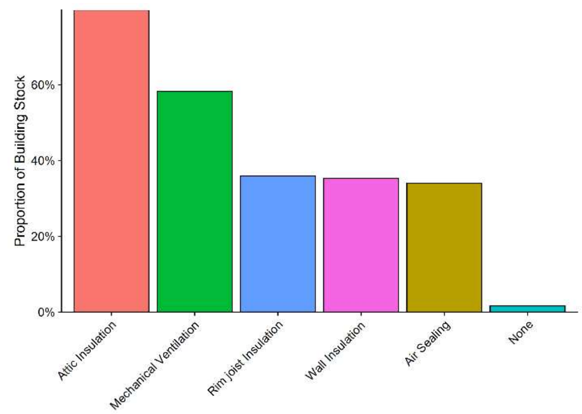
Weatherization

- Most homes have had one or more weatherization measure
- Yet most homes built before <1990 can still benefit from multiple basic weatherization measures



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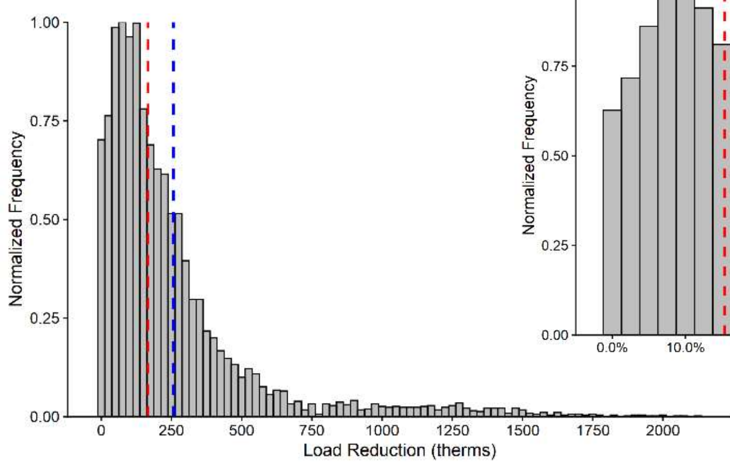
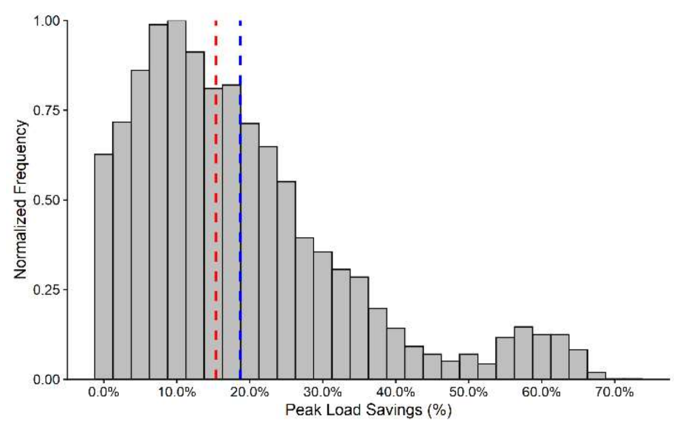
Very high savings are achievable





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Celebrating the Weatherization Assistance Program

- Weatherization saves!
  - Net savings to investment
  - Carbon savings
  - Average energy savings ~20%+ 280 $/yr
  - Savings accrue to participants and rate payers
  - Non Energy benefits 200% energy benefits (13k/4k)
- Everyone loves weatherization!
  - 94% satisfaction rate among participants
  - 80% satisfaction rate among weatherization staff
- Weatherization is scalable!
  - 100,000/yr to 350,000/yr
  - 8,500 to 28,000 jobs
  - Quarter of households eligible for WAP

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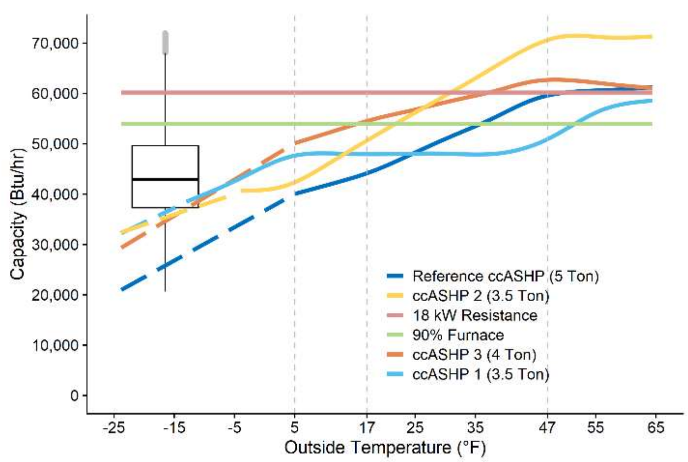
Switching gears to ccASHPs

- ccASHPS offer promise for large site energy savings and emissions reductions
- And many models do work at these very cold design temperatures!
- But they still have significant capacity limitations compared to space heating needs



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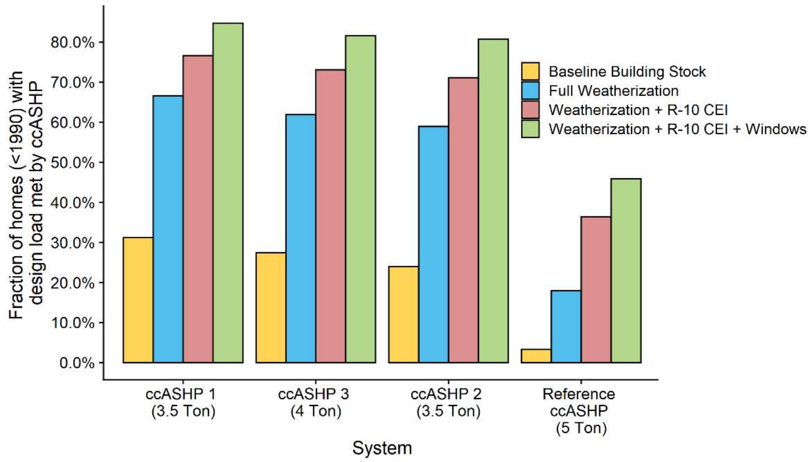
Envelope work enables ASHP electrification

- Weatherization doubles the number of homes that are ASHP-ready
- Continuous exterior insulation (CEI) and new code minimum windows prepare nearly the entire building stock



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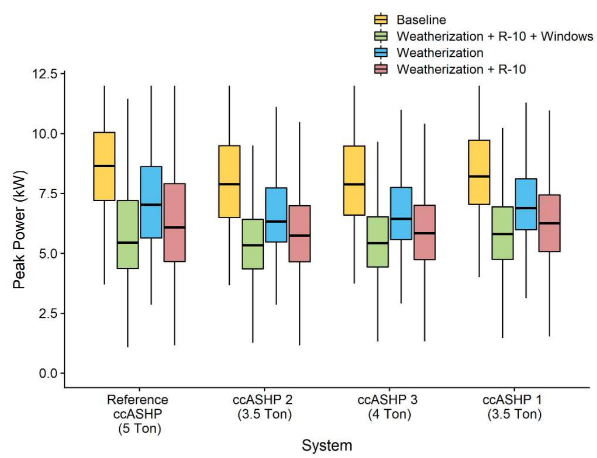
Significant reduction in peak load

- Envelope work lowers peak loads, auxiliary energy requirements, and ASHP equipment size
- Weatherization and deep envelope retrofit work **reduce** peak load by **more than** current cooling driven peaks!
- Avoided costs to the future grid promised by low risk envelope efficiency is not fully appreciated



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Elevating the role of envelope work

- ccASHPs are the ***second most important*** very cold climate building decarbonization (electrification) measure
- Envelope work enables space heating electrification in cz 6+
  - Plus are a low-risk way to enable all future space heating technologies
- How do we elevate the role envelopes play in
  - Decarbonization via building (space heating electrification)?
  - Lowering ccASHP sizing requirements
  - Limiting auxiliary energy needs
  - Reducing grid impacts & burden of meeting peak winter load w/ low carbon grid

Remember 70%+ of energy use is combusting gas for space heating; the success of any electrification campaign depends on reliable solutions

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Electrifying all 1-4 unit homes: What does it take?

Scenario 1

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What are we doing?

✓ **Electrification includes:**

- Electric service upgrades including EV charging circuit
- Weatherization
  - Wall insulation, attic insulation, rim joist insulation, and air sealing
- Space Heating Systems
  - Furnaces → centrally ducted ccASHPs
  - Boilers → multi-split ccASHPs
- Domestic Hot Water (HPWH)
- Clothes Dryers (Heat Pump Clothes Dryers [HPCD])
- Cooking Equipment (Induction ranges and electric ovens)

Electrification excludes:

- Pools, hot tubs, grills, lawn equipment, other end uses

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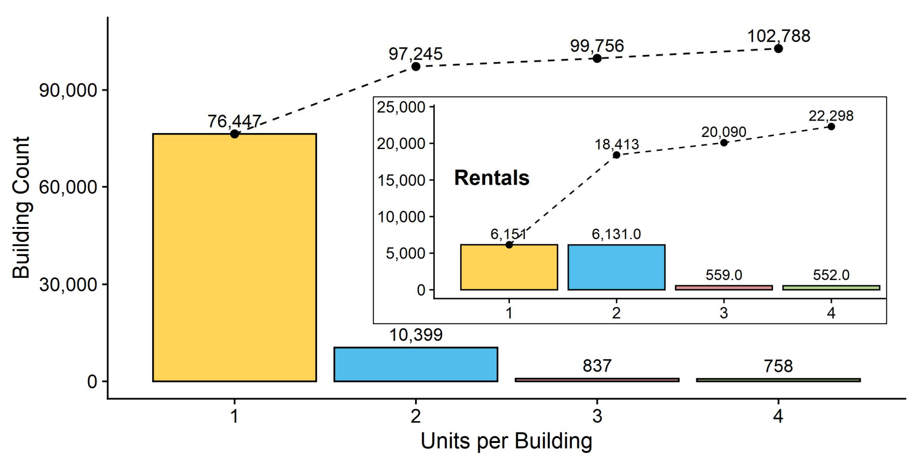
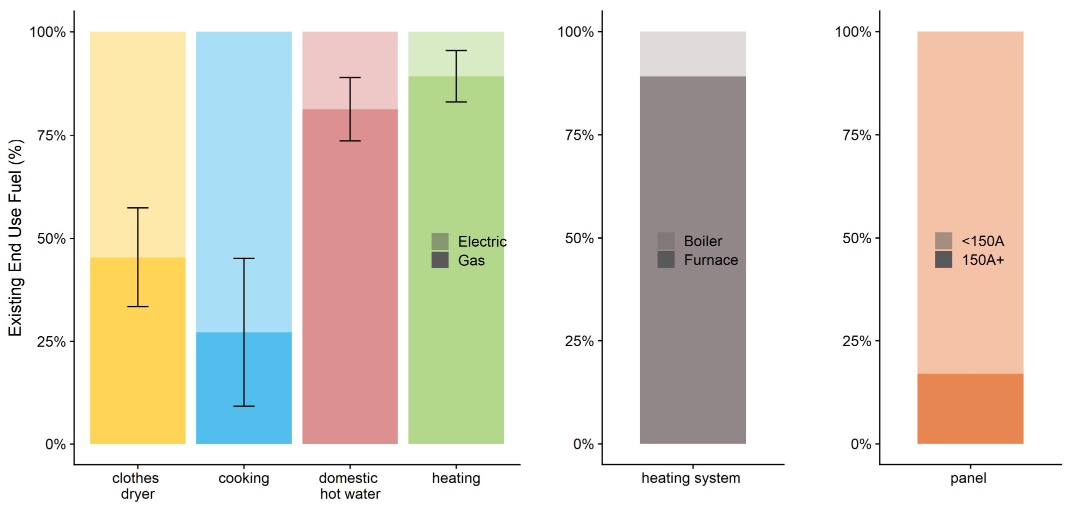
Starting Point – The Building Stock



Which building loads are already electric?



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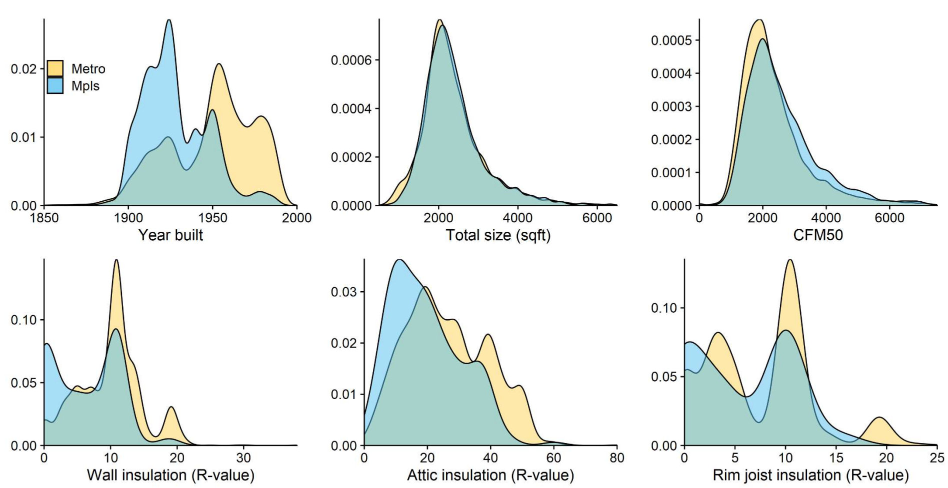
How do Minneapolis Buildings Compare?



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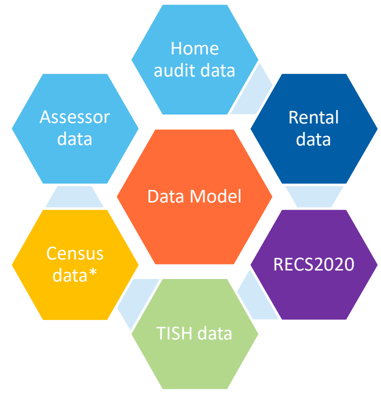
Methodology



Model Development

1. Combine sparse data sources
2. Identify statistical relationships between all sets of variables
3. Sample data to construct representative buildings
4. Apply changes to buildings & observe results

Data

- Typology
- Location
- Devices
- Fuels
- Ownership
- Electric Service
- Occupants

Process

1. Identify electrification building needs for representative sample
2. Apply all measures necessary for electrification
3. Schedule projects according to Mpls. science-based target
4. Aggregate results

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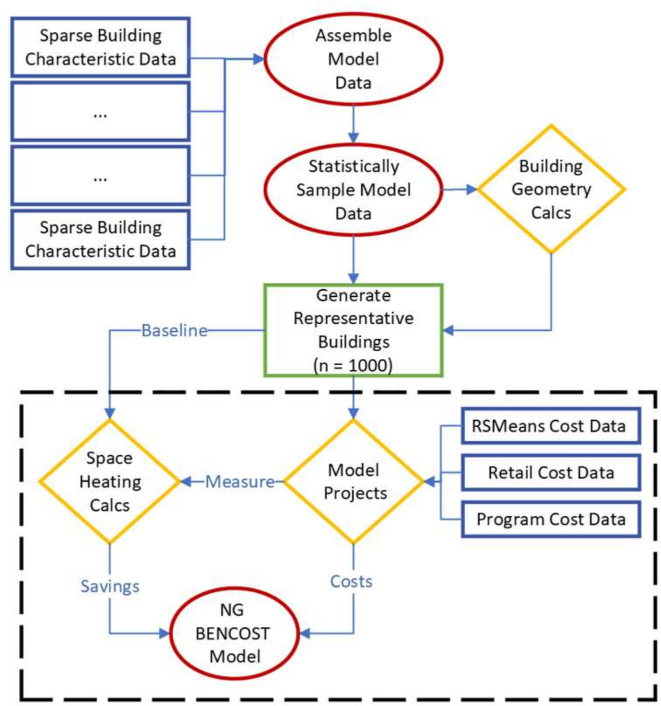
Model Overview

- Capture variations in real building characteristics and performance data
- Generate representative buildings
  - Calculate space heating loads
  - Estimate envelope projects
  - Cost effectiveness testing

Variable
Building age (decade)
Building size (total sq ft)
Building type (e.g., one-story, split-level)
Cladding type (siding material)
Window area/ratio (sq ft)
Attic geometry
Attic insulation R-value
Wall insulation R-value
Air leakage
Window type/details



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Methodology for Assessing Electrification

- Where data came from
- Building set characteristics
  - Can we get bar charts showing some of this (counts by age, etc)?
  - Can we show % of homes are gas vs electric by equipment?
- Technology upgrade assumptions
- Rates

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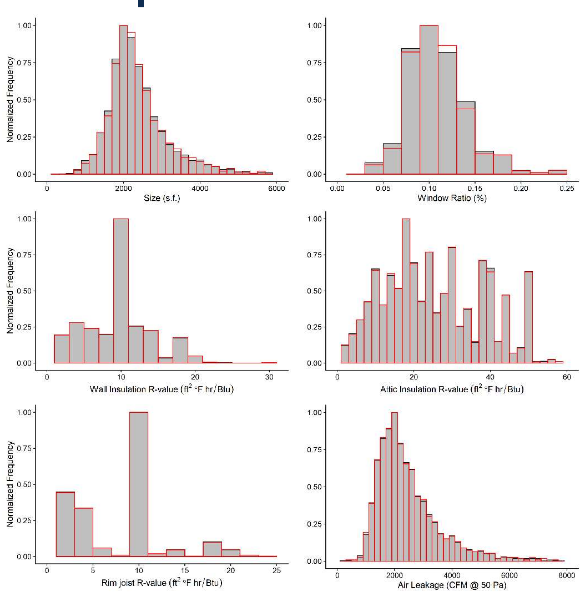
Example Modeled Data



- Modeled data (red outline) match underlying datasets (grey bars) within a few percent
- N = 1,000 complete buildings match performance attributes of 11,000 sparse samples
- We can now do things to these model buildings and observe the results

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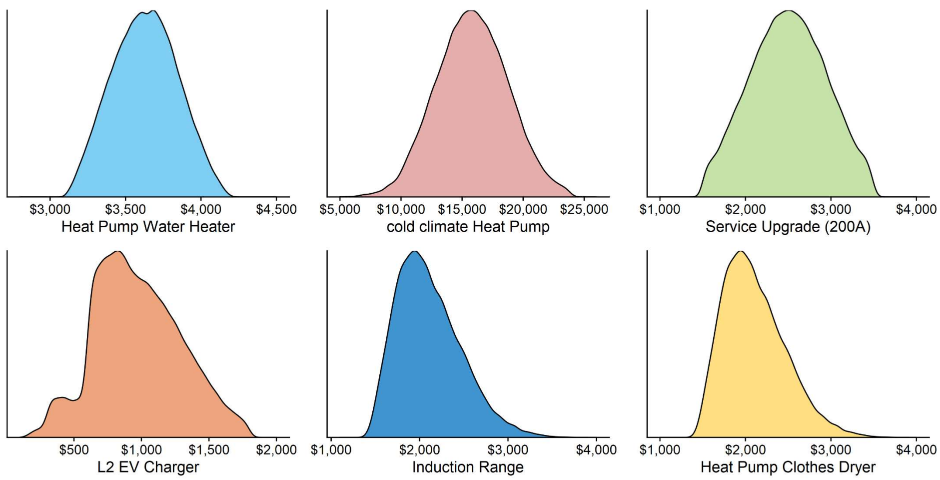
Electrification Measure Costs



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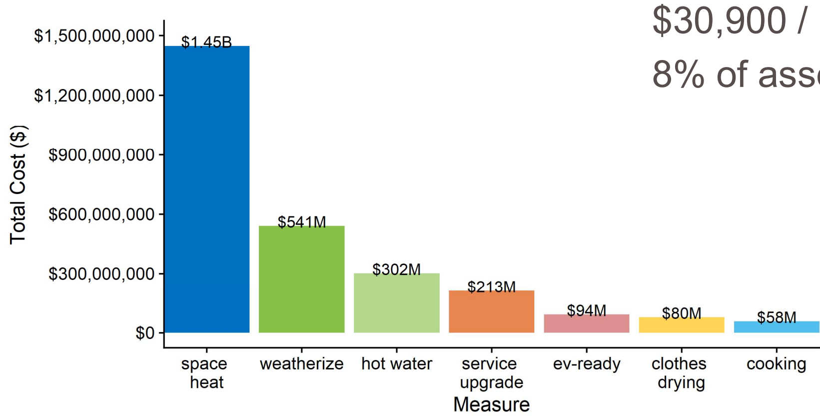
Headline Results

$2.74B to fully electrify all 88,441 1-4 unit buildings in Minneapolis

$30,900 / building

8% of assessed value



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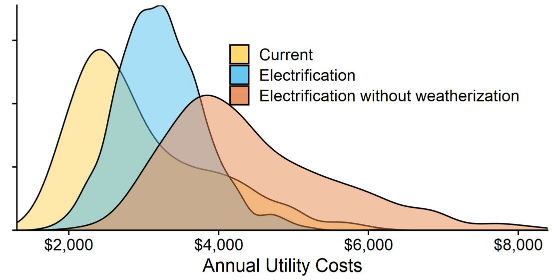
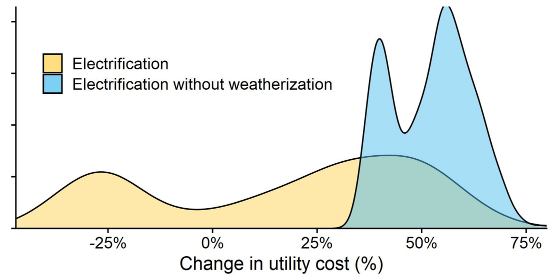
Annual Energy Costs of Electrification

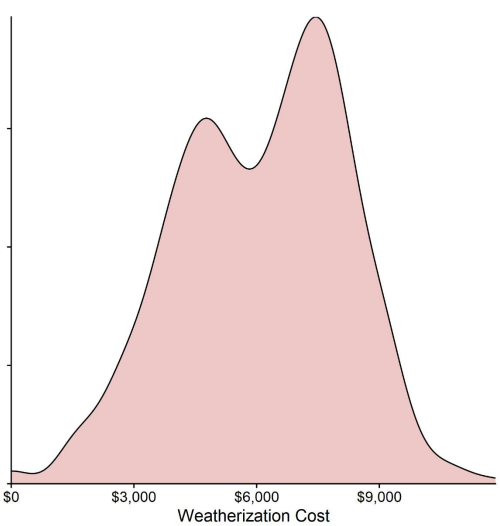
- Utility costs
  - Trailing 12mo weighted volumetric costs
  - Electric – 0.155 $/kWh
  - Natural gas – 0.88 $/therm

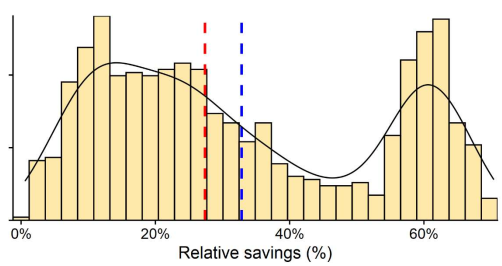
- **<u>Annual bills increase by $272 (17%) on average</u>**, but building outcomes vary greatly
  - ~25% of buildings see bill reduction
  - ~75% see bill increases

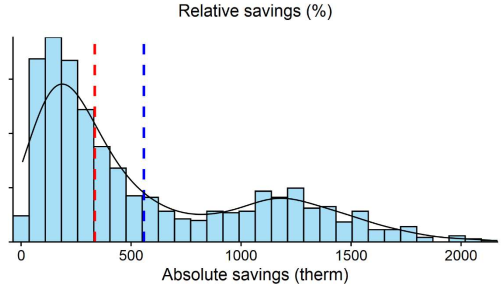




Weatherization Results







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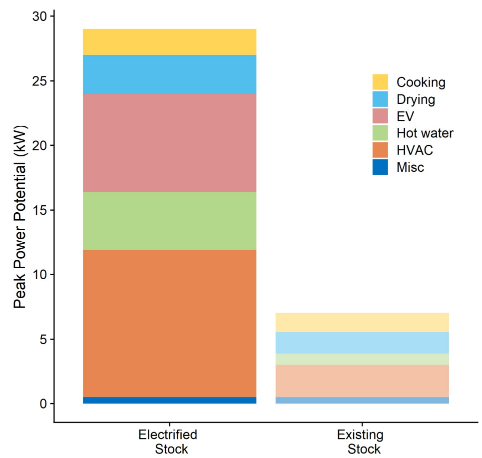
Grid impacts

- If Minneapolis electrification pathway exceeds utility infrastructure investment schedules
  - there may be insufficient local distribution to handle new load and larger peaks
  - This may lead to congestion, reliability issues, and outages
  - today's grid, designed for summer peaking and high availability of natural gas, fails to accommodate the
    - doubling to tripling or more of volumetric energy sales per customer,
    - tripling or more the potential peak load
    - and shifting it from summer to winter



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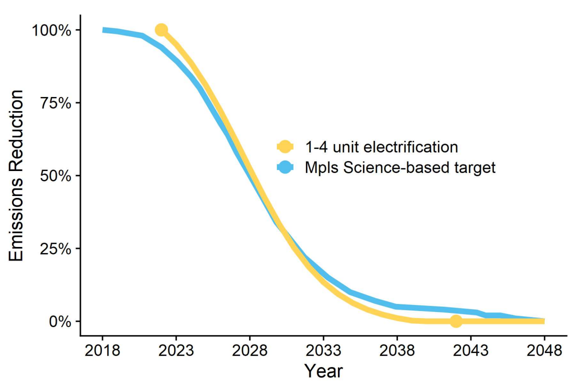
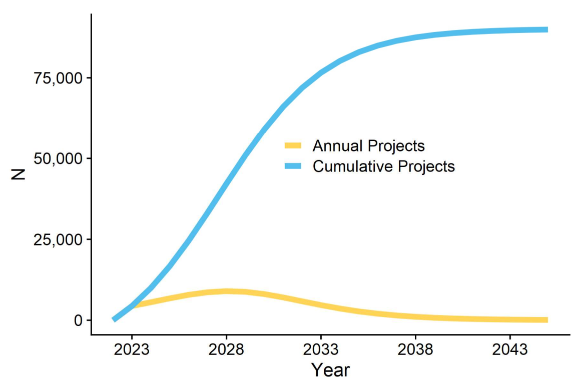
Decarbonization timeline





Year	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041
Projects	4,400	5,558	6,761	7,853	8,647	8,979	8,773	8,076	7,038	5,846	4,666	3,608	2,721	2,015	1,471	1,063	763	545	387

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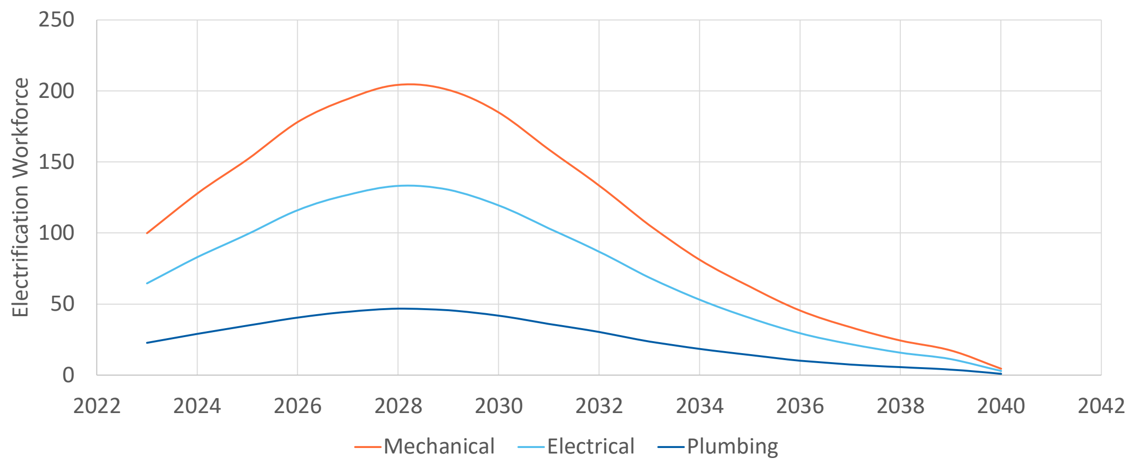
Labor Requirements (excluding wx)



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Ramifications

- Operational cost impacts
- Workforce needs vs existing capacity
- Grid needs/impacts
  - Another reason we're focusing on envelope/weatherization

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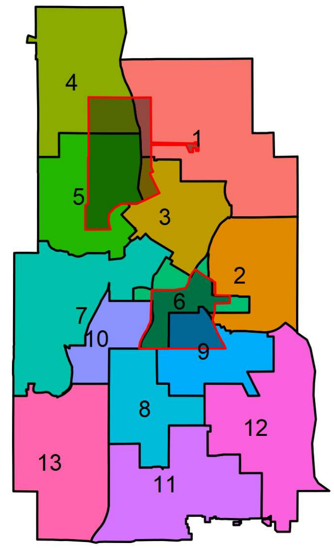
Additional Considerations

- Where are these buildings?
- Who lives in these buildings?



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Discussion

Post-it time!

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Why is decarbonizing homes important?

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What stood out to you from the modeling scenario?

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Advantages and Concerns

Advantage	Concern

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Given these, how should the model evolve?

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Where and when does your org touch/interact with homes?

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Next Steps

1. Evolve the model
2. Dive deeper into barriers and solutions (existing and brainstorming new)

Thank You!

Katie Jones - kjones@mncee.org

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City of Minneapolis Comprehensive Electrification Vision and Roadmap Workshop 2

2022.11.17

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1

Agenda

Intros
Review Workshop 1
Heat Pump Overview
Scenarios Round 2
- Break –
Discussion

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2

The approach criteria

- Develop a pathway to:
  - Meet the City's climate target and timeline
  - In a way that advances equity
  - With technology that exists today
  - In today's regulatory environment
  - That is scalable
  - In the most cost-effective way possible

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Workshop 1 Scenario: WX + Elect of 90k 1-4 unit homes

✓ **Weatherization:** wall insulation, roof insulation, rim joist insulation, upgrading single pane windows

✓ **Electrification includes:**

- Electric service upgrades including EV charging circuit
- Weatherization
  - Wall insulation, attic insulation, rim joist insulation, and air sealing
- Space Heating Systems
  - Furnaces → centrally ducted ccASHPs
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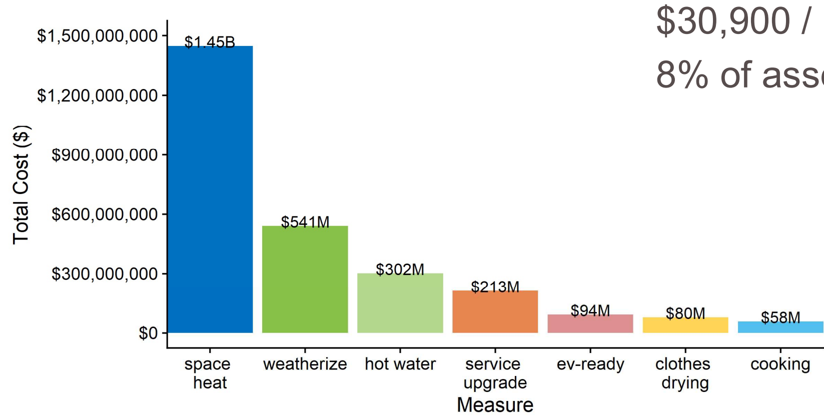

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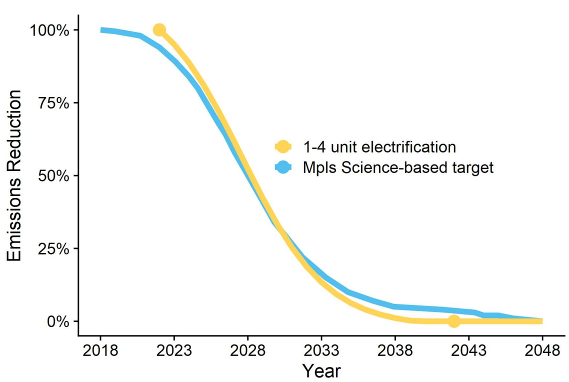
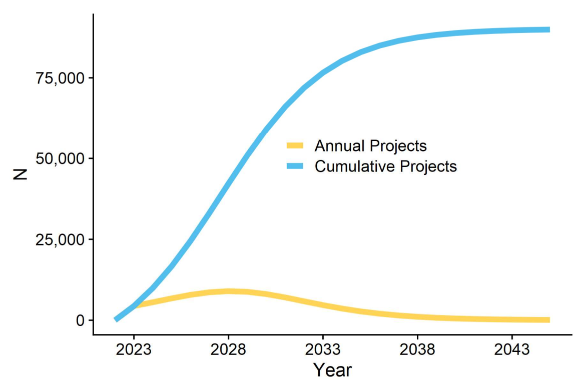
Decarbonization timeline





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The approach criteria

- Develop a pathway to:
  - Meet the City's climate target and timeline
  - In a way that advances equity – depends on roll out and rates
  - With technology that exists today
  - In today's regulatory environment
  - That is scalable
  - In the most cost-effective way possible - depends on roll out

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What we heard – why electrify?

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What we heard – benefits of the scenario?

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What we heard – general reactions to the scenario

I'm excited that Minneapolis is willing to try, even with a $2.74B price tag	I was impressed by the range of data sources	Increased cost of electricity is higher than I've seen in the models we've done with continuous exterior insulation and triple pane windows	We need to put the investment needed in context of the benefits and current operating costs. For example, "we spend $200 million per year paying for residential energy right now"
How does shifting to distributed renewable energy fit in?	Divergence between macro and individual impacts	Need to know incremental cost compare to total cost (BAU)	What impact on resident energy cost would dual fuel/hybrid systems cause?
What is energy cost sensitivity analysis when considering fuel price variations?	Incremental when things need replacing	The out-sized impact of space heating in terms of the contribution and prevalence of gas in this space. Helps focus the discussion.	Surprising that 25% would save money. This is where we should start.

What we heard – concerns from scenario 1

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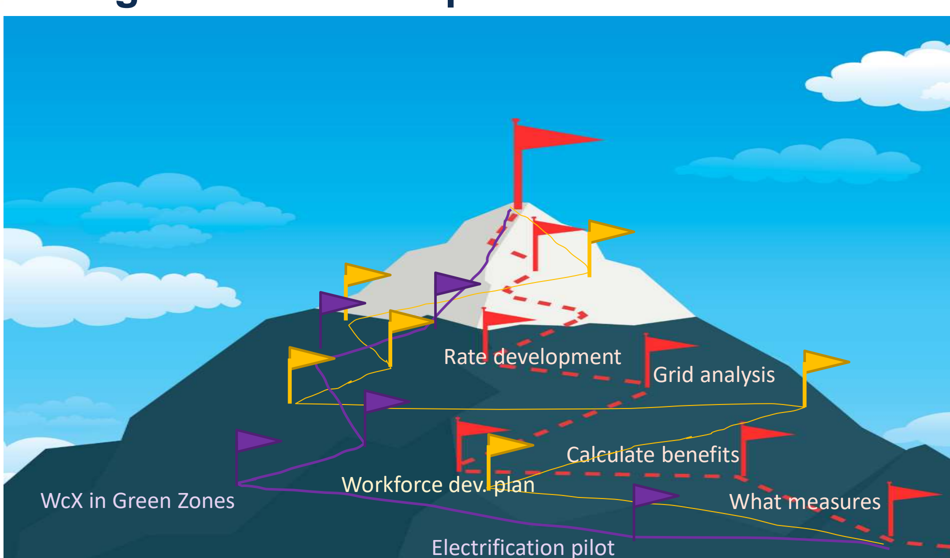
Filling in the Roadmap



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Q&A

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Heat pump tech overview

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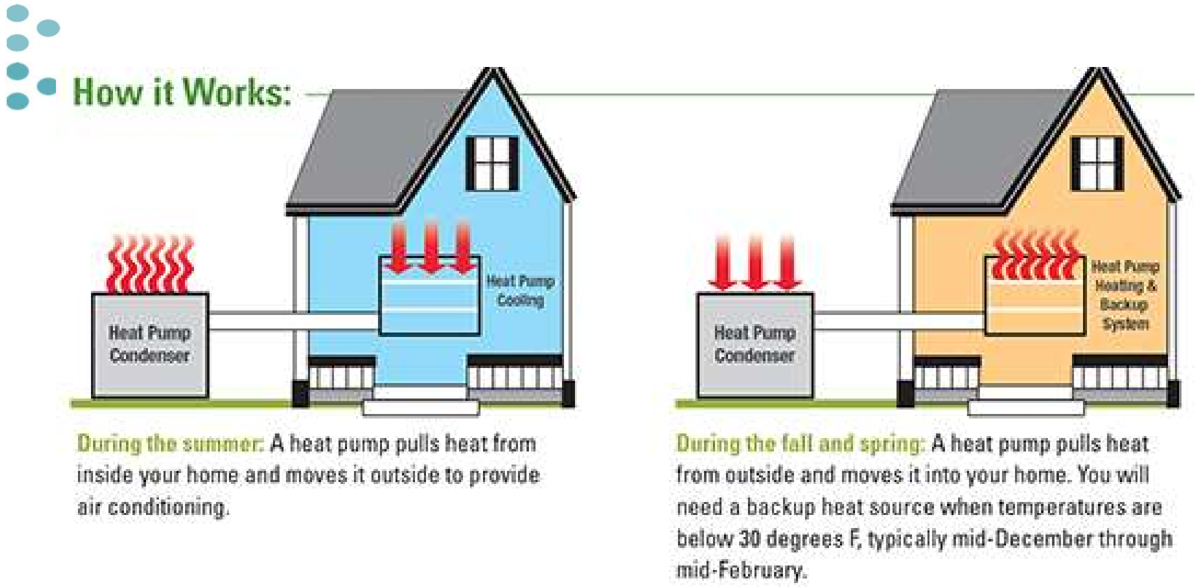

Image Source: MN Power

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Non-ducted system

Indoor unit

Outdoor unit

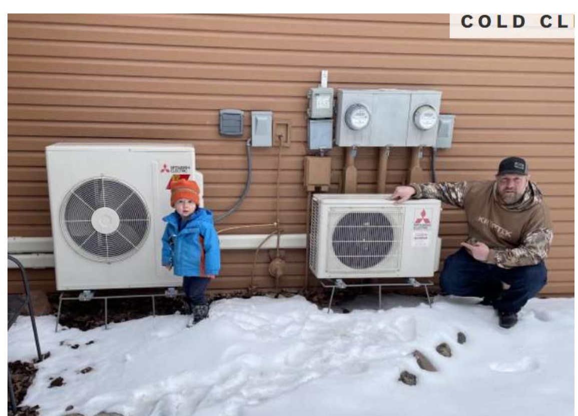

Image credit: CERTs

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Ducted system

Indoor unit

Outdoor unit

Image credit: CERTs

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Dual Fuel HP

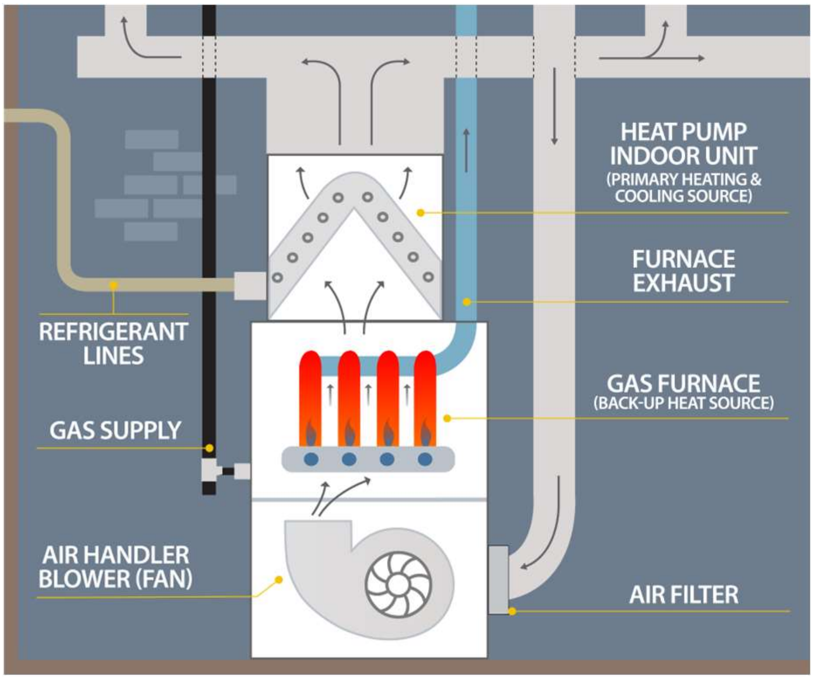
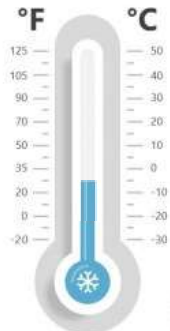


Image credit: Slipstream

Dual Fuel HP Electric Operation



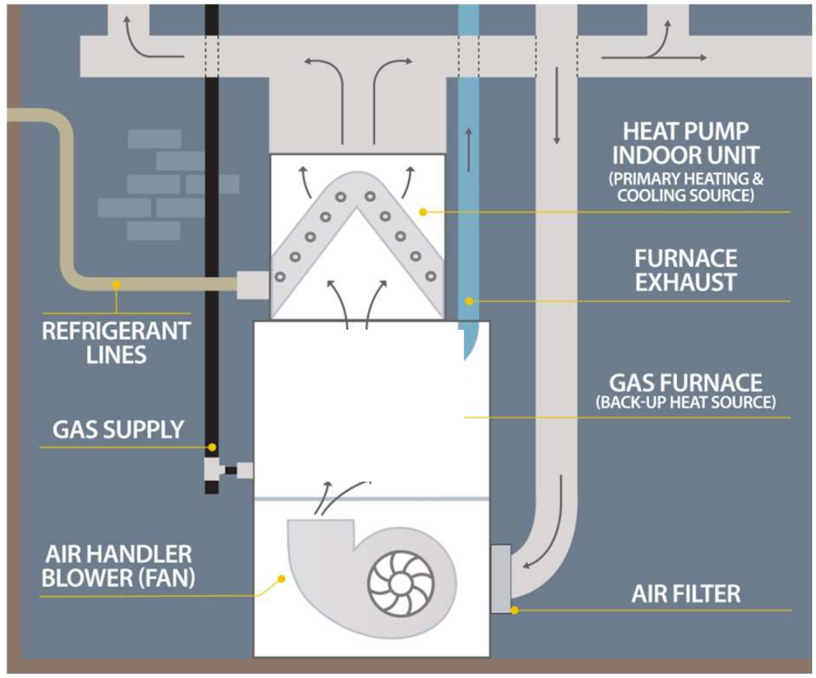


Image credit: Slipstream

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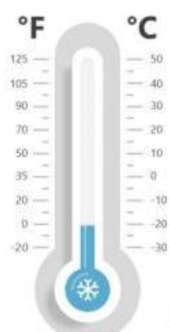
Dual Fuel HP Gas Operation



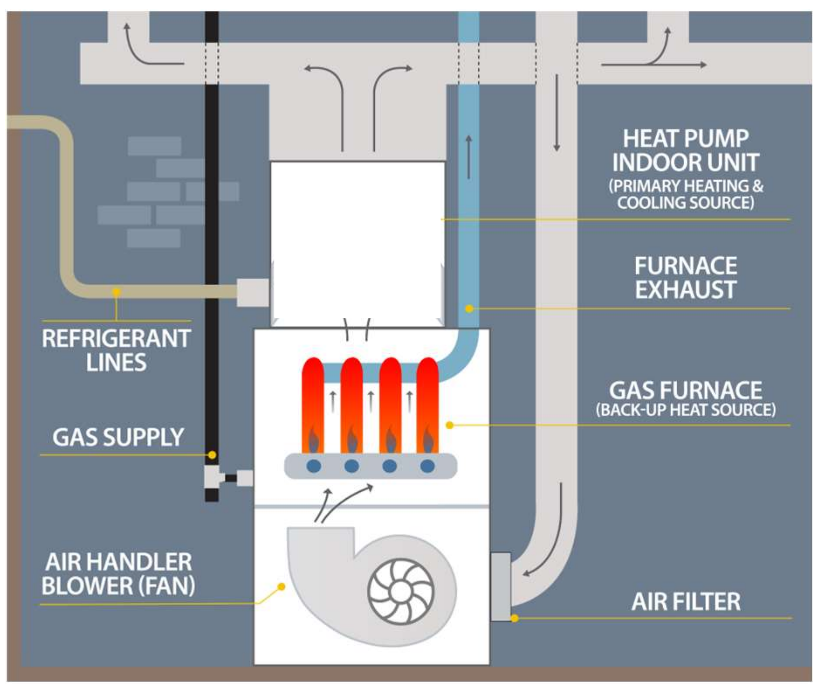


Image credit: Slipstream

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Dual Fuel HP

Can cover heating when it is $$ adventageous

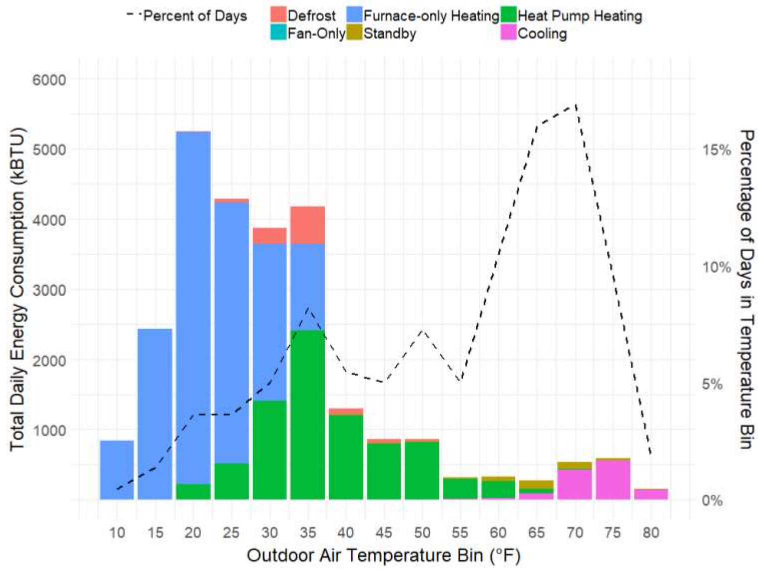

Image credit Slipstream: https://slipstreaminc.org/sites/default/files/2022-05/dual-fuel-air-source-heat-pump-pilot.pdf

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Scenarios Round 2

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Aim:

- Understand the impact of dual fuel measures
- Understand the impact of different electric vs gas rates
- Understand the incremental cost

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Assumptions & Results Update

- **Baseline:** How do electrification costs compare to that otherwise spent on gas equipment?
  - ***Assumption:*** A natural baseline comprises the natural rate of annual spending on conventional systems based on equipment lifetime
- **Upper Costs Bounded:** Can we establish a reasonable lower bound?
  - ***Assumption:*** Cost of technology will decline with increasing manufacturing scale, market familiarity, and installation and program efficiencies
- **At current rates, ASHPs increases energy costs**
  - ***Question:*** *How do dual-fuel vsASHP heat pumps affect annual energy costs?*
  - ***Question:*** *How do utility rates impact energy costs?*

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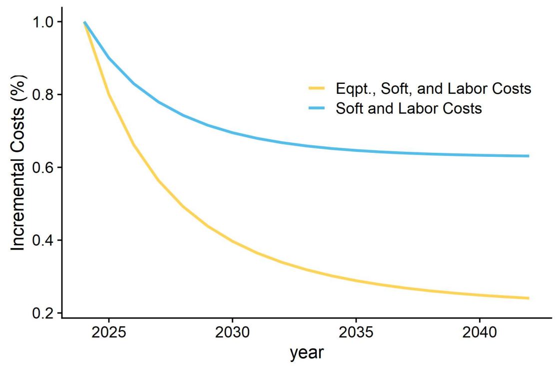
Additional Electrification Cost Scenario

- Second electrification cost scenario:
  - ***Assumption:*** Cost of technology will decline with increasing manufacturing scale, market familiarity, and installation and program efficiencies
    - Modeled from solar adoption (2010-2020)
  - Contrast with workshop 1 high-cost scenario
    - No incremental cost reduction from 2022



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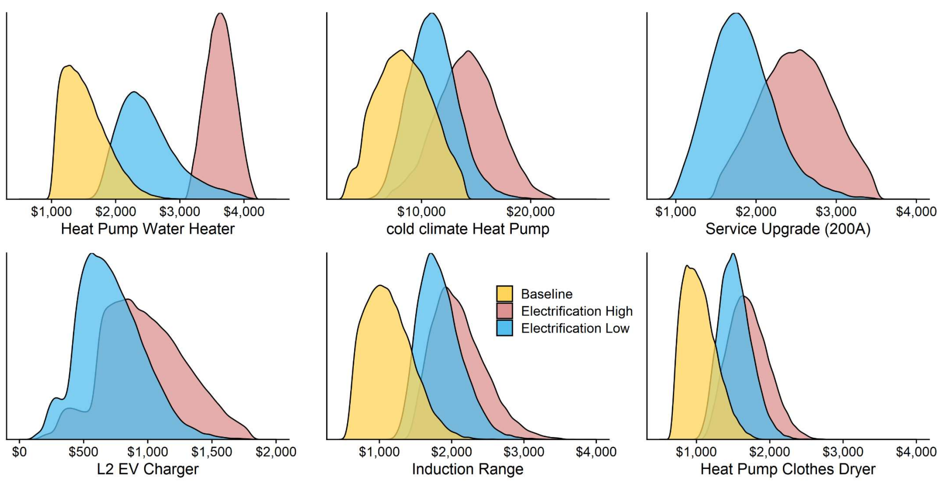
Measure Costs



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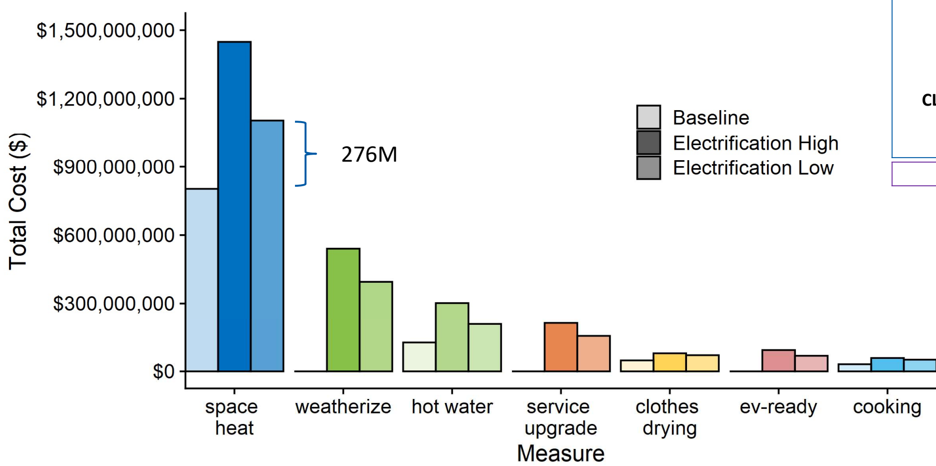
Electrification Costs Compared to Baseline



	HIGH	LOW	BASE
HVAC	1449M	1133M	857M
WX	534M	391M	-
DHW	302M	208M	127M
PANEL	213M	156M	-
CLOTHES	79M	71M	48M
EV	94M	69M	-
COOK	58M	51M	31M
TOTAL	2.74B	2.10B	1.06B

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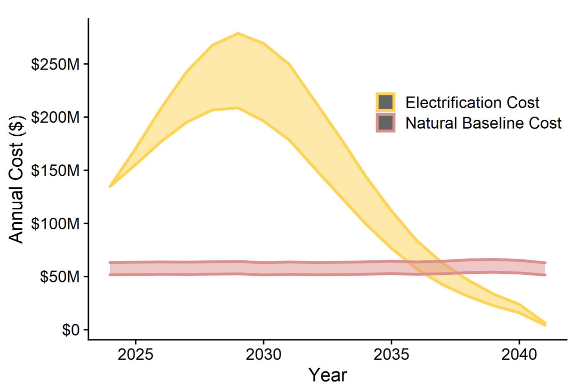
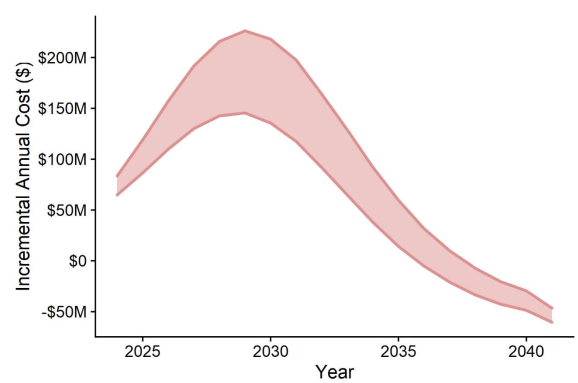
Upfront Electrification Costs Compared to Baseline





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Energy (Operating) Cost Scenario Inputs

- Energy (Operating) costs strongly depend on electric and gas rates
- Scenario 1 yielded average energy cost increase of 272 $/yr

Electric Rates			Gas Rates	
	Current	0.15 $/kWh	Last year	0.88 $/therm
	Rate Increase	0.19 $/kWh	Current	1.05 $/therm
	Dual-fuel for HVAC	0.10 $/kWh	High	1.30 $/therm

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Annual Energy Costs

All Electric

Elec Rates ($/kWh)	Gas Rates ($/therm) 0.88	1.05	1.3
0.15	$ 272	$ (32)	$(465)
0.09	NA	NA	NA
0.19	$ 769	$ 475	$ 42

Elec Rates ($/kWh)	Gas Rates ($/therm) 0.88	1.05	1.3
0.15	10%	-1%	-14%
0.09	NA	NA	NA
0.19	26%	15%	1%

Dual Fuel

Elec Rates ($/kWh)	Gas Rates ($/therm) 0.88	1.05	1.3
0.15	$ (147)	$ (393)	$(758)
0.19	$ 154	$ (93)	$(455)
0.15 -> 0.10	$ (344)	$ (590)	$(952)
0.19 -> 0.10	$ (207)	$ (451)	$(811)

Elec Rates ($/kWh)	Gas Rates ($/therm) 0.88	1.05	1.3
0.15	-5%	-13%	-22%
0.19	5%	-3%	-12%
0.15 -> 0.10	-13%	-20%	-28%
0.19 -> 0.10	-7%	-14%	-22%

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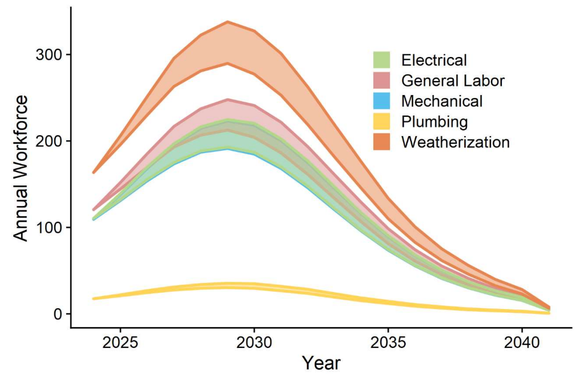
Workforce Requirements

- Peak workforce 2029
  - 920 to 1070 total jobs
  - 290 – 340 Weatherization
  - 210 – 250 General Labor
  - 195 – 225 Electrical
  - 190 – 220 Mechanical
  - 030 – 035 Plumbing



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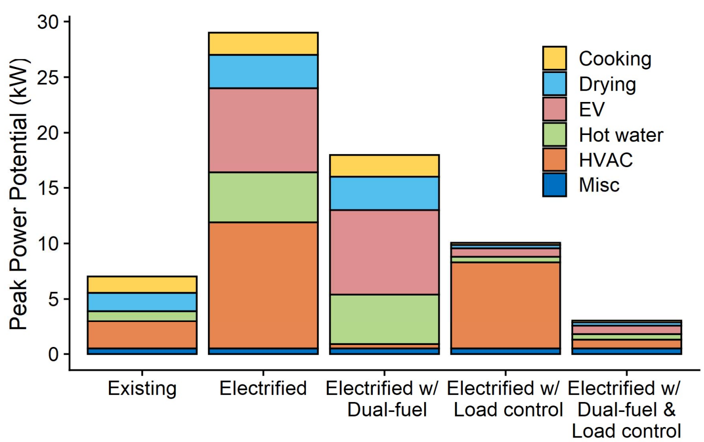
Additional Grid Considerations



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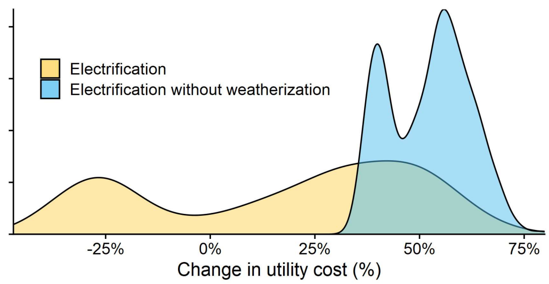
Wx Update

- Analyze savings ~ f(building chars, geography, rental, income)
- Remind of cost outcomes
  - Plot them in base case
  - Wx does heavy lifting
  - For who does it lift?
- If time, worker update



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Q&A

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5 min break

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Small Group Activity

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Small group rotations

Rates with Josh

Measures with Arbor

Incremental costs with Katie

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THANK YOU!

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City of Minneapolis Comprehensive Electrification Vision and Roadmap Workshop 3

2022.12.19

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Agenda

Review Workshop 2
Scenarios Round 3
- Rates and Emissions
- Incremental Costs
- Labor
- Sequencing

Break
Activities
- Sequencing
- Pilot

2

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Workshop 2: Recap

Utility rates: How do electric and gas rates impact ongoing energy costs?

Incremental cost: How does electrification spending compare to that otherwise spent on gas equipment?

High-cost Scenario: Can we establish a more reasonable cost scenario using scaling efficiencies?

Dual-fuel: How do dual-fuel heat pumps affect annual energy costs?

Workshop 2: Feedback Recap

- Rates:
  - Electric and gas rates are ok, but could be improved. Examine:
    - Electric prices under all-electric and dual-fuel scenarios
    - The cost of meeting decarbonization goals using natural gas
    - All-electric rates
    - Energy costs will only go up
- Incremental costs:
  - Equipment & soft cost reductions are feasible, but labor markets are likely to remain constrained, offsetting future labor efficiencies
- Dual fuel:
  - Given the high-cost savings, but limited emissions reductions of dual-fuel ASHPs, can we trade cost savings for deeper emissions reductions (80% vs 50% of heating load)
  - Heating and weatherization most important steps

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Rates

Gas Rates	
	$/therm
Low	1.05
Med	1.3
High	1.5
Renew	3.1

Electric Rates	
	$/kWh
Low	0.22
High	0.275
All Electric	0.11
Duel Fuel	0.10

- Gas
  - Low = current gas costs
  - Med = higher
  - High = highest
  - Renew = decarbonized gas

Unlikely to be this low ever again

- Electric
  - Low = electric + gas backup
  - High = all-electric space heating
  - All-electric = current option
  - Dual-fuel = gas backup option

Projected future rates from e21

Current available rates

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Baselines

Takeaway: costs will likely increase significantly if we do nothing to our buildings.

- ~30 to 50% now realized on gas; electric is TBD (slower process)

- What are future gas rates?
  - Increasing market volatility? More fracking?
  - End of war?
  - Accelerated LNG development?
  - Recession?

- What are future electric rates?
  - Pending rate case
  - Changing capacity expansion drivers

	Baseline Costs				
		Gas			
		Low	Med	High	Renew
Elec	Low	$ 3,218	$ 3,651	$ 3,998	$ 6,770
	High	$ 3,569	$ 4,002	$ 4,348	$ 7,121

	Baseline Costs % of today				
		Gas			
		Low	Med	High	Renew
Elec	Low	130%	147%	161%	273%
	High	144%	161%	175%	287%

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Quick check: natural gas decarbonization pathway

Decarbonization via **electrification** is

25% to 70% less costly

On consumer bills than **decarbonizing** the **natural gas** supply.

Even at low end of estimated renewable gas costs and high electric costs, there are sufficient savings to finance all electrification work.

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All-electric scenarios

- Anticipated future electric rates introduce cost burdens
- Current all-electric rates can drive immediate savings
- How long will the current all-electric rates continue?

	All Electric Costs				
		Gas			
		Low	Med	High	Renew
Electric	Low	30%	15%	5%	-38%
	High	47%	31%	20%	-27%
	All Electric - Low	-35%	-43%	-48%	-69%
	All Electric - High	-41%	-48%	-52%	-71%

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All-electric scenarios - $

	All Electric Costs				
		Gas			
		Low	Med	High	Renew
Electric	Low	$ 966	$ 533	$ 186	$ (2,586)
	High	$ 1,661	$ 1,228	$ 882	$ (1,891)
	All Electric - Low	$ (1,126)	$ (1,559)	$ (1,906)	$ (4,678)
	All Electric - High	$ (1,477)	$ (1,910)	$ (2,256)	$ (5,029)

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Dual-fuel scenarios (5° F switchover ~80% of heating load)

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- Dual fuel savings vanish at regular rates due to high ASHP use (80% vs 50%)
- Dual fuel rates lead to high $ savings
- Dual fuel rates, paired with upcoming utility, state, and IRA fed incentives can finance the *incremental* costs of electrification

	Duel Fuel Costs				
		Gas			
		Low	Med	High	Renew
Electric	Low	14%	1%	-8%	-46%
	High	28%	14%	5%	-36%
	Duel Fuel - Low	-9%	-20%	-27%	-57%
	Duel Fuel - High	-3%	-14%	-20%	-51%

*targets 80% of load

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Dual-fuel scenarios (5° F switchover ~80% of heating load)

- Dual fuel savings vanish at regular rates due to high ASHP use (80% vs 50%)
  - Can always back off emissions reductions for more savings
- Dual fuel rates lead to high savings
- Dual fuel rates, paired with upcoming utility, state, and IRA fed incentives can finance the *incremental* costs of electrification

	Duel Fuel Costs				
		Gas			
		Low	Med	High	Renew
Electric	Low	$ 465	$ 32	$ (315)	$ (3,087)
	High	$ 1,007	$ 574	$ 228	$ (2,545)
	Duel Fuel - Low	$ (292)	$ (725)	$ (1,072)	$ (3,844)
	Duel Fuel - High	$ (108)	$ (541)	$ (887)	$ (3,660)

*targets 80% of load

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Reminder: Dual Fuel HP and Switchover Temperatures

Gas can cover heating when it is $$ advantageous

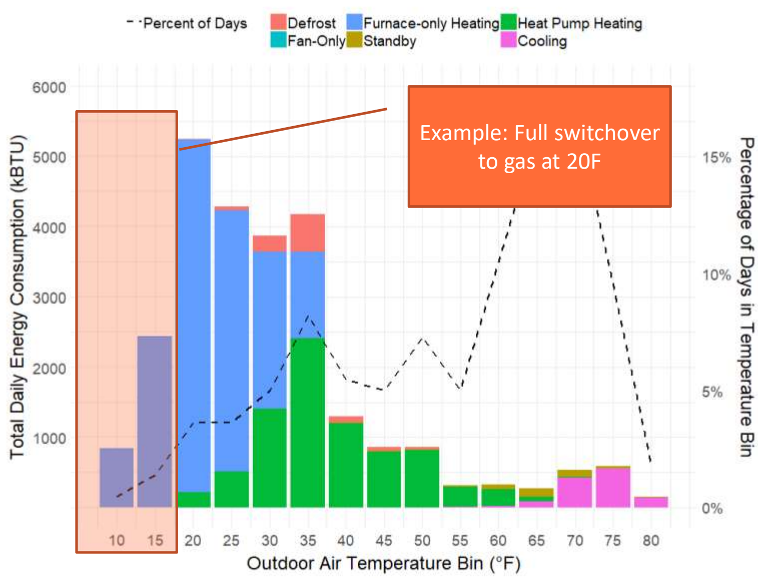

Image credit Slipstream: https://slipstreaminc.org/sites/default/files/2022-05/dual-fuel-air-source-heat-pump-pilot.pdf

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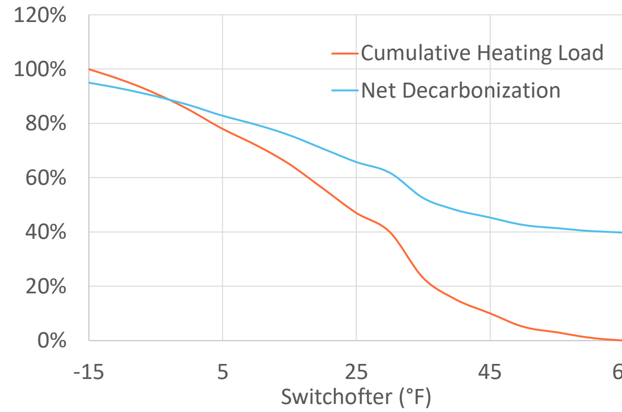
Switchover / Dual-fuel Emissions Outcomes

How close do we get to the City's decarb goal at differing switchover temps?

Examples:
@ 5F ~80%
@ 25F ~ 50%



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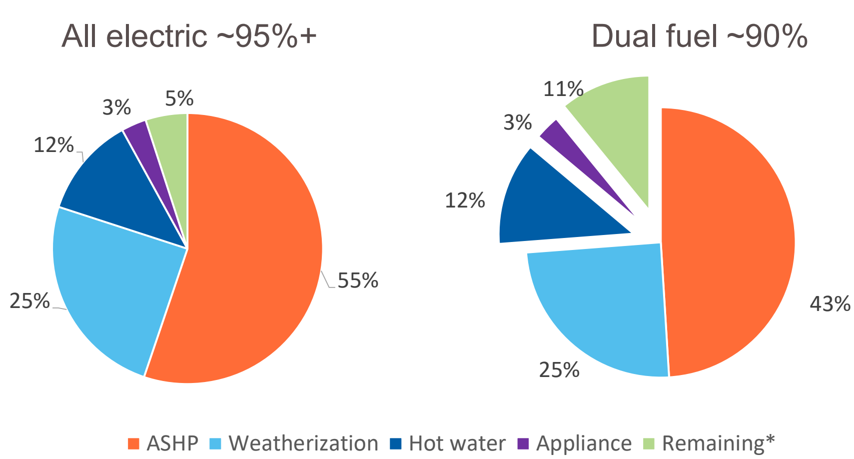
Electrification Emissions Reductions By Source



*Green = unaccounted gas (e.g. fireplaces, pool heaters), and for dual fuel, remaining natural gas heating

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What about water heater and appliance bill costs?

Electric Cooking	Heat Pump Water Heaters	Electric Dryers
Negligible increase	Cost-neutral	Negligible increase

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Rates and Emissions
Questions and Discussion

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Rates and Emissions Questions and Discussion

Of the three pathways:

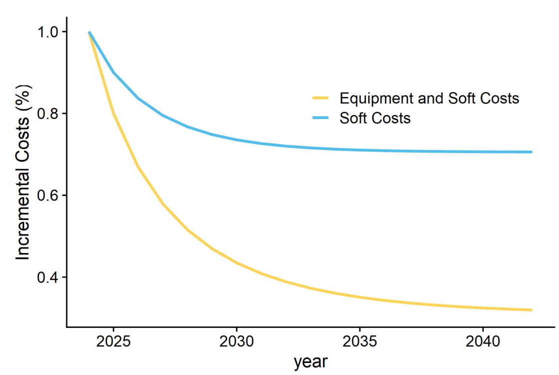
All electric
Dual fuel
Decarbonized gas

…which should the City pursue/incentivize?
…would your recommendation differ by building/occupant?

Updated Incremental Cost Curve

New model for "Electrification-Low" increases by about 7 to 11% due to higher labor costs

Still maintained:
- Other soft cost improvements
- Equipment incremental cost improvement



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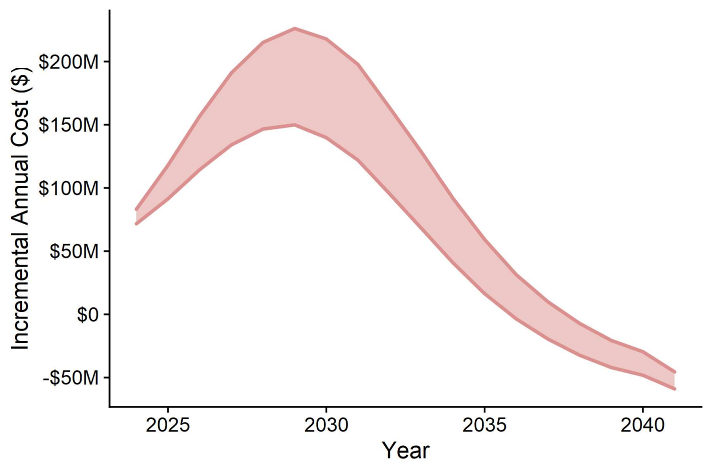
Updated Incremental Costs over time

New model for "Electrification - Low"(bottom line) increases by about 7 to 11% due to higher labor costs

Still maintained:

- Other soft cost improvements
- Equipment incremental cost improvement



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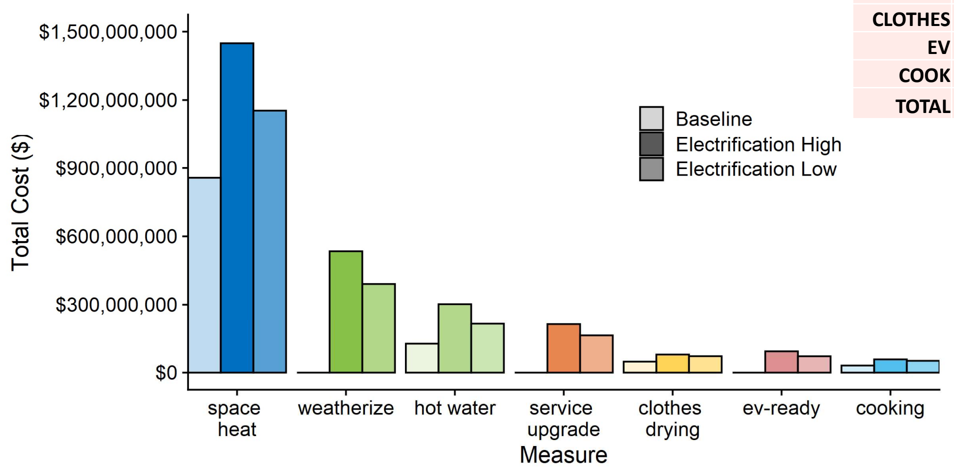
Updated Upfront Costs

	HIGH	LOW	BASE
HVAC	1449M	1154M	857M
WX	535M	391M	-
DHW	302M	215M	127M
PANEL	213M	164M	-
CLOTHES	79M	72M	48M
EV	94M	72M	-
COOK	58M	52M	31M
TOTAL	**2.73B**	**2.12B**	**1.06B**



Baseline – cost of gas equipment replacement at end of life
Elect high – workshop 1 scenario; full electrification no efficiencies
Elect low – workshop 3 scenario; full electrification with efficiencies

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Incremental Costs Questions and Discussion

Thumb vote (up, sideways, down):

Did we land on a reasonable model range for scaled electrification in 1-4 units in Mpls?

	HIGH	LOW	BASE
HVAC	1449M	1154M	857M
WX	535M	391M	-
DHW	302M	215M	127M
PANEL	213M	164M	-
CLOTHES	79M	72M	48M
EV	94M	72M	-
COOK	58M	52M	31M
TOTAL	**2.73B**	**2.12B**	**1.06B**

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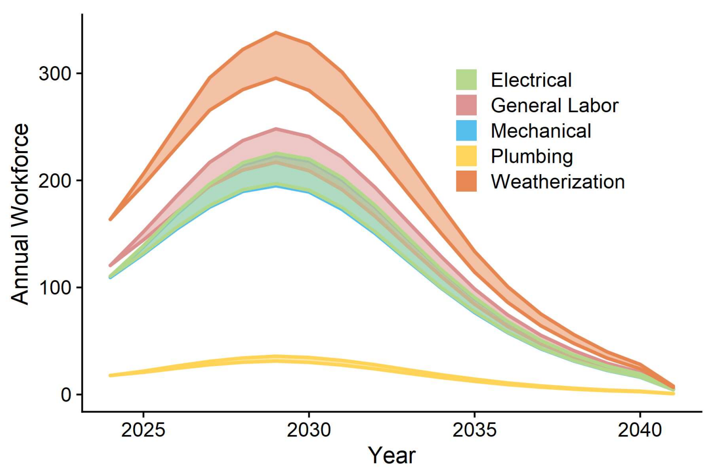
Labor requirements



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Labor Questions and Discussion

What comes to mind when you see the labor requirements?

Concerns?
Opportunities?
Actions for the City?

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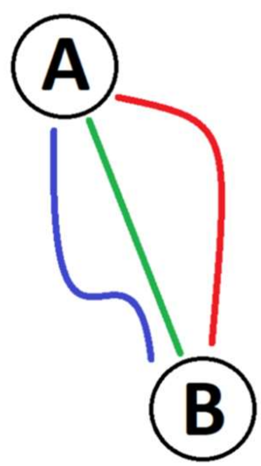
Decarbonization path matters

- Infinite pathways to reach decarbonized destination
- Path dependence means that the net emissions produced until full decarbonization depends on path taken
- Mpls emissions goal establishes aggressive path baseline (green)
- Sequencing is path alteration
  - Rate of project work (projects/yr)
  - Project outcomes (savings/project)

KJ1



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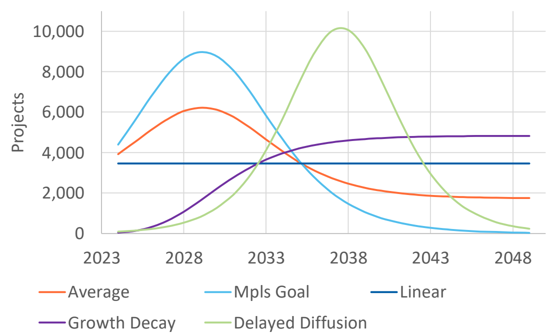
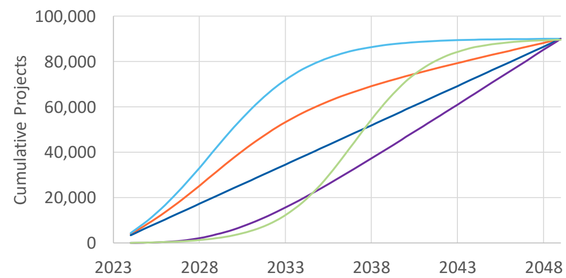
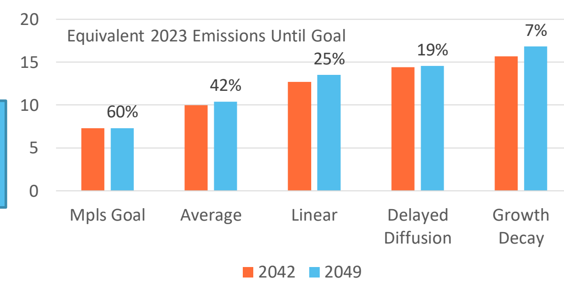
Decarbonization path matters





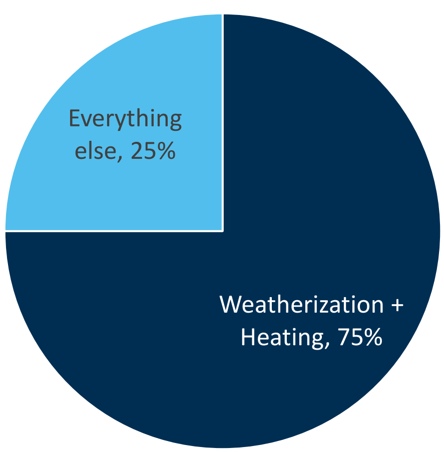


KJ0

Takeaway: operational $$ and emissions variables pull the path in opposite directions. How the City balances these will impact path.

Decarbonization Basics

1-4 Unit Decarbonization Potential



- Weatherization is the critical path
  - Provides large emissions savings regardless of equipment
  - Cost-effective savings
  - Necessary to unlock all-electric space heating for most homes
  - Largest workforce requirements
- Dual-fuel heat pumps buy time for weatherization & service upgrades
  - dfASHP operation optimized for emissions savings or financing additional work

A cost-neutral replace-on-fail (ROF) strategy

- AC/Furnace replace-on-fail with ccASHP dual-fuel system
  - Can be operated cost-neutral without dual fuel rate
  - Plan for Wx
    - Soon -> aggressively operate dfASHP (80%+)
    - Later -> modestly operate dfASHP (25-50%) KJ0
- Independent appliance RoF with electric technologies
- ~80% of decarb done by 2042
  - Lags Mpls' desired trajectory & intervening emissions are 1.5 to 2.5X goals
  - Among lowest-cost pathways
  - Minimum sensitivity to workforce limitations (exclusive to Wx trades)

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Sensitivities of RoF strategy

Risks

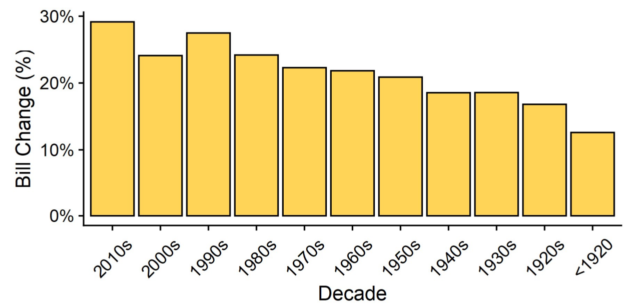
- Slow market shift: every conventional RoF is a lost opportunity and a delay
- Slow Wx ramp (e.g. workforce limitations)
- Dual fuel rate barriers
- Best Wx projects may have more pre weatherization costs (added health & safety items)

Opportunities

- Wx'ed, new homes (>1990), & inclined owners to leapfrog DF in favor of AE
- Integrate Wx w/ change of ownership, occupancy, or major renovation work and leapfrog DF in favor of AE
- Savings and impacts can be magnified by special DF or AE rates
- **Target worst buildings & couple with AE to provide deep savings**

Affect Critical Path: What are the opportunities?

- Buildings with low to zero wall and attic insulation
- Top 25% homes have nearly ***8X*** savings as bottom 25% homes
- Building age is best (only?) predictor
- Older buildings up to 2.5X less bill impacts as new buildings



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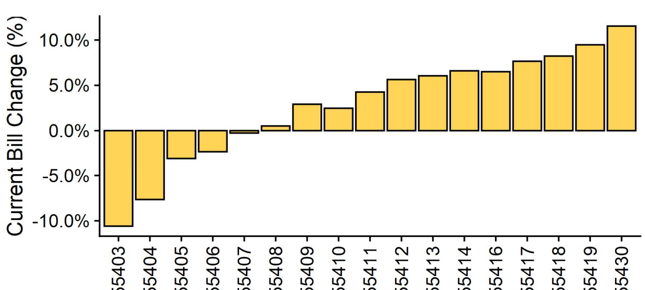
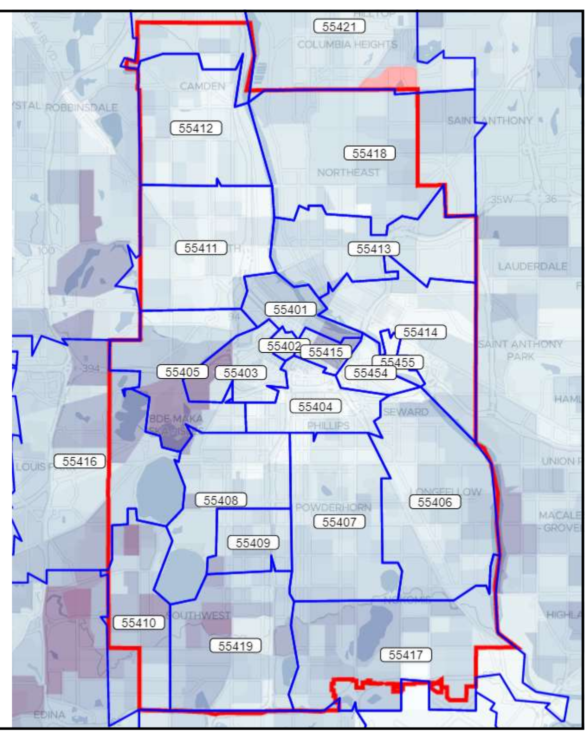
Where are the opportunities?

- Southside green zone (~55404)
- Northside green zone (~55411, 55412)



*Model assumes Wx + dual fuel heat



Southside Green Zone – high opportunity

Zip: 55404	~1.5% of the building stock 1388 buildings / 1591 units / 26% rental

- **Weatherization $9M**
  - $6,915/building, which is +22% compared to city average
  - ~2.1X median savings
  - Cost savings under both all electric and dual fuel operation at current rates
- Remaining **electrification costs of $34M**

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Northside Green Zone – average opportunity

Zip: 55411	~7.2% of the building stock 6400 buildings / 7469 units / 30% rental

- **Weatherization $38M**
  - City average weatherization costs
  - Slightly better than average Wx savings
  - All electric and dual fuel to see cost increases at today's rates
    - Dual fuel systems can be operated at 50% for cost savings
- Remaining **electrification costs of $160M**

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A RoF strategy

Aggressive acceleration of **all** RoF opportunities	Displace **all** conventional RoF as fast as possible Identify & target beyond life and near RoF opportunities
Prioritize Wx projects among top 25%	~2-3X impact per project Verification/audit confirmation required Sequencing can reduce early labor requirements
Heavy promotion of leapfrog efforts among bottom 25%	Forgo Wx entirely on bottom ~10%
Build a workforce to grow Wx capacity	
Remove DF rate barriers	Customer bearing DF rate swap costs is prohibitive

Sequencing Questions

Sequencing activity

With your table, your activity is to sequence the measures on the timeline.

- In what order would you sequence the measures?
- What would you leave out?
- What could happen concurrently?
- What have we missed (add to post-it)

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If there were to be a pilot…

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Benefits of a pilot

ESTABLISH CONTRACTOR SET THAT CAN DO THIS WORK

FIND AND WORK THROUGH UNIQUE COMPLEXITIES

FIND EFFICIENCIES AND LEARN LESSONS THAT MAKE SCALING EASIER

Among others…

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What would we want to learn from a pilot?

Discuss as a table.

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Implementation structure

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Options

- Pilot admin – hire a GC
- Pilot admin is the GC

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Activity: If there were to be a pilot program…

…that covers the full cost of and tests the weatherization and electrification a sample of buildings…

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You're helping to select pilot candidates.

We have funding for 5 buildings.

You have building characteristics/variables on sticky notes. Add any other characteristics to sticky notes as you see fit.

Build out a hypothetical set of pilot buildings using your variables.

Use only 1 variable per building.

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We found funding for 5 more buildings.

Would you apply remaining characteristics to test within that new set of 5 buildings?

Would you want more than one building with a specific characteristic?

Use as many sticky notes as needed to create your ideal mix of characteristics of the 10 pilot buildings.

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THANK YOU!

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