Appendix Y - Alternative Scenario from EEA Secretary's GHG Goals Letter

Executive Summary

On March 1st, 2024, Secretary Tepper published a letter identifying the greenhouse gas (GHG) emissions reduction requirements for the PAs in their 2025-2027 Three Year Energy Efficiency Plan. The letter calls for a reduction of one million metric tons of carbon dioxide equivalent (MMTCO2e) in 2030 from the measures installed in 2025-2027; the Program Administrators' (PAs) 2025-27 Energy Efficiency and Decarbonization Plan (EE Plan), referred to in this document as scenario 1, aligns with this goal.

The letter also directed the PAs to model a second scenario (referred to herein as scenario 2) that estimates the total cost to achieve 2.2 MMTCO2e reductions of GHG emissions.[1] The PAs approached this exercise as a two-step process; the PAs first calculated the total cost of the investments required to achieve 2.2 MMTCO2e, and then estimated how much of that cost would need to be covered through incentives, grants, or tax credits in order for customers to be willing to make those investments.

The PAs focused this exercise on two primary measures, heating system electrification and building envelope improvements (weatherization), as those are the core measures highlighted in the 2030 CECP for the Building Sector. In order to provide a holistic cost estimate, the PAs sought to enumerate the costs not just of the measures themselves, but also of any associated repairs or improvements that the building stock is expected to need. For example, prior to weatherizing a home, steps such as removing knob and tube wiring or mitigating asbestos may be needed (often referred to as "pre-weatherization barriers").

In developing this cost estimate, the PAs used multiple inputs; they leveraged the extensive data available from the existing Mass Save programs, they conducted a literature review of costs in other jurisdictions, and they looked at pilot efforts that are testing new approaches and technology. The PAs then used their expertise as program administrators to make certain assumptions about how costs would change if programs were tasked with a ~2.2X increase in scale. For example, the PAs believe it would not be possible to achieve that type of scale in residential weatherization by simply continuing to do the type of weatherization that the programs have been doing. The weatherization projects that customers have traditionally chosen to pursue generally include air sealing and insulation by minimally invasive means to achieve modest energy savsings at relatively low cost. For scenario 2, the PAs modeled a greater

[1] The PAs understand that this is a modeled scenario for informational purposes and is not a goal that the PAs are mandated to achieve.

proportion of more invasive, deep energy retrofit work that will achieve significantly higher savings, but at a higher cost per unit of energy savings.

Similarly, the PAs modeled an increasing prevalence of repair work for scenario 2, as it can be expected that significant expansion of the programs would require treating a greater proportion of older/more difficult building stock that is more likely to have barriers to weatherization.

After developing these robust per-unit cost and savings estimates for each measure, the PAs determined how many of each measure would be necessary to reach 2.2 MMTCO2e total. For the purposes of this exercise, the PAs did not make assumptions about the relative achievability of one measure category vs another, and instead scaled each by the same amount relative to the scenario 1 savings, while maintaining the ratio of savings between sectors as dictated by the Secretary's letter. This model showed that 395,647 residential buildings would need to be weatherized, 268,466 residential buildings would need to be electrified, and approximately 70M square feet of C&I building space will likely need to be electrified, in order to achieve the scenario 2 GHG emission reduction target.

The result of this exercise is an estimate that the overall total cost to achieve 2.2 MMTCO2e is approximately $16.3B.[2] This is the total cost of the measures and associated repairs, regardless of funding sources, and represents a 2.8x increase from the total costs for scenario 1. Costs have scaled at a higher rate than savings due to the expected increase in complexity of jobs and necessary barrier repair, as noted earlier.[3] The PAs note, however, that while they have produced a robust analysis that utilized the best available data, scaling the programs so substantially would require expansion into areas that are still emerging in the marketplace and carry a high level of uncertainty.

One particular area of uncertainty is the costs to electrify commercial and industrial (C&I) buildings. To date, there have been very few examples of actual C&I building electrification projects, in Massachusetts or in other jurisdictions. To estimate the costs to electrify C&I buildings, the PAs relied on technical assessment (TA) studies conducted in the last few years, a literature scan of costs to electrify C&I buildings from across the country, and conversations with engineering firms. This resulted in estimates ranging from $19/sq ft to $95/sq ft, depending on the building type and its existing heating system configuration. A similarly uncertain area is large multifamily electrification; for this, the PAs have modeled a "best case" scenario of window heat pumps, which are substantially less expensive and less disruptive than installation

---

[2] This does not include inflation.
[3] The PAs did apply economies of scale where appropriate, and have modeled administration costs increasing only 1.5x from scenario 1 to scenario 2.

of new central heating and cooling systems, but which are not yet commercialized and have only been installed in a handful of pilot projects.

There are also categories of costs that the PAs were unable to estimate with certainty at this time, such as residential pre-electrification costs. The PAs know that some homes will need to upgrade their electric systems, for example, but do not have enough data to estimate what percent of all homes will need that. The PAs were also unable to estimate the costs for housing stock that may need deeper repairs, such as new roofs, new siding, structural work, etc.

Taking this all together, the PAs believe the estimate of $16.3B is a conservative estimate and that actual costs could well be 30-50% higher.

Estimating the necessary level of customer incentives is even more uncertain, as no jurisdiction has ever attempted to achieve adoption of these measures at this pace. However, the PAs used their best judgement based on past programmatic experience to assume the following:

- 100% of costs must be covered for Low- and Moderate-Income customers for all measures.
- 100% of weatherization and pre-weatherization barrier costs must be covered for all customers.
- 90% of electrification costs must be covered for non-LMI customers.

The result of this exercise was an estimate that the total program costs for scenario 2 (where "program" may include incentives offered through the Mass Save program, federal tax credits, financing programs, or other grants) would be $14B, or 84% of the total project costs. The PAs note that again this is likely a conservative estimate, as it does not account for things like the need to address heat pump operating costs for customers who are currently utilizing gas. Absent a mechanism to address that key economic concern, customers' willingness to adopt heat pumps, even at a steep discount, is likely to be substantially impacted.

Contents

List of Figures

Introduction

The Massachusetts natural gas and electric utilities, Berkshire Gas, Eversource, Liberty, National Grid, and Unitil, along with the Cape Light Company operating as a municipal aggregator, jointly administer the Mass Save program. These administrators are known as the Program Administrators (PAs). Mass Save is the Commonwealth's energy efficiency program and empowers residents, businesses, and communities to make energy efficient and electrification upgrades by offering a wide range of services, rebates, incentives, trainings, and information.[4] As part of Mass Save, the PAs are working to grow the Commonwealth's energy efficiency workforce and promote equity. The PAs are committed to training new and diverse workers, increasing coordination with high schools and community colleges to educate students about careers in energy efficiency, and upskilling contractors and existing workers.[5] The PAs are promoting equity by offering enhanced incentives to income eligible households providing grants to municipalities and community based organizations that serve underserved, environmental justice communities, and addressing customer language barriers by creating and implementing a language access plan.[6]

An Act Creating a Next Generation Roadmap For Massachusetts Climate Policy ("2021 Climate Act") requires the PAs to construct three-year plans to meet or exceed the greenhouse gas (GHG) goal set by the Energy and Environmental Affairs (EEA) Secretary.[7] On March 1st, 2024, EEA Secretary Tepper released a letter setting the GHG emissions reduction requirements for the PAs in their 2025-2027 Three Year Energy Efficiency Plan. A draft of this plan was submitted on April 1st, 2024 (scenario 1). In addition to the statutorily mandated goal of 1 million tons of GHG emissions reductions over the term of the 2025-2027 three-year plan, Secretary Tepper also directed the PAs to model a second scenario for informational purposes. As with each Three-Year Energy Efficiency Plan, the PAs closely collaborated on the scenario 2 analysis. This report describes the results of the scenario 2 analysis and how the PAs reached these conclusions. In addition, the model was also made available to the EEA.

This analysis examines the total cost of achieving 2.2 MMTCO2e reduced. Although the PAs modeled higher incentive levels that could be offered through the Mass Save program to help customers better afford weatherization and electrification. However, the PAs were not focused on costs to customers after all possible incentives have been utilized. The PAs did not include the

---

[4] https://www.masssave.com/en/about-us
[5] https://www.masssave.com/en/about-us/workforce-development
[6] https://www.masssave.com/en/about-us/equity
[7] G.L. c. 25, § 21(d)(4).

impacts of other sources of funding, such as Federal IRA funds, funds from the Climate Bank, and other sources of funding.

The PAs have modeled the costs of achieving 2.2 MMTCO2e emissions reduction by 2030, using the same relative sector allocations as the draft plan and increasing the ratio of equity/market rate investment compared to the draft plan submitted on April 1st.

The scenario 2 analysis focuses on residential and commercial and industrial (C&I) electrification of space heating and weatherization, as well as other energy efficiency (EE) measures for C&I buildings that can be scaled. All other residential energy efficiency measures, including heat pump water heaters, electric stoves, and dryers, and other measures have been held constant from the scenario 1 analysis as the PAs focused on the most impactful measures.

The Massachusetts Clean Energy and Climate Plan (CECP) for 2025 and 2030 established building sector decarbonization reduction sublimit for 2025 and 2030. For 2025, the building sector has a sublimit of 17.2MMTCO2e, which is a 28% reduction from 1990. For 2030, the building sector has a sublimit of 12.5MMTCO2e, which is a 47% reduction from 1990.[8] The building sublimit includes building emissions from both residential and commercial buildings (excludes industrial buildings). While both the 2025-2027 Energy Efficiency Plan and scenario 2 would be essential to help achieve the building sector sublimit, there are significant barriers to achieving scenario 2 and it is only for information purposes.

Model Description

The scenario 2 analysis represents the PAs' modeling effort of the likely range of costs and number of buildings that may need to be weatherized and electrified in order to achieve 2.2 MMTCO2e of emissions reductions by 2030. There are significant and real barriers to achieving the 2.2 MMTCO2e of emissions reductions by 2030, which include workforce limitations and supply chain constraints. This analysis was done independent of any analysis of the feasibility of achieving these levels of customer adoption of modeled measures which could result in a significantly higher cost of customer adoption.

Figure 1 shows the GHG emissions reduction targets by sector for each scenario as well as the percentage increase in GHG emission reductions by sector between scenario 1 and 2. The PAs modeled a 150% increase in GHG emissions reductions from heat pump installations and weatherization in residential households;, and a 201% increase in GHG emissions reductions

[8] Massachusetts Clean Energy and Climate Plan for 2025 and 2030, pg. 51. https://www.mass.gov/info-details/massachusetts-clean-energy-and-climate-plan-for-2025-and-2030

from installing heat pumps, weatherizing, and scaling EE measures in C&I buildings; while keeping GHG emissions reductions from all other plans consistent with scenario 1. Non-scalable "Other EE" measures have been held at the same savings, costs, and incentives as the April 1st draft plan.

Other C&I energy efficiency measures were grouped into scalable and non-scalable. C&I other EE (scalable) are measures that are may be realistic to increase adoption rates compared to scenario 1 to help achieve the scenario 2 GHG emission reduction target. These measures include customer HVAC equipment, custom building shell, customer heat recovery, and custom water heating, among other measures. C&I other EE (non-scalable) are measures that may not be realistic to increase adoption rates compared to scenario 1 to help achieve the scenario 2 GHG emission reduction goal. These measures include standards adoption, refrigeration, customer lighting systems, induction cooktops, among other measures.

Figure 1: GHG Emissions by Sector:

Cost Category	Scenario 1 GHG	Scenario 2 GHG	% Increase GHG
Res+LI Heat Pumps	415,347	1,039,308	150%
Res+LI HP Barriers			
Res+LI Wxn	184,035	460,505	150%
Res+LI Wxn Barriers			
Res+LI other EE	200,044	200,044	0%
C&I Heat Pumps	76,753	231,341	201%
C&I Wxn	11,000	33,156	201%
C&I other EE (Scalable)	43,785	131,973	201%
C&I other EE (Non Scalable	103,674	103,674	0%
Heat Loan			
Admin			
Total	**1,034,639**	**2,200,000**	**113%**

The heat pump and weatherization adoption rates were separate exercises. The PAs assume that 395,648 homes are weatherized, and 268,465 homes are electrified.

The building types are broken into single family homes, 2-4 units, 5-19 units, and 20+ units. The PAs categorized single family homes into four different age groups: pre-1940 (379,454 homes);

1940-1969 (499,463 homes); 1970-1999 (493,561 homes), and 2000-present (193,149 homes). The PAs categorized multifamily buildings into three different age groups: pre-1970 (691,780 units); 1970-1999 (311,026 units); and 2000-present (150,194 units). The PAs used different age groups for single family and multifamily buildings as there are very few pre-1940 multifamily buildings in the Commonwealth. These buildings are further categorized by fuel type (electricity (electric resistance heating), delivered fuels (propane and heating oil), and utility gas (natural gas)), and income of building occupant (0-60% state median income (SMI), 60-80% SMI, and 80+% SMI). DNV provided this data upon request from the PAs.

In the “Res” tab, the median heat pump cost populates the central heat pump (CHP) and mini-split heat pump (MSHP) cost columns, using the assigned percentage of heat pump installations that are full or partial. Using these two columns, the average heat pump cost-per-unit is calculated using an assigned percentage of CHPs or MSHPs installed. The weatherization cost is linked to the “Res Wxn&Barriers” tab and paired with the proper bin (each row). GHG savings estimations have been matched to the model’s housing bins based on their description in the 2025-2027 benefit cost (BC) model.

To estimate the cost of reaching the residential GHG goal, each bin has a “% Implemented” column for heat pump installations and weatherization installations, which can be independent of one another. This produces units that receive heat pump installations and units that are weatherized, which is then multiplied by the cost and GHG savings for each bin. The bins are then all added together in the “Res Summary” tab, broken down by income levels.

To reach the scenario 2 target and maintain equity, the PAs calculated ratios of low income, moderate income, and market rate installations for both heat pump and weatherization measures. The “% Implemented” values were adjusted until the income level ratios matched that of scenario 1. Figure 2 shows that the number of residential units that the PAs assume would be electrified and weatherized by income level.

Figure 2: Residential Units Electrified and Weatherized by Income Level

Median Income	Housing Units with Heat Pumps Installed	Housing Units Weatherized
0-60 SMI	56,518	131,590
60-80 SMI	15,942	39,650
80+ SMI	196,006	224,407
Total	268,466	395,647

The PAs scaled the administration costs, which includes all non-incentives costs, including administration and marketing costs, by 50% from scenario 1 to scenario 2. These costs were scaled by 50% rather than 120% as administering the program could be more efficient the larger the program becomes.

Residential Methodology

To model the range of scenario 2's costs, the PAs first developed GHG targets to maintain a similar proportion of GHG reductions from each sector as the April 1st draft plan. The PAs maintained a similar ratio of residential and C&I GHG savings to scenario 1. The PAs are focusing more on equity and weatherizing and electrifying homes in the scenario 2 modeling than scenario 1. As seen in Figure 3, of the total heat pumps proposed to be installed in scenario 1, 5.56% would be installed in low-income (income is 0-60% of SMI) occupied housing. In scenario 2, the PAs assume that 18.23% of the total heat pump tonnage is installed in low-income occupied housing (Figure 3).

Figure 3: Percentage of residential heat pump tonnage installed by income level

	Low Income (0-60% SMI)	Moderate Income (60-80% SMI)	Market Rate (80+% SMI)
Scenario 1	5.56%	4.48%	89.96%
Scenario 2	18.23%	5.68%	76.09%

As seen in Figure 4, the PAs proposed that 17.37% of the homes to be weatherized in scenario 1 will be occupied by low-income residents. In scenario 2, the PAs model 34.48% of the homes to be weatherized will be low income occupied (Figure 4).

Figure 4: Percentage of homes weatherized by income level

	Low Income (0-60% SMI)	Moderate Income (60-80% SMI)	Market Rate (80+% SMI)
Scenario 1	17.37%	7.84%	74.79%
Scenario 2	34.48%	34.48%	31.03%

To reach the residential target of 1,699,857 MTCO2e reduced, with an as accurate as possible estimate of these costs, the PAs developed bins for the state's housing stock. Using data from an analysis firm, DNV, the housing stock was split by building units, building age, current heating fuel, and median income of the occupants.[9] This results in 108 different combinations with unit counts assigned to each bin. From there the PAs utilized six sources on the cost of electrification and weatherization (residential only) for each bin. Each source had a different scope and level of

---

[9] Massachusetts energy data can be explored in the MA Customer Profile Dashboard, which DNV manages. This dashboard houses 10 years of the PAs' residential and C&I billing and tracking data, as well as third party data, including data from the US Census American Community Survey, Level 3 tax data, and Enhanced 911 data.

detail, so some bins either will not have costs from a source, or a similar cost to another bin. For example, NMR Group's analysis only has a cost per ton for the heat pump technologies, so the same cost was used regardless of income level, building age, or fuel it is displacing. The five utilized sources are:

- Historical cost data on Boston Housing Authority buildings. Some of this data was included in a Boston Housing Authority presentation that ARUP prepared in February 2024.[10]
- The PAs rebate processing vendor, Resource Innovations. They provided electrification data for the second half of 2023.
- NMR Group. MassCEC Heat Pump Invoice Analysis from NMR group provided to the PAs and EEAC. This analysis was released in November 2023.
- Historical data from PA tracking systems. The PAs use this tracking system for all MA electrification and weatherization projects. The costs from this system are real estimates that vendors have uploaded.
- Cost data from benefit cost (BC) model total resource cost (TRC), which was submitted in the April 1st draft plan.
    - Used GHG savings column in the BC Model for GHG savings in this analysis.

These sources all include data that is from completed electrification and weatherization projects rather than high level modeling that is used to generate cost estimates in most studies.

For heat pumps, the PAs retrieved data from the 6 heat pump sources (above) and matched the reported costs with the housing bins in the model (found in the "Res HP" tab). The PAs show the median of these sources to eliminate the most extreme cost estimates whether low or high. Low end and high-end cost estimates are also available through a dropdown selection in the "Res Summary" tab.

Figure 5: Heat Pump Tonnage by Average Square Footage of Unit

10 https://www.bostonhousing.org/BHA/media/Documents/Departments/Procurement/BHA_Arup_final_decarb_report.pdf

Building Type	Displacement	Square Foot Assumption	Tonnage/Unit
1 unit	Full	2,107	4.00
2 - 4 units	Full	1,724	3.27
5 - 19 units	Full	1,043	1.98
20+ Units	Full	1,043	1.98
1 unit	Partial	2,107	4.00
2 - 4 units	Partial	1,724	3.27
5 - 19 units	Partial	1,043	1.98
20+ Units	Partial	1,043	1.98

As seen in Figure 5, the PAs approximated heat pump tonnage based on the average square footage of the unit. Single family homes, which are estimated to be larger than units in multifamily buildings, are estimated to install a larger heat pump than units in multifamily buildings. There is no differentiation between heat pump tonnage associated with full and partial displacement as the PAs modeled that the customer would install a heat pump at full capacity even if the customer chooses to retain a backup (previous) fuel source. At the time of failure of the previous fuel source, the customers heat pump is expected to be larger enough to serve the full home, which ensures that the customer will not need to upgrade their heat pump.

Electrification assumptions:

- For single family homes, it is assumed that 100% of customers that live in buildings built before1940 buildings will install a minisplit heat pump; that 25% customers that live in buildings built between 1940-1969 will install a minisplit heat pump system and 75% will install a central heat pump system; 75% of customers that live in buildings built from 1970-2000 will install central heat pumps and 25% will install a minisplit heat pump system; and that 100% of customers that live in buildings built since 2000 will install a central heat pump system.
- For all multi-family buildings, it is assumed that only minisplit heat pumps are installed.
- Electric resistance heating will be fully replaced by ASHPs.

Single Family Weatherization

The residential weatherization costs are broken down in three categories that conjoined provide the quantifiable cost to weatherize a household. There may be additional costs that aren't quantifiable. These are addressed in the "Not Included in This Analysis" section. Each cost segment is provided by unit and adjusted by unit size, type of fuel, and building age.

The three categories of weatherization costs[11] are:

- Weatherization costs. These costs are directly related to the weatherization process; building insulation, air sealing and duct sealing are among some of weatherization measures that are included in the weatherization process.
- Traditional barriers. These costs are related to the repair and remediation of the household in order to successfully complete the weatherization process. i.e. knob and tube wiring replacement
- Maintenance barriers. These are additional barriers tied to health, safety or structural concerns, that prevent weatherization upgrades and must be resolved in order to complete the process. i.e. roof or structural replacements

In the model, traditional and maintenance barriers for each housing bin are presented as an average (Columns F & G in the "Res Wxn&Barriers" tab of the model). These averages include homes that may not have any barriers to weatherization, which lowers the average. Therefore, the actual cost to mitigate barriers to weatherization may be higher than the average costs presented in the model.

For single family homes, traditional and maintenance barriers have been combined in the traditional barrier column in the model ("Res Wxn&Barriers" tab), as it was not possible to sperate the barrier data into these two groups.

The GHG savings for weatherization were taken from the 2025-2027 draft plan BC model.

<u>Multifamily Weatherization</u>

Achieving the scenario 2 GHG emission reduction target requires the retrofit of multifamily buildings through traditional and non-traditional retrofits. Traditional retrofits are air sealing and insulation by minimally invasive means at relatively low cost, which customers have been choosing to do for years. Non-traditional retrofits are more expensive, highly invasive, deep energy retrofit or gut renovation work that achieves more GHG savings than traditional retrofits but at a higher cost. Due to the higher cost, participants have not been choosing to move forward with these non-traditional retrofits. In order to achieve the scenario 2 GHG emission reduction target, customers would need to select non-traditional retrofits as there are limited opportunities for only traditional retrofits.

The PAs analyzed real decarbonization project plans of three types of multifamily building stock within Boston Housing Authority's portfolio. The three types of building stock correlate to the three different size multifamily buildings in the MA Building Decarbonization Report (2-4 units;

---

[11] More detail on single family weatherization costs and what was included for weatherization barriers (LMI and market rate customers) can be found in the "Wxn SF Barriers Assumptions" tab in the model.

5-19 unit; 20+ unit). Figure 6 shows the costs of traditional and non-traditional weatherization approaches analyzed for each building type.

Figure 6: Weatherization Costs in Multifamily Buildings ($/unit)

	Weatherization Measure	**2-4 units multifamily building**	**5-19 unit multifamily building**	**20+unit multifamily building**
Traditional				
	Air Sealing	$470	$269	$269
	Insulation	$1,535	$682	$341
Non-traditional				
	Air sealing	$5,134	$1,286	$338
	Exterior Walls	$18,968	$14,173	$14,635
	Attic/roof	$16,181	$4,005	$1,213
	Fenestration	$11,293	$29,279	$9,588

Weatherization Assumptions:

- 80% of GHG emissions savings from small multifamily buildings (2-4 units) are attributed to traditional retrofit measures and 20% are attributed to non-traditional retrofit measures.
- 50% of GHG emission savings from mid-rise multifamily buildings (5-19 units) are attributed to traditional retrofit measures and 50% are attributed to non-traditional retrofit measures.
- 20% of GHG emission savings from large multifamily buildings (20+ units) are attributed to traditional retrofit measures and 80% are attributed to non-traditional retrofit measures.

Commercial and Industrial Methodology

The PAs interviewed 6 mechanical design professionals from across the country to ask about the cost per square foot and potential challenges to decarbonize the different building types included in the Building Sector Decarbonization Report and compared the results of these discussions to the modeled cost and emissions impact projections by sector. These discussions are summarized in Appendix 1.

In order to reach the target of 231,341 MTCO2e reduced, approximately 1,600 C&I buildings or 70,000,000 square feet of C&I square footage in Massachusetts will need to be electrified, which is 5% of the total C&I square footage in Massachusetts. This may cost between $1.8B and $6B. There is high uncertainty regarding these costs as there has been very little electrification of C&I buildings across the country. These costs are based on the PAs technical analysis studies, electrification costs of reports, studies that model the costs of electrification in C&I buildings, and conversations with mechanical design professionals.

For the C&I sector, many building types are difficult to electrify due to technical challenges, and costs are highly variable depending on building vintage, existing mechanical equipment type, and electric infrastructure capacity/condition This analysis has focused on the building types where the technical opportunities and higher adoption rates may exist in the short term, such as smaller office buildings, municipal offices, and schools.

State of Electrification in Large C&I Space (Retrofit)

The PAs have assisted customers in Massachusetts interested in electrification by offering electrification scoping studies.[12] Since 2022 nineteen of these assessments have been completed for customers pursuing full electrification. In 2023, one small office was fully electrified. An additional eight facilities have had scoping level costs developed for hybrid systems as an option, and a single library had a hybrid system constructed, however for purposes of this study, these costs have been excluded, as they do not represent full electrification.

Implementation of fully electrified HVAC retrofits in the C&I space both in Massachusetts and nationwide has very limited adoption to date. In Massachusetts, C&I customers are at very preliminary stages of exploring electrification with scoping assessments and master planning studies. Interest has primarily been in the municipal (schools and municipal offices) and higher education sectors which have clearly defined sustainability goals and a willingness to implement this technology despite potential higher operational cost. It is worth noting that within the municipal sector, higher interest has been shown by towns in electrifying older buildings (50-100 years old) within their portfolio that have HVAC systems near the end of their useful life. These sites are less compatible with electrified HVAC equipment; therefore, the cost of implementation is higher for these facilities. For example, aging facilities may require significant updates to their electrical infrastructure to support this equipment, whereas newer buildings with a town's portfolio may not require this. It may be more cost effective to replace some of these older buildings with newer, all electric buildings than electrifying them.

The for-profit sector has been slower to begin preliminary studies and implementation, however local ordinances such as BERDO (Building Emissions Reduction and Disclosure) in Boston and

---

[12] Studies include a site walkthrough, preparation of potential electrification options, as well as high level opinion of probable cost and energy impact estimates for each electrification option studied. Additionally, the studies include a preliminary analysis of the existing electric infrastructure and offer an opinion as to whether it can support fully electrified HVAC. Detailed system design, equipment sizing, energy modelling, and cost estimation is not included.

BEUDO (Building Energy Use Disclosure Ordinance) in Cambridge both establish emissions limits for facilities and are beginning to drive interest in these sectors. Customer goals are generally more long term (2030 and beyond) therefore resulting in an implementation approach aligned with the customer's capital improvement plans. Interest has been higher in replacing equipment approaching its end of useful life ("replace on burnout"), as opposed to full system replacement for the entirety of a given facility. Customers have concerns with potential increased maintenance costs associated with electrified HVAC performance concerns, resiliency, backup generation requirements, and shorter equipment lifetimes associated with heat pump equipment versus conventional HVAC equipment. It is noted in the C&I Methodology section and bears repeating that sectors such as laboratories and hospitals have very limited engagement for full electrification due in part to being difficult to electrify facility types due to their highly ventilation driven heating loads relative to other segment types, however partial electrification is being explored.

<u>Cost Range Discussion</u>

Given the lack of widespread implementation in the C&I retrofit space in both Massachusetts and nationwide, cost range data compiled for this report is highly uncertain and limited to scoping level cost data based on high level opinions of probable cost. The opinions of probable cost for each project are estimated by the technical assistance (TA) vendor performing the scoping study using engineering best practices. Cost data for implemented projects is very limited and biased toward projects with more favorable economics, simpler existing HVAC system types/configurations, and lower initial costs. Existing conditions are highly variable and therefore the costs to fully electrify are wide ranging. There is a wide range in price depending on whether full electrification requires <u>equipment replacement</u> versus <u>full HVAC system replacement</u>. Costs to fully electrify a given facility range from $20-$95/square foot based on the data set analyzed. It is worth noting that partial electrification does not imply lower first cost than full electrification of a given facility. The driving factor for the range in cost is a function of the existing building conditions, existing HVAC system complexity, and overall building compatibility/incompatibility with electrified HVAC equipment currently available on the commercial market.

A full system replacement would not only include replacement of the existing equipment (example: boiler, chiller, rooftop unit (RTU)), but replacement of existing distribution system (hydronic piping, ductwork) and terminal units. More complex existing systems, or existing systems in poor condition requiring full system replacement are at the higher end of the price range estimated in this report. This is most likely what will be seen in the market as a whole once studies have been performed across different segments, given the variability in building conditions.

For example, a small office facility installed variable refrigerant flow (VRF) equipment to fully replace an existing failing oil-fired hydronic boiler system. The cost of implementation was $20/square foot, however there were no updates required to the existing electrical infrastructure, nor were updates made to the ventilation system to add airside heat recovery. Given the more favorable project economics, the project progressed to implementation.

In another example, a municipal library installed a hybrid air to water heat pump (AWHP) system with a full implementation cost of $27/square foot, however this system is not capable of fully displacing the gas heating load for the site and relies on the existing gas boiler to heat the facility at low ambient outdoor temperatures. The primary driver to install the AWHP was to replace a failed air-cooled chiller and reduce the building emissions using the new system in a hybrid manner. No ventilation system, distribution, or electric infrastructure upgrades were performed. In order to fully electrify, additional AWHP modules would be required, as well as complete replacement of the existing hydronic infrastructure and terminal units (for compatibility with low temperature heating hot water), which would add significantly to cost.

Given the nature of these studies, the cost range presented is likely to be higher once a given project progresses to the design phase due to a number of site-specific variables. This is consistent with the feedback provided by Mechanical, Electrical, Plumbing (MEP) Design Professionals to the PAs. It is worth noting that costs for the case studies in the US DOE paper *"Guidance Document on Space Heating Electrification for Large Commercial Buildings with Boilers"*[13], costs ranged from $17-$200/square foot, with said costs highly dependent on existing conditions and challenges present. Costs at the lower end of the range are not representative of segments as whole. This is discussed further in the "Challenges" section, in terms of how these items may impact first cost, and these challenges are consistent with the findings contained within the US DOE paper.

Assumptions:

- Cost includes customer first cost of implementation only. Full life cycle costing and operation and maintenance (O&M) cost impacts excluded from analysis. While not included in this analysis, the potentially higher O&M costs associated with electrified

[13] Goetzler, William, Jim Young, Mark Butrico, Ryan Murphy. *Guidance Document on Space Heating Electrification for Large Commercial Building with Boilers.* US Department of Energy, 2024. https://www.energy.gov/sites/default/files/2024-04/Large%20Building%20Boiler%20Electrification%20Guidance.pdf

HVAC will impact the potential achievability of the scenario 2 GHG emissions reduction target in this timeframe.

- 231,341 MTCO2e reduced total goal for Large C&I for electrification (ELX).
- Cost range and emissions impacts developed from analysis of nineteen scoping level electrification level feasibility assessments, performed in School, Small Office, and Medium Office segments, as well as costs/emissions impacts from one project constructed in the Small Office sector.
- Scoping level assessments do not include detailed cost estimation or energy modeling.
- Modeled emissions impacts account for full electrification of HVAC systems only. Other building systems such as cooking, domestic hot water, and process equipment are excluded from this analysis.
- Total segment area derived from Figure 8, *Buildings Sector Report: A Technical Report of the Massachusetts 2050 Decarbonization Roadmap Study*.[14]
- Implementation rates for each respective sector assumed based on customer interest to date and relative suitability to fully electrify each respective sector. Assumes zero adoption of full electrification in laboratories and hospitals, which are difficult to electrify relative to other sectors. It is worth noting that there has been some interest in partial electrification within the hospital and laboratory sectors as evidenced by a single PA supported scoping study as well as customer engagement with design professionals performing master planning decarbonization roadmaps for hospitals and labs.
- 2030 emissions factors used to evaluate emissions impact of each project and derive emissions impacts on a per square foot basis for each segment.
- Emissions impacts are based upon scoping level estimates assuming the heat pump equipment performs at its rated efficiency/COP. In application, system COP may be lower than rated COP due to a myriad of design factors, therefore adversely impacting the decarbonization potential of a given project.
- Only full electrification costs were considered; partial electrification was not part of this analysis. Full electrification includes both multiphase and non-phased full electrification projects for schools. Multiphase full electrification costs included for schools due to construction scheduling requirements. Costs for partial electrification of a given facility type, and costs of hybrid equipment excluded from analysis, which is consistent with the *Massachusetts 2050 Decarbonization Roadma*p.
- Costs of geothermal projects excluded from analysis, which is consistent with energy conservation measure (ECM) 2 definition. ECM #2 consists of electrifying space and

[14] Buildings Sector Report, A Technical Report of the Massachusetts 2050 Decarbonization Roadmap Study. December 2020, pg. 26. https://www.mass.gov/doc/buildings-sector-technical-report/download

water heating and the replacement of other gas appliances, such as a stove or electric dryer, with electric alternatives and improved roof and wall insulation and improved airtightness.[15]

- Cost data for processed C&I prescriptive heat pump applications excluded from analysis due to uncertainty in data with respect to whether the project costs and affected area on processed applications represent the full cost of electrification as well as the entire area for a given facility.
- Analysis does not account for escalation of equipment and labor costs.
- For sectors in which there is no data for constructed costs nor scoping-level costs, cost range and emissions impacts from School sector were applied; to date, this is the most extensively studied sector with most favorable decarbonization potential on a per square foot basis of segments studied.
- Due to the high variability in electrification costs for C&I facilities, costs are expressed as a range. Costs are highly contingent upon existing conditions. See below for further detail.

Challenges:

Variables which can contribute to elevated first cost of implementation, incompatibility with fully electrified HVAC equipment include but are not limited to:

- Inadequate electrical infrastructure/service on site
- Inadequate mechanical ventilation
- Absence of airside heat recovery, in particular for schools with unit ventilators
- Lack of available space for new mechanical equipment and distribution (ductwork and hydronic piping)
- Existing hydronic infrastructure designed for high temperature heating hot water (HHW), and limitations of temperature output of commercially available heat pump equipment.
- Significant disruption to occupants and disturbances of finished surfaces, requirements for relocation of staff during construction.
- Structural upgrades to support weight of new equipment.
- Presence of hazardous materials such as lead and asbestos.
- Limited windows of time for construction (schools, laboratories).

[15] Buildings Sector Report, A Technical Report of the Massachusetts 2050 Decarbonization Roadmap Study. December 2020. Pg. 43. https://www.mass.gov/doc/buildings-sector-technical-report/download

- Significant building envelope deficiencies which must be addressed due to the lower temperature output of heat pump equipment relative to fossil fuel fired equipment.
- Refrigerant changes which will necessitate additional leak detection/monitoring equipment for VRF systems.
- Distribution systems well beyond useful life, which require replacement (example, corroded hydronic mains).

Model Results

As mentioned in the Executive Summary it may cost approximately $16.3B in total costs to achieve the scenario 2 emission reduction target of 2.2 MMTCO2e. These costs are a "best guess" of the total costs, including costs for incentives, costs for participants after any incentives, and costs for program administration and heat loans. The possible range of total project costs is approximately $14.6B to $18.8B.

Commercial and Industrial Results

Figure 7 shows the minimum and maximum range of costs per square foot to decarbonize each C&I building type as well as the percentage of the total statewide square footage that will likely need to be electrified in order to achieve the C&I GHG emissions reduction of 231,341 MTCO2e. For example, the PAs found that it could cost $21-$95 per sq ft to electrify a school and that 12% of the 186,000,000 square feet of schools in Massachusetts will likely need to electrify to reduce 83,403 MTCO2e, which is 36% of the goal of avoiding 231,341 MTCO2e from the C&I sector. After speaking with various mechanical design professionals, the PAs determined that it is likely that the electrification costs are closer to the higher range.

Figure 7: Decarbonization of the Commercial and Industrial Sector

Building Type	Min Cost/sf	Max Cost/sf	Total Segment Area Statewide (sq ft)	Percent Implementable by sector	Annual Emissions Impact (tons CO2e)	Percent total goal
School (k-12)	$21	$95	186,000,000	12.00%	83,403	36.05%
Small/Medium Office	$19	$75	170,000,000	20.82%	100,175	43.30%
Supermarket	$22	$22	10,000,000	3.00%	1,347	0.58%
Large Office	$21	$95	450,000,000	2.00%	33,630	14.54%
Warehouse	$21	$95	195,000,000	0.50%	3,643	1.57%
Retail	$19	$75	250,000,000	0.50%	3,537	1.53%
Convention/Assembly	$21	$95	80,000,000	1.00%	2,989	1.29%
Hospital	$21	$95	25,000,000	0.00%	-	0.00%
Laboratory	$21	$95	50,000,000	0.00%	-	0.00%
Hotel	$21	$95	50,000,000	1.00%	1,868	0.81%
Restaurant	$21	$95	20,000,000	1.00%	747	0.32%
				TOTAL	**231,341**	**100.00%**

Residential Results

The PAs are moderately certain of the residential heat pump costs as they are based on actual projects and are mostly similar to costs from electrification projects in California. TECH Clean California, which is an initiative to accelerate the adoption of clean space and water heating across California, has published data on heat pump installations in single family and multifamily buildings.[16] Figure 8 compares TECH Clean California electrification costs to the electrification costs in this analysis. The PAs only used single family data from TECH Clean California in this analysis as the sample size for multifamily buildings was not large enough to gather useful information across the building types that the PAs examined.

Although the scenario 2 electrification costs and TECH Clean California electrification costs are relatively similar, it is important to note that there are differences in climate between Massachusetts and California and that California has a younger building stock than Massachusetts and potentially fewer barriers to weatherization and electrification. These barriers may also exist in fewer buildings in California than Massachusetts.

Figure 8: Comparison of Scenario 2 Single Family Electrification Costs and Single Family Electrification Costs in California

Fuel Type	Heat Pump Type	Scenario 2 Electrification Costs	TECH Clean California Electrification Costs
Delivered Fuels	Central	$19,402	$17,802
Natural Gas	Central	$18,293	$17,443
Electric Resistance Heatin	Central	$30,712	$14,979
Delivered Fuels	Minisplit	$17,692	$18,740
Natural Gas	Minisplit	$17,301	$20,685
Electric Resistance Heatin	Minisplit	$22,986	$15,648

Figure 9 shows the possible costs to weatherize each multifamily unit. The multifamily weatherization costs per unit may be lower for smaller multifamily buildings than for larger multifamily buildings. These higher costs for larger buildings are due to more expensive non-traditional retrofit measures in larger multifamily buildings than in smaller multifamily buildings.

Figure 9: Residential Weatherization and Barrier Costs Per Unit

[16] https://techcleanca.com/public-data/download-data/

Buildng Type	**Range of Weatherization Costs**	**Weatherization Cost Average**	**Range of Barrier Costs**	**Barrier Cost Average**
Single Family	$3,500-$7,300	$5,300	$1,000-$2,200	$1,782
2-4 units multifamily building	$3,400-$9,400	$6,300	$500-$10,400	$3,700
5-19 unit multifamily building	$9,000-$21,000	$14,200	$400-$6,300	$2,900
20+ unit multifamily building	$6,200-$15,500	$10,800	$900-$4,000	$2,300

Comparison of Scenario 2 Costs to MA Building Sector Technical Report

The costs from actual projects and costs from studies may vary due to a number of factors, especially that costs from studies are usually generated through high level modeling rather than examining specific buildings, but the PAs have found that the costs to electrify buildings and achieve the target of 2.2 MMTCO2e reduced are higher than the costs that were included in the MA building sector technical report, for most building types.[17] Figure 10 shows the MA Building Sector Technical Report costs per square foot to electrify buildings. These costs are based on ECM package #2, which consists of electrifying space and water heating and the replacement of other gas appliances, such as a stove or electric dryer, with electric alternatives and improved roof and wall insulation and improved airtightness.[18]

Figure 10: MA Building Sector Costs per square foot to electrify buildings:

[17] Buildings Sector Report, A Technical Report of the Massachusetts 2050 Decarbonization Roadmap Study. December 2020. https://www.mass.gov/doc/buildings-sector-technical-report/download
[18] Buildings Sector Report, A Technical Report of the Massachusetts 2050 Decarbonization Roadmap Study. December 2020. Pg. 43. https://www.mass.gov/doc/buildings-sector-technical-report/download

Building Type	ECM #2 Costs per sq ft
Single family	$15.16
Small multifamily (2-4 units)	$20.58
Large multifamily (5-19 units)	$23.78
Large mutltifamily (20+ units) wood	$30.56
Large multifamily (20+units) steel	$28.38
Small office	$31.57
Medium office	$25.19
Retail	$32.81
Supermarket	$28.41
Convention/Assembly	$21.97
Large office	$20.97
School (k-12)	$24.09
Hospital	$24.28
Laboratory	$24.34
Hotel	$26.51
Restaurant	$35.34
Warehouse	$34.50

Figure 11 shows the costs per square foot to electrify each building type identified in the Massachusetts Building Sector Technical Report, that the PAs identified as part of the scenario 2 analysis.

Figure 11: Costs per square foot to electrify each building type from Scenario 2

Building Type	Scenario 2 Decarbonization Costs per sq ft
Single family	$12.52
Small multifamily (2-4 units)	$20.18
Large multifamily (5-19 units)	$59.44
Large mutltifamily (20+ units) wood	$46.81
Large multifamily (20+units) steel	$46.81
Small office	$19-$75
Medium office	$19-$75
Retail	$19-$75
Supermarket	$22.00
Convention/Assembly	$21-$95
Large office	$21-$95
School (k-12)	$21-$95
Hospital	$21-$95
Laboratory	$21-$95
Hotel	$21-$95
Restaurant	$21-$95
Warehouse	$21-$95

As the costs in the scenario 2 analysis are based on costs from actual buildings rather than high level modeling, which helps explain why the costs identified by the PAs are higher than the costs, for most building types, identified in the MA Building Sector Technical Report. Because the decarbonization costs calculated by the PAs are based on completed projects rather than high level modeling, these costs, especially the residential costs, may prove to be more accurate than the costs from studies that use high level modeling.

Not Included in This Analysis

In the residential weatherization section, the PAs outlined traditional and maintenance barriers to weatherization, which were included in the model. In addition to these known weatherization barrier costs, there are "known unknowns" or weatherization and electrification barrier costs that the PAs know customers may incur but are difficult to quantify and not included in this analysis. Some unknowns include insufficient electric supply from street or transformer; hazardous materials including lead paint; structural or design limitations, including no space for ducted system, floor plan that is not conducive to mini-split installation, or insufficient space or access for outdoor equipment. The costs associated with these barriers have not been traditionally covered through the Mass Save program and the PAs did not model them being covered by Mass Save in this analysis. Therefore, these are additional expenses that will have to be paid by someone before the building can be weatherized or electrified. Although all of these costs are difficult to quantify, the below examples of hypothetical buildings show how these costs can increase costs to electrify common building types in Massachusetts.

Boston Housing Authority building with lead paint

In an illustrative example, it could cost $121,351 dollars to electrify each unit of a 2–4-unit Boston Housing Authority (BHA) building. A four-unit BHA building could have a total electrification cost of $485,404. The per unit costs to electrify a unit in this four-unit building could be:

- $10,400 for domestic hot water
- $6,800 for efficiency upgrades
- $12,100 for electrical upgrades
- $26,000 for space heating
- $3,100 to electrify the kitchen
- $3,951 to electrify laundry
- $59,000 for weatherization.

If this building has lead paint, it would increase costs higher than the $121,351 per unit cost estimate.

Massachusetts triple decker with insufficient electric service

In 2020, the MA Clean Energy Center (MA CEC) created a triple decker design challenge, which helped identify scalable renovation and electrification strategies for existing triple deckers.[19] Various designers, developers, and students submitted designs that best balanced upfront costs, long-term operational savings, and greenhouse gas (GHG) emissions reductions. The cost of renovations ranged from $152,149-$529,564. At the lower end of this range, Zephyer Architects, proposed an estimated construction cost of $152,129, which included installing ducted ASHPs, and hybrid heat pump water heater. Their design estimates a 94% decrease in annual energy use(HERS rating change from 174 to 11). At the higher end of this range, Sustainable Energy Analytics submitted a design, with an estimated cost of $529,564, that would improve the building envelope, and install a ductless ASHP and heat pump water heater.[20] They estimated a 79% decrease in annual energy use.

As many older homes have a smaller electric panel that can't support an ASHP, adding an electric service upgrade could be an additional expense to electrify the building.

[19] https://www.masscec.com/program/triple-decker-design-challenge
[20] https://filescdn.masscec.com/featureimages/The%20Future%20is%20Electric%20Energizing%20Existing%20MA%20Triple%20Deckers%20Poster.pdf

Transformers in densely populated areas

In Cambridge, there is a 9-unit multifamily building that will require installation of an on-site transformer in order to be electrified. There are two different types of transformers that can be installed, a pad mount transformer and a vault transformer. A pad mount transformer would cost $150,000 and would take up a parking space. The customer is also concerned that the pad mount transformer would be an eye sore. The vault transformer would cost $300,000, but can be installed underground, so no parking spot is lost. The transformer would add $16-32/sf to the cost to electrify this building. For either option, the customer would pay for the transformer. These costs only include the cost of the transformer. There are additional costs for electrical modifications, as well as the cost of the heat pump and installation. The customer may also revenue if the parking space is rented out.

These additional costs are an additional barrier to electrification that can be common in densely populated areas where grid capacity is more constrained.

Buildings that require electric panel upgrades

Main electrical panels (e.g. 100A servicing one or more units) may cost upwards of $5,000 to upgrade to a panel with a rated capacity adequate for electrification. In 2-4 units building this could mean approximately $5,000 per-unit if individually metered, or in excess of $5,000 for the building if master-metered. In some cases, sub-panels may service individual units or may be necessary additions to support electrification in multifamily buildings; upgrading these to a rated capacity adequate for electrification (e.g. from 60A to 200A) may cost upwards of $2,000 per unit, which may be required in addition to upgrading the main electrical panel of the building.

The PAs have data on electrical panel upgrades in low and moderate single-family housing. Since 2022, 5 units have upgraded electric panels for a total cost of $15,668 or an average of $3,134 per upgrade. It is unclear how many buildings will require electric panel upgrades before the building can be electrified. In addition to the above weatherization and electrification barriers that aren't included in this analysis, there are other costs that may affect customer adoption of weatherization and electrification measures. These may include soft costs and operating costs.

Operating costs

Although heat pump operating costs are not included in this model, they are an additional expense that customers would have to pay once a heat pump is installed. Costs to heat a home with a heat pump could be higher than costs to heat a home with natural gas. It could cost $2,767 annually to heat an 1800 sq ft home with an electric heat pump and $1,723 to heat the same home with a natural gas furnace. This assumes that the thermostat is set to $68^{OF,}$ the heat pump is newer and more efficient, both the heat pump and natural gas furnace are newer and more efficient, and the price for natural gas is $2.023/therm and the price for electricity is $.328/kWh.[21]

Soft Costs

Soft costs are not directly related to the construction process but are part of additional expenses, such as legal fees and building permits that may be necessary for building weatherization or electrification. Soft costs can also include the costs of moving the building residents to a hotel during renovations and providing a meal voucher. Some of the more extensive retrofit projects can last for months, which can make soft costs a very expensive part of any retrofit project. Soft costs as a detriment to the feasibility of achieving the scenario 2 GHG emissions target is expanded upon in the Feasibility Considerations section.

New net zero construction can replace older buildings

While some older buildings with significant and costly weatherization and electrification barriers may need to be weatherized and electrified in order to achieve the scenario 2 target, it may not make sense to retrofit some buildings in the Commonwealth. Some buildings may be near the end of their useful life and have such extensive barriers to weatherization and electrification that it makes sense to replace these buildings with new net zero construction. Massachusetts' residents should be deliberate in which buildings are retrofitted.

Massachusetts has the third oldest building stock in the country, with the median age of owner-occupied housing being 57 years old[22] and 65% of the current built square footage was constructed before 1980[23], it may be cheaper to replace some older buildings with new net zero buildings than electrifying these older buildings, which may have significant barriers to weatherization and electrification.

According to the MA Building Sector Technical Report, 19% of the building stock in 2050 (baseline growth scenario), is expected to be buildings constructed between 2020 and 2050.[24] In the high growth scenario, new construction would represent 25% of the building stock in 2050.[25]

---

[21] https://c03.apogee.net/mvc/home/hes/land/el?utilityname=eversource&spc=hcc
[22] https://eyeonhousing.org/2023/02/age-of-housing-stock-by-state-4/
[23] Buildings Sector Report, A Technical Report of the Massachusetts 2050 Decarbonization Roadmap Study. December 2020, pg. 7. https://www.mass.gov/doc/buildings-sector-technical-report/download
[24] Buildings Sector Report, A Technical Report of the Massachusetts 2050 Decarbonization Roadmap Study. December 2020, pg. 6. https://www.mass.gov/doc/buildings-sector-technical-report/download
[25] Buildings Sector Report, A Technical Report of the Massachusetts 2050 Decarbonization Roadmap Study. December 2020, pg. 29. https://www.mass.gov/doc/buildings-sector-technical-report/download

Ideally, under either scenario, most of these newly constructed buildings will be built to net zero specifications[26] and replace older buildings that are not cost effective to electrify.

Incentives Needed to Achieve Scenario 2 Emission Reduction Targets

In order to achieve the scenario 2 GHG emission reductions, additional incentives beyond what the PAs currently offer through the Mass Save program will be needed.

For weatherization, the PAs currently offer incentives equal to 100% of the project costs for residential low-income customers and 75% of the project costs plus $250 for low-cost barrier remediation for market rate customers. These no cost weatherization upgrades for low-income customers could include installation of additional attic, wall, and basement insulation, air sealing of the drafty areas of your home, among other measures.[27]

For electrification, the PAs currently offer incentives of $10,000 per home for residential market rate customers that install heat pumps as the sole source of heating and cooling and $1,250 per ton (up to $10,000) for market rate customers that plan on keeping an existing boiler or furnace in place. Mass Save also offers an income based enhanced incentive up to $16,000.[28]

For C&I customers, insulation and weatherization incentives are based on the size of the building and where the insulation happens. For example, there are greater incentives for basement insulation than attic insulation for C&I buildings with less than 8,000 square feet.[29] For C&I buildings with more than 8,000 square feet, there are custom incentives available through Mass Save.[30] $2,500 per ton are available to C&I customers who choose to install air source heat pumps.[31]

In the April 1st draft EE plan, the PAs proposed over $1 billion in incentives for energy efficiency and electrification improvements for low-and moderate-income customers and renters, which is the largest investment in these customer groups ever in Massachusetts and possibly the nation (pg. 23).

---

[26] New buildings that are built to comply with the Municipal Opt-In Specialized Building Code would be designed to achieve GHG limits and sublimits and be consistent with a net-zero Massachusetts economy in 2050.
[27] https://www.masssave.com/en/residential/programs-and-services/income-based-offers/income-eligible-programs
[28] https://www.masssave.com/en/residential/rebates-and-incentives/heating-and-cooling/heat-pumps/air-source-heat-pumps
[29] https://www.masssave.com/en/business/rebates-and-incentives/building-insulation-and-weatherization-incentives
[30] https://www.masssave.com/en/business/rebates-and-incentives/custom-building-insulation-and-weatherization-incentives
[31] https://www.masssave.com/en/business/rebates-and-incentives/heating-and-cooling/heat-pumps/air-source-heat-pumps

In order to achieve the scenario 1 GHG emissions savings and increase GHG emissions reductions by 113% from scenario 1 to scenario 2, higher incentive levels will be required. Higher incentive levels will spur adoption by lowering the price that participants will pay. These higher incentive levels will need to be available to all residential customers. No change in average incentive rates for C&I customers from scenario 1 to scenario 2 was modeled.

As part of the scenario 2 analysis, the PAs have modeled an increase in incentives. The PAs assume that market rate customers are offered incentives equal to 90% of the total project costs to install an ASHP and 100% of the total project costs to weatherize, including the costs of any barrier remediation, such as mold or asbestos. For LMI customers, the PAs modeled offering incentives equal to 100% for both weatherization and electrification, including any the costs of any barrier remediation.

The higher incentives for LMI customers should help ensure that environmental justice communities and LMI customers are not left behind during the energy transition. According to a recent American Council for an Energy Efficient Economy (ACEEE) study, *The Value of Prioritizing Equitable, Efficient Building Electrification*, equitable electrification can help maximize societal benefits and lead to billions in net cost savings nationally, assuming that 75% of residential buildings are electrified. Equitable electrification can also help reduce LMI households reduce the percentage of income that is spent on energy. As the Northeast is a region of the US where it may be most expensive to electrify households, policies other than higher incentives, may be required to support LMI household electrification.[32] These additional policies are outside of the PAs control.

The PAs do not have a strong basis for estimating what level of incentives will be necessary in order for customers to electrify 268,466 residential buildings and weatherize 395,648 residential buildings and for C&I customers to electrify 1,600 buildings. However, it is possible that 90%-100% incentive levels would be required in order to meet the scenario 2 GHG emissions target. Incentives that are higher than current levels (but less than 90%-100%) may be insufficient to achieve the scenario 2 emission target.

During the COVID-19 pandemic, the PAs offered 100% incentives for all customers. These higher incentive levels increased adoption of weatherization and electrification measures. However, there was a project backlog as there weren't enough qualified contractors to do this

---

[32] Fadali, Lyla, Michael Waite, and Paul Mooney. 2024. *The Value of Decarbonizing Equitable, Efficient Building Electrification*. Washington, DC: ACEEE. www.aceee.org/researchreport/b2405.

work. As the contractors worked through the backlog, contractors asked about upcoming projects as there were fewer projects scheduled.

It is a fundamental economic principle that as prices decrease, production, or in this case, adoption of weatherization and electrification measures will increase.[33] For example, if the net project cost to participants (after incentives) is $10,000 for customers to install an ASHP, there will be less adoption at this price point than if the net project cost was $3,000. A $0 net project cost (100% incentives) would have even more adoption than a net project cost of $3,000.

Offering 90%-100% incentive levels indefinitely rather than for a set period of time (as was the case during the COVID-19 pandemic) may initially create an initial backlog of projects, unless more contractors are able to perform the work. This may spur more contractors to enter the market, which would help satisfy demand and return the market to equilibrium (no backlog of projects).

In addition to the higher incentive levels, the Commonwealth could pursue policy and rate design changes, such as the use of building codes, appliance standards, time of use rates, and other forms of mandated equipment replacement that could help increase heat pump adoption, especially among low-income customers. Changes to rate design could help customers afford heat pumps and lower their operational costs. An example is a higher fixed charge rate, with lower volumetric costs, which has been adopted or is being considered in some jurisdictions, including Maine and California. For example, the Maine Public Utilities Commission approved a pilot seasonal rate that lowers the volumetric delivery charge during the winter to encourage heat pump usage but increases the fixed monthly charge.[34]

While these policy and rate design changes are may be worth considering, they are outside of the PAs control.

Feasibility Considerations

The PAs note that this scenario is for informational purposes only and is not meant to represent that the PAs believe this to be a feasible implementation pathway. There are a number of barriers, including both supply side and demand side barriers, to scaling production at this magnitude under such a short time frame, many of which may be outside the Commonwealth's or PA's control.

Supply side barriers

[33] https://open.lib.umn.edu/principleseconomics/chapter/3-1-demand/
[34] Yim, E., and S. Subramanian. 2023. *Equity and Electrification-Driven Rate Policy Options*. Washington, DC: ACEEE. https://www.aceee.org/white-paper/2023/09/equity-andelectrification-driven-rate-policy-options.

Supply side barriers include manufacturing constraints, supply chain vulnerabilities, and shortages of skilled contractors to do the installs. Perhaps the largest barrier to implementation of scenario 2 is that there aren’t enough contractors to do the amount of electrification work that is necessary to achieve the scenario 2 GHG emission reduction target. As mentioned in the prior section, higher incentive levels would spur more customers to participate in weatherization and electrification programs, which would likely spur more contractors to enter the market and do electrification and weatherization work through the Mass Save program. It is unclear if enough contractors will enter the market to be able to perform electrification at the scale necessary to achieve scenario 2. In addition to the incentives for customers to better afford heat pumps and weatherization work, incentives may be needed to attract heating ventilation and air conditioning (HVAC) professionals to the Commonwealth and to train individuals to become qualified HVAC professionals.

Manufacturing constraints can limit the number of heat pumps that can be installed in a given year even if there are sufficient qualified contractors to install the heat pumps. These constraints can be nationwide or universal and are outside of the Commonwealth’s or PAs control.

Demand side barriers

As discussed in the prior section, higher incentives can help alleviate demand side barriers. However, if incentives are offered at less than 100%, then the participants would be responsible for some of the cost for the weatherization or electrification project. This can act as a demand side barrier to the implementation of weatherization and electrification projects.

Even with the higher modeled incentive levels (90%-100%) there may be some customers that are not interested in weatherization and electrification retrofits, either because they’re unaware of the higher incentives or they don’t want the hassle of building retrofits.

The hassle of retrofitting buildings is a real concern that may give customers pause. In many cases when a residential building is being retrofitted, the residents can’t live there while the retrofit work is happening. During the retrofit work, residents would need to move out and stay in a hotel or another house for the duration of a retrofit. In some cases, this could be weeks or even months. This could be a very high expense, especially for the owner of a multifamily building (who rents out units to tenants). In this case the owner could have to pay for multiple families to stay elsewhere while the retrofit is happening. Residents would also need food vouchers as they would lose access to a kitchen. If the hotel isn’t close to their home, there may be issues with getting to work or the kids to school, especially if the resident doesn’t have a car or if the hotel isn’t zoned for the kids’ school.

Ideally, a C&I building would be retrofitted when vacant. If this isn't possible, employees could work from home, temporarily close, or temporarily relocate to another building. While some companies may allow employees to work from home during renovations, this is not realistic for some companies, like factories, laboratories, hospitals, restaurants, and hotels, where employees work in person. Some companies may not allow (or not prefer) employees to work from home, which would require employers to temporarily relocate or close the business during renovations. Either temporarily relocating or closing the business would be a major expense (and potential loss of revenue) for the business.

Conclusion

After modeling the costs and how many buildings will likely need to be weatherized and electrified in order to reduce GHG emissions by 2.2 MMTCO2e, the PAs have calculated the estimated total costs to be approximately $16.3B over the next three years. This is the estimated total cost to achieve this GHG emission reduction target, regardless of funding source. There is uncertainty regarding this number, as there are very few C&I buildings that have been electrified and therefore the costs of electrifying C&I buildings are largely estimated. The PAs are more confident about the accuracy of the residential costs as these costs are based on actual projects. However, there is still uncertainty regarding residential weatherization and electrification barriers and associated costs.

The program costs are assumed to be 84% of the total cost, or approximately $14B. These program costs include the higher incentives that would be available to customers. Other sources of funding, including federal incentives can reduce the program costs, but not the total costs.

There are limited economies of scale associated with this analysis. As customers more frequently select non-traditional weatherization projects and electrification of harder to electrify buildings, costs are expected to increase. There could be economies of scale with administration and heat loan costs, which have been scaled at lower rates than other cost categories. The PAs modeled heat loan costs decreasing in scenario 2 compared to scenario 1.

Appendix 1: Commentary from MEP Design Professionals

As part of this study, the PAs consulted with six (6) MEP Design Professional firms to discuss costs of electrifying existing C&I facilities, as well as their feedback on the C&I electrification landscape. Feedback on costs and challenges was consistent. In terms of the landscape, they indicated that implementation has been very limited or non-existent to date. Municipalities and higher-education customers are beginning to explore electrification, through completion of decarbonization studies. Additionally, there is some interest from customers with immediate needs to replace portions of their existing HVAC equipment. For example, replacement of a portion of RTUs for their facility that are approaching the end of their useful life. Interest in full electrification has been limited due to project economics, with most customers expressing interest in replace on burnout (partial), phased, or hybrid strategies due to the more favorable project economics. Some customers with planned major renovations for a given facility are exploring full electrification options, as the economics are more favorable when done in conjunction with a major renovation. The prevalence of hydronic-based systems in Massachusetts and the limitations in temperature output of available air to water heat pump (AWHP) equipment was cited by all firms as a challenge. The existing hydronic distribution and terminal units in these facilities are sized for high-temperature heating hot water (180°F), however AWHP equipment currently available on the commercial market is limited to 140°F temperature output, therefore necessitating distribution and terminal unit replacement in order to make the system compatible with the available technology. This in turn drives up project costs for AWHP systems, which have benefits in terms of system resiliency, durability, and reducing refrigerant concentrations in occupied spaces when compared to air-to-air equipment such as VRF. In terms of implementation windows from design to construction, feedback was consistent that this would be a 2-3 year minimum. For municipalities, town approval for funding appropriation is required for all steps along the way, from master planning, design work, grant applications, to the actual construction of the project. Requirements for competitive bidding can extend the timeframe of implementation for municipalities. Grant and incentive applications often require the town to retain a firm to perform a preliminary design, which must be funded by the town with no guarantee of grant approval, which presents a measure of risk for the town. Additionally, equipment lead times contribute to a protracted implementation window, with heat pump equipment lead times ranging from 12-40 weeks, and electrical switchgear lead times of 60-70 weeks. Short windows of construction for schools were cited as a challenge which escalates cost due to requirements for project phasing. Hybrid systems and phasing of electrification to replace end-of-life equipment (in alignment with capital improvement plan), and staging HVAC electrification to align with planned renovations of portions (or entirety) of a given facility were presented as alternative strategies to yield better project economics for the customer and still meet their long term decarbonization goals. The firms universally recommended decarbonization master planning for customers, in order for client to make informed decisions to align with their goals and budget, and have an understanding on life cycle costs associated with different options. On a life cycle basis, implementation of electrified options may have more favorable economics than continuing “business as usual” for customers, so this is important to illustrate. Some cost ranges provided by these MEP firms are in Figure 12. These costs are aligned with the costs in scoping studies.

Figure 12: Electrification Cost Range from MEP Firms

Building/Project Type	Cost Range ($/square foot)	Comments
Hospital	$85-$100	Partial ELX using Hybrid Equipment
Laboratory	$50-$90	Partial ELX using Hybrid Equipment
K-12 School	$30-$95	Partial ELX using Hybrid Equipment
K-12 School	$85-$100	Full ELX
Municipal Office	$65-$80	Full ELX
Ventilation System Replacement	$40	Includes adding airside heat recovery
Electric Infrastructure Upgrades	$20-$60	Low end of range is for basic switchgear replacement, highly contignent upon existing conditions
Distribution System Replacement	$65-$80	Ductwork, Hydronic Piping, and/or Terminal Units

Appendix 2: Literature Review

As part of this analysis, the PAs have examined published literature, from across the US, that examines the cost to electrify a building. Generally, these studies are based on high level modeling exercises rather than electrification of actual buildings and technical analyses of electrifying actual buildings. Therefore, electrification costs from these studies were not included in the analysis.

Real examples of electrifying buildings, particularly large multifamily buildings and commercial and industrial buildings may have costs that aren't incorporated into the selected studies, such as general maintenance costs and soft costs. As the studies are national, many of them will have lower housing, labor, and supply costs than is realistic in Massachusetts.

A breakdown of studies to electrify buildings and their costs can be found in the Appendix.

The studies that have been published largely focus on single family homes and multi-family buildings, with less studies being published on costs to electrify commercial and industrial buildings. Of the studies that have been published on the costs to electrify commercial and industrial buildings, most have been on office buildings. There has been very few, if any, published studies that estimate the costs to electrify harder to electrify buildings, such as hospitals, laboratories and warehouses.

These studies did not involve inspection of individual buildings and development of costs based on real world conditions of the existing structures and potential challenges to electrify commercial and industrial facilities. Some studies are limited in scope in terms of heat pump technology considered. Given imminent changes to regulations in Massachusetts with respect to refrigerants, hydronic based heat pump technologies may be more favorable for implementation due to resiliency and considerations with respect to refrigerant concentration limits, whereas these studies were limited to high-level modelling of air-based equipment only. Other studies selectively examined in-kind single zone CAV RTU replacement with heat pump RTUs only, which is not representative of the C&I segment as a whole.

The PAs have conducted an extensive literature review of sources that have looked at the costs to electrify buildings. These are the sources that the PAs have found:

BEI- Boston Funding Gap Analysis for Residential Building Decarbonization[35]

[35] *Boston Funding Gap Analysis for Residential Building Decarbonization*. New Buildings Institute, updated 2024. https://static1.squarespace.com/static/5b6a482db27e39e8fcf65bbf/t/65ef4488c1d0827259981000/1710179465284/BEI-Boston+Funding+Gap+Analysis_Feb2024.pdf

- This project estimates the gap in current funding to equitably decarbonize the nearly 70,000 small and medium sized buildings in Boston.
- It could cost $78,000-$107,000 to electrify a single-family home (pg. 17).
- It could cost $54,000-$80,000 to electrify each unit in a multifamily home (pg. 17).

Guidance Document on Space Heating Electrification for Large Commercial Building with Boilers[36]

- This report summarizes key considerations for commercial building owners whose buildings currently use hot water or steam boilers and are looking to retrofit their space heating systems to one or more electric heat pump technologies.
- While this report didn't detail expected initial costs for commercial building owners to electrify, it did include case studies of buildings that were electrified (pg. 29-40).
  - For multifamily buildings, the initial costs ranged from $13,200 per unit ($1,320,000 total) to $18,500 per unit ($185,000 total).
  - For office buildings, the initial costs ranged from $1,500,000 to $10,000,000.

How Much Does Heat Pump Installation Cost?[37]

- A central air source heat pump can cost between $3,000-$11,000, with the higher cost assuming a high-efficiency unit.
- A ductless mini-split heat pump could cost $1,500-$8,000 per unit.

Why Heat Pumps Are the Future, and How Your Home Could Use One[38]

- This New York Times article provides an overview of heat pumps and estimates that installing a heat pump in a single-family home can cost upward of $20,000.

TECH Clean California: Incremental Cost Study- Final Phase 1 Findings[39]

- This study surveyed contractors across California on cost estimates, across six scenarios, to electrify space heating in residential single-family homes. The two most relevant

[36] Goetzler, William, Jim Young, Mark Butrico, Ryan Murphy. *Guidance Document on Space Heating Electrification for Large Commercial Building with Boilers*. US Department of Energy, 2024. https://www.energy.gov/sites/default/files/2024-04/Large%20Building%20Boiler%20Electrification%20Guidance.pdf

[37] Bonk, Lawrence. *How Much Does Heat Pump Installation Cost?* Forbes, 2024. https://www.forbes.com/home-improvement/hvac/heat-pump-installation-cost/

[38] Howard, Hilary. *Why Heat Pumps Are the Future, and How Your Home Could Use One*. New York Times, 2024. https://www.nytimes.com/2024/04/14/nyregion/heat-pumps-climate-change.html?smid=nytcore-ios-share&referringSource=articleShare

[39] *TECH Clean California: Incremental Cost Study- Final Phase 1 Findings*. Opinion Dynamics, 2024. https://techcleanca.com/public-data/evaluation-studies/

scenarios to this analysis are (5) converting from a central AC and gas furnace to a central, ducted heat pump and (6) converting from a gas furnace to central, ducted heat pump. The costs do not include electrical modifications, equipment relocation, or duct replacement. Costs are based on a 1700 sq ft home.

- The average cost for scenario 5 (3-ton unit) is $13, 281 and (4-ton unit) is $14,529 (pg. 14-15).
- The average cost for scenario 6 (3-ton unit) is $14,909 and (4-ton unit) is $15,555 (pg. 14-15).

Options for Decarbonizing Residential Space Heating in Cold Climates[40]

- This study analyzes different options for decarbonizing residential space heating in cold climates. Two different installed heating costs are used for ccASHPs: $15,000, which is based on data from the Northeast and Northwest. This study also uses $8,920 as a cost to install a ccASHP, which may be used in regions outside of the Northeast and Northwest and this is also what costs could be in the future, to install ccASHPs, as competition increases (pg. 20).

EIA- Technology Forecast Updates- Residential and Commercial Building Technologies-Reference Case[41]

- This study develops baseline and projected performance/cost characteristics for residential and commercial end use equipment.
- The typical install cost of a residential split system ASHP is $6,880, but costs could be as high as $8,620. This is based on a 3-ton ASHP (pg. 39).
- The typical install cost of a residential ductless mini-split ASHP is $2,030 per ton (pg. 43).

How Much Does Heat Pump Installation Cost? (2023 Guide)[42]

- There are many factors that can influence the cost of a heat pump. Heat pump costs will vary by type (central ASHPs and ductless mini-split ASHPs), size (tonnage), brands, efficiency, labor, and whether or not ductwork and permits are required.

---

[40] Nadel, Steven, Lyla Fadali. 2024. *Options for Decarbonizing Residential Space Heating in Cold Climates*. Washington, DC: ACEEE. https://www.aceee.org/research-report/b2404

[41] *EIA- Technology Forecast Updates- Residential and Commercial Building Technologies- Reference Case.* Prepared by Guidehouse and Leidos, 2023. https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/appendix-a.pdf

[42] *How Much Does Heat Pump Installation Cost? (2023 Guide).* American Society of Home Inspectors. https://www.homeinspector.org/consumers/hvac/heat-pump-installation-cost

- In general, a central ASHP will cost between $3,500-$7,000 and a ductless mini-split heat pump will cost $2,000-$5,000.

Window of Opportunity: New York's Small Multifamily Buildings, Expiring Equipment, And Clean Energy Goals[43]

It can cost $100,000 to retrofit a unit, including electrical system upgrades, efficiency measures, and electrification (Pg. 9).

Clean Heat At What Cost? Economic Optimization of Residential Space Heating in Massachusetts[44]

- This report analyzes the prospects and preconditions, including costs of electrifying space heating in single family homes in Massachusetts. This report finds that:
    - The median total cost of a 3-ton whole home system is approximately $18,000 (pg. 37).
    - Electrifying space heating in a 1,700 sq ft single family without ductwork could cost $19,000-$30,000 depending on the heat pump capacity and efficiency (pg. 45).

The Future of Buildings New York's Carbon Neutral Building Roadmap[45]

- It could cost approximately $30,000 to electrify[46] and retrofit an oil heated pre-1980 home in upstate NY with a comfort shell upgrade (air sealing and attic insulation). Pg. 93
- A retrofit of a 7-story, gas or oil heated, pre-1980 multifamily building in Downstate NY could cost approximately $45,000. This retrofit includes a distributed ccASHP, HPWH, code compliant shell, LED lighting, and smart, electric appliances. Pg. 98-99.
- A retrofit of a pre-1980 500,000 sq ft 12 story office building in downstate NY could cost approximately $25/sq ft to electrify. This cost estimate includes a distributed ccASHP, HPWH, code compliant shell, LED lighting, and smart, electric appliances. Pg. 105

---

[43] Scott, Jacob, Claire Kramer Mills. *Window of Opportunity: New York's Small Multifamily Buildings, Expiring Equipment, And Clean Energy Goals.* Federal Reserve Bank of New York, 2023. https://www.newyorkfed.org/medialibrary/media/outreach-and-education/climate/window-of-opportunity-new-yorks-small-multifamily-buildings-expiring-equipment-clean-energy-goals

[44] McBride, Jameson. *Clean Heat at What Cost? Economic Optimization of Residential Space Heating in Massachusetts*. Massachusetts Institute of Technology, 2022. https://dspace.mit.edu/handle/1721.1/144617

[45] *The Future of Buildings, New York's Carbon Neutral Buildings Roadmap.* New Buildings Institute, RMI, Energy and Environmental Economics, Inc., and Build Edison, 2022. https://www.nyserda.ny.gov/All-Programs/Carbon-Neutral-Buildings

[46] Electrification includes a ducted ccASHP and HPWH.

New York Building Electrification and Decarbonization Costs[47]

- This report is an extensive review of existing literature related to building electrification and decarbonization costs. The cost estimates below include a ASHP, HPWH, cooktop range, and clothes dryer.
- Rosen Consulting Group (RCG) found that it could cost $17,400-$31,700 to electrify an existing single-family home in New York (pg. 8).
- RCG finds that it could cost $13,000-30,100 per unit to electrify an existing 2–19-unit multifamily building and $19,400-$42,900 per unit to electrify an existing 20+ unit multifamily building (pg. 10). RCG finds that it could cost $12-21 per sq ft to electrify and existing office building (pg.11).

New York State Climate Action Council Draft Scoping Plan Integration Analysis Technical Supplement, Section 1, Annex 1: Inputs and Assumptions[48]

- As part of the New York State Climate Action Council's Scoping Plan development process, E3 developed costs of installing different devices in different housing types. The costs for an ASHP are (Building Residential Device Cost tab, reference trajectory):
    - $14,678 to install an ASHP in a single-family home (row 66).
    - $13,643 to install an ASHP in each unit of a small multi-family building (row 82).
    - $26,873 to install an ASHP in each unit of a large multi-family building (row 98).
    - $14.51/sq ft to install an ASHP in a commercial building (Building, Commercial Device Cost tab, reference trajectory).

Los Angeles Affordable Housing Decarbonization Study Phase 2[49]

- A 31-unit building could cost approximately $450k to electrify (approximately $175k for buying new electrical capacity at the incoming service, $50k for upgrading the common areas, and $7k to electrify each unit). Slides 69-71
- A 62-unit building could cost approximately $600k (approximately $175k for buying new electrical equipment for the building, $75k to electrify common areas, and $5k to electrify each unit). Slides 69-71.

---

[47] Rosen, T. Kenneth, David Bank, Max Hall, Irina Chernikova, Scott Reed. *New York Building Electrification and Decarbonization Costs*. Rosen Consulting Group, 2022. https://www.nyserda.ny.gov/-/media/Project/Climate/Files/2022-Comments/NY-Building-Electrification-Cost-Full-Report-June2022

[48] *New York State Climate Action Council Draft Scoping Plan Integration Analysis Technical Supplement, Section 1, Annex 1: Inputs and Assumptions*. Energy and Environmental Economics, 2021. https://climate.ny.gov/resources/scoping-plan/-/media/project/climate/files/IA-Tech-Supplement-Annex-1-Input-Assumptions-2022.xlsx

[49] *Los Angeles Affordable Housing Decarbonization Study Phase 2*. ARUP, 2021. https://www.nrdc.org/sites/default/files/la-affordable-housing-decarbonization-study-phase2-20211108.pdf

Overcoming Weatherization Barriers. An Overview of Programs Working to Mitigate Barriers to Home Weatherization Projects[50]

- This presentation on weatherization barriers by Energize CT, was part of a weatherization barriers workshop hosted by the Energy Efficiency Board and the CT Department of Energy and Environmental Protection (DEEP).
- This presentation cites 50 homes that has completed for remediation of weatherization barriers and finds these cost ranges and average costs for the weatherization barriers (per unit) are:
    - Asbestos: $4,299-$31,908; average of $14,721
    - Mold: $11,305-$35,575; average of $23,886
    - Vermiculite: $3,318-$38,114; average of $20,167
    - Asbestos/mold: $10,917-$58,670; average of $35,237
    - Asbestos/mold/pests: $ $40,426; average of $40,426
    - Vermiculite/mold: $13,997-$15,910; average of $14,954
    - Asbestos/pests: $16,025-$30,042; average of $23,034
    - Mold/pests: $25,729-$25,729
- The total range across all weatherization barrier types was $3,318-$58,670 with an average of $20,910.

Electrification of Commercial and Residential Buildings[51]

- For single family homes, total retrofit electrification costs are $20,400. This includes electrical modification, HPWH, and ASHP (pg. 12). This is based on a 3,000 sq ft home.
- For office buildings, total retrofit electrification costs are $241,200. This includes a central ASHP, HPWH, and electrical modifications (pg. 14). This is based on a 28,000 sq ft office building.

Going Electric Retrofitting NYC's Multifamily Buildings[52]

---

[50] Fasey, Richard. *Overcoming Weatherization Barriers. An Overview of Programs Working to Mitigate Barriers to Home Weatherization Projects.* Energize CT, 2020. https://portal.ct.gov/-/media/deep/energy/conserloadmgmt/weatherization-barriers-workshop-1-slides.pdf

[51] *Electrification of Commercial and Residential Buildings*. Group 14 Engineering, 2020. Prepared for Community Energy, Inc. https://www.communityenergyinc.com/wp-content/uploads/Building-Electrification-Study-Group14-2020-11.09.pdf

[52] *Going Electric Retrofitting NYC's Multifamily Buildings*. Urban Green Council, 2020. https://www.urbangreencouncil.org/wp-content/uploads/2022/11/2020.04.22-Going-Electric-v2.pdf

- This study examined retrofitting and electrifying NYC's multifamily buildings. Urban Green Council estimates that the costs are:
    - Central systems (whole building) can cost from $15-22k per apartment, with the potential to cost at least 15% more if heating and cooling are needed (pg. 18).
    - Unitary systems (required in each building unit) can cost from $9-12k for an apartment with three indoor units (one unit for each room). Costs could increase by 10% if electrical upgrades are needed (Pg. 18).

RetrofitNY Cost-Compression Study Phase One: Evaluation of Deliverables and Main Cost Drivers[53]

- This report outlines the top cost drivers for each of the five pilot net zero designs. The five pilot net zero designs and costs are:
    - Bronx: This project is a 42 unit building that has a total cost of $6,251,802 to electrify.
    - Brooklyn: This project is a 46 unit building that has a total cost of $9,432,903 to electrify.
    - New York (Manhattan): This project is a 21 unit building that has a total cost of $2,409,079 to electrify.
    - Phoenix: This project is a 40 unit building that has a total cost of $3,523,399 to electrify.
    - Portville: This project is a 24 unit building that has a total cost of $3,315,628 to electrify.
- These buildings were not retrofitted, but are retrofit designs that could be scaled across NY multifamily buildings.
- The total project costs do not include contingencies for hard or soft costs.
- The biggest cost drivers included HVAC equipment, façade, and general conditions and site, including concrete, metals, and elevator work.

Large VRFs Versus Mini/multi Split Heat Pumps: A Comparison[54]

- This document found that variable refrigerant flow (VRF) heat pumps cost $15-34/sq ft, with an average of $22/sq ft, from a sample of 13 quotes.
- Small mini/multi-split heat pumps cost $8-23/sq ft from a sample of 8 quotes (pg. 7).

Heat Pump Retrofit Strategies for Multifamily Buildings[55]

---

[53] *RetrofitNY Cost-Compression Study Phase One: Evaluation of Deliverables and Main Cost Drivers.* Steven Winter Associates, 2020. Prepared for NYSERDA. https://www.nyserda.ny.gov/All-Programs/RetrofitNY-Program/RetrofitNY-Articles/New-Reports-Highlight-Findings

[54] Shapiro, Ian. *Large VRFs Versus Mini/multi–Split Heat Pumps: A Comparison*. Taitem Engineering, 2020. https://www.nyc.gov/assets/hpd/downloads/pdfs/services/large-vrfs-mini-split-heat-pumps-comparison.pdf

[55] *Heat Pump Retrofit Strategies for Multifamily Buildings*. Steven Winter Associates, 2019. Prepared for the Natural Resources Defense Council. https://www.nrdc.org/sites/default/files/heat-pump-retrofit-strategies-report-05082019.pdf

- This study examined nine different retrofit projects:
    - Retrofit 1: Steam or hot water retrofit to central heat pumps with hydronic distribution. Hydronic buildings: $5/SF for new central plants + $2/SF for new room heaters. Steam buildings: $5/SF for new central plant + $10/SF for new distribution piping and room heaters.
    - Retrofit 2: Steam or hot water retrofit to Ground loop hydronic with room by room heat pumps. Cost is $30+/SF
    - Retrofit 3: Steam or hot water retrofit to packaged terminal heat pumps (PTHP). Cost is $6-12/SF. Limitations in cold weather performance.
    - Retrofit 4: Steam or hot water high rise retrofit to central heat pumps with refrigerant distribution. Cost is $15-20/SF.
    - Retrofit 5: Steam high rise an stream or hot water low rise retrofit to min-split HPs serving single units. Cost is $10-18/SF, 50/50 split between labor and equipment.
    - Retrofit 6: Hot air furnace retrofit to split heat pumps serving single units with ducting. Cost is $8-12/SF.
    - Retrofit 7: Packaged gas room heaters retrofit to packaged terminal heat pumps (PTHP. Limitations in cold weather. Cost is $4-8/SF.
    - Retrofit 8: DHW: Central DHW Plant retrofit to central AWHP plant. Limitations in cold weather performance. Cost is $1.5-3/SF.
    - Retrofit 9: DHW: Per-unit DHW retrofit to per-unit HPWH. Limitations in cold weather performance. Cost is $1.5-5/SF.

The Economics of Electrifying Buildings: How Electric Space and Water Heating Supports Decarbonization of Residential Buildings[56]

- This study examined costs to electrify single family homes in 4 different locations: Oakland, CA; Houston, TX; Providence, RI; Chicago, IL. Results are based on a 2,401 sq ft single family home with centrally ducted heating and air conditioning.
- In Providence, a water heater's fixed costs are found to be $2,132 and space heating fixed costs are $7,522. This cost is found to be lower in Houston, Chicago, and Oakland (pg. 64).
- This study found that electrification should prioritize customers currently using heating oil or propane as this will have the greatest immediate carbon and cost benefit impact.

Cost Savings from Energy Retrofits in Multifamily Buildings[57]

---

[56] Billimoria, Sherri, Mike Henchen, Leia Guccione, and Leah Louis-Prescott. *The Economics of Electrifying Buildings: How Electric Space and Water Heating Supports Decarbonization of Residential Buildings*. Rocky Mountain Institute, 2018, http://www.rmi.org/insights/reports/economics-electrifying-buildings/
[57] Taylor, W. Nicholas, Jennison K. Searcy, and Pierce H. Jones. *Cost Savings from Energy Retrofits in Multifamily Buildings*. MacArthur Foundation. https://www.macfound.org/media/files/hhm_brief_-_cost_savings_from_energy_retrofits_in_multifamily_buildings.pdf

- This study compared energy use in 81 units in Orlando, FL before and after energy efficiency upgrades. Upgrades included high-efficiency HVAC systems, refrigerators, compact fluorescent lighting, and water saving showerheads and aerators. The average cost per unit was $4,359 or a total cost of $1M. The total cost was for retrofitting four apartments with a total of 232 units (Pg. 2).

Impacts of Residential Appliance Electrification[58]

- This report summarizes the potential impact of residential appliance electrification for homeowners throughout California.
- It may cost $17,000-19,000 to electrify an existing multifamily building. This includes a heat pump water heater (HPWH), ASHP, electric stove and dryer, and electrical upgrades (pg. 12). These costs are based on a 6,960 sq ft home.
- It may cost $17,000-19,000 to electrify an existing single family home. This includes a heat pump water heater (HPWH), ASHP, electric stove and dryer, and electrical upgrades (pg. 12).

---

[58] *Impacts of Residential Appliance Electrification*. Navigant Consulting, 2018. Prepared for the California Building Industry Association. https://cbia.org/wp-content/uploads/2022/01/2019-Navigant-Report-Impacts-of-Residential-Appliance-Electrification.pdf

Appendix 3: Definitions

Scoping Study: The PAs have assisted customers in Massachusetts interested in electrification by offering electrification scoping studies. Since 2022, Nineteen (19) of these assessments have been completed for customers pursuing full electrification. One (1) small office has fully electrified their facility. An additional eight (8) facilities have had scoping level costs developed for hybrid systems as an option, and a single office had a hybrid system constructed, however for purposes of this study, these costs have been excluded, as they do not represent full electrification.

Studies include a site walkthrough, preparation of potential electrification options, as well as high level opinion of probable cost and energy impact estimates for each electrification option studied. Additionally, the studies include a preliminary analysis of the existing electric infrastructure and offer an opinion as to whether it can support fully electrified HVAC. Detailed system design, equipment sizing, energy modelling, and cost estimation is not included.

Full Electrification: HVAC system updates which utilize either electrically-operated heat pump technology, or heat pump equipment with electric-resistance backup heat, to satisfy 100% of the space heating load for an entire facility, and eliminates use of any fossil-fuel fired HVAC equipment across the entirety of a given site. Full electrification can include ventilation system updates and addition of airside heat recovery as well as addition of space cooling to previously uncooled areas, depending on code and customer requirements. It may be achieved in single or multiple phases.

Partial Electrification: HVAC system updates which utilize either electrically-operated heat pump technology, or heat pump equipment with electric-resistance backup heat, to satisfy a portion of the space heating load for an entire facility. The remaining load is continued to be satisfied with fossil fuel fired HVAC equipment.

Hybrid System: A partially electrified HVAC system or piece of HVAC equipment which utilizes fossil fuel fired HVAC equipment for peak heating purposes. Examples include hybrid heat pump RTUs which utilize natural gas fired furnace sections for backup at low-ambient outdoor temperatures, as well air-to-water heat pumps (AWHPs) that rely on a fossil fuel fired boiler for backup at low-ambient outdoor temperatures. Hybrid systems may be able to displace 80-90% of the fossil fuel consumption associated with the affected area served by the equipment.

Bibliography

Billimoria, Sherri, Mike Henchen, Leia Guccione, and Leah Louis-Prescott. The Economics of Electrifying
Buildings: How Electric Space and Water Heating Supports Decarbonization of Residential Buildings. Rocky Mountain Institute, 2018, http://www.rmi.org/insights/reports/economics-electrifying-buildings/

Bonk, Lawrence. *How Much Does Heat Pump Installation Cost?* Forbes, 2024. https://www.forbes.com/home-improvement/hvac/heat-pump-installation-cost/

Boston Funding Gap Analysis for Residential Building Decarbonization. New Buildings Institute, updated 2024. https://static1.squarespace.com/static/5b6a482db27e39e8fcf65bbf/t/65ef4488c1d0827259981000/1710179465284/BEI-Boston+Funding+Gap+Analysis_Feb2024.pdf

Buildings Sector Report, A Technical Report of the Massachusetts 2050 Decarbonization Roadmap Study. December 2020. https://www.mass.gov/doc/buildings-sector-technical-report/download

Decarbonizing Boston's Affordable Housing. Prepared by ARUP for Boston Housing Authority. https://www.bostonhousing.org/BHA/media/Documents/Departments/Procurement/BHA_Arup_final_decarb_report.pdf

EIA- Technology Forecast Updates- Residential and Commercial Building Technologies- Reference Case. Prepared by Guidehouse and Leidos, 2023. https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/appendix-a.pdf

Electrification of Commercial and Residential Buildings. Group 14 Engineering, 2020. Prepared for Community Energy, Inc. https://www.communityenergyinc.com/wp-content/uploads/Building-Electrification-Study-Group14-2020-11.09.pdf

Fadali, Lyla, Michael Waite, and Paul Mooney. 2024. *The Value of Decarbonizing Equitable, Efficient Building Electrification*. Washington, DC: ACEEE. www.aceee.org/researchreport/b2405.

Goetzler, William, Jim Young, Mark Butrico, Ryan Murphy. *Guidance Document on Space Heating Electrification for Large Commercial Building with Boilers.* US Department of Energy, 2024. https://www.energy.gov/sites/default/files/2024-04/Large%20Building%20Boiler%20Electrification%20Guidance.pdf

Going Electric Retrofitting NYC's Multifamily Buildings. Urban Green Council, 2020. https://www.urbangreencouncil.org/wp-content/uploads/2022/11/2020.04.22-Going-Electric-v2.pdf

Heat Pump Retrofit Strategies for Multifamily Buildings. Steven Winter Associates, 2019. Prepared for the Natural Resources Defense Council. https://www.nrdc.org/sites/default/files/heat-pump-retrofit-strategies-report-05082019.pdf

Howard, Hilary. *Why Heat Pumps Are the Future, and How Your Home Could Use One*. New York Times, 2024. https://www.nytimes.com/2024/04/14/nyregion/heat-pumps-climate-change.html?smid=nytcore-ios-share&referringSource=articleShare

How Much Does Heat Pump Installation Cost? (2023 Guide). American Society of Home Inspectors. https://www.homeinspector.org/consumers/hvac/heat-pump-installation-cost

Impacts of Residential Appliance Electrification. Navigant Consulting, 2018. Prepared for the California Building Industry Association. https://cbia.org/wp-content/uploads/2022/01/2019-Navigant-Report-Impacts-of-Residential-Appliance-Electrification.pdf

Los Angeles Affordable Housing Decarbonization Study Phase 2. ARUP, 2021. https://www.nrdc.org/sites/default/files/la-affordable-housing-decarbonization-study-phase2-20211108.pdf

McBride, Jameson. *Clean Heat at What Cost? Economic Optimization of Residential Space Heating in Massachusetts*. Massachusetts Institute of Technology, 2022. https://dspace.mit.edu/handle/1721.1/144617

Nadel, Steven, Lyla Fadali. 2024. *Options for Decarbonizing Residential Space Heating in Cold Climates.* Washington, DC: ACEEE. https://www.aceee.org/research-report/b2404

New York State Climate Action Council Draft Scoping Plan Integration Analysis Technical Supplement, Section 1, Annex 1: Inputs and Assumptions. Energy and Environmental Economics, 2021. https://climate.ny.gov/resources/scoping-plan/-/media/project/climate/files/IA-Tech-Supplement-Annex-1-Input-Assumptions-2022.xlsx

RetrofitNY Cost-Compression Study Phase One: Evaluation of Deliverables and Main Cost Drivers. Steven Winter Associates, 2020. Prepared for NYSERDA. https://www.nyserda.ny.gov/All-Programs/RetrofitNY-Program/RetrofitNY-Articles/New-Reports-Highlight-Findings

Rosen, T. Kenneth, David Bank, Max Hall, Irina Chernikova, Scott Reed. *New York Building Electrification and Decarbonization Costs*. Rosen Consulting Group, 2022.

https://www.nyserda.ny.gov/-/media/Project/Climate/Files/2022-Comments/NY-Building-Electrification-Cost-Full-Report-June2022

Scott, Jacob, Claire Kramer Mills. *Window of Opportunity: New York's Small Multifamily Buildings, Expiring Equipment, And Clean Energy Goals.* Federal Reserve Bank of New York, 2023. https://www.newyorkfed.org/medialibrary/media/outreach-and-education/climate/window-of-opportunity-new-yorks-small-multifamily-buildings-expiring-equipment-clean-energy-goals

Shapiro, Ian. *Large VRFs Versus Mini/multi–Split Heat Pumps: A Comparison*. Taitem Engineering, 2020. https://www.nyc.gov/assets/hpd/downloads/pdfs/services/large-vrfs-mini-split-heat-pumps-comparison.pdf

Taylor, W. Nicholas, Jennison K. Searcy, and Pierce H. Jones. *Cost Savings from Energy Retrofits in Multifamily Buildings*. MacArthur Foundation. https://www.macfound.org/media/files/hhm_brief_-_cost_savings_from_energy_retrofits_in_multifamily_buildings.pdf

TECH Clean California: Incremental Cost Study- Final Phase 1 Findings. Opinion Dynamics, 2024. https://techcleanca.com/public-data/evaluation-studies/

The Future of Buildings, New York's Carbon Neutral Buildings Roadmap. New Buildings Institute, RMI, Energy and Environmental Economics, Inc., and Build Edison, 2022. https://www.nyserda.ny.gov/All-Programs/Carbon-Neutral-Buildings

Yim, E., and S. Subramanian. 2023. *Equity and Electrification-Driven Rate Policy Options*. Washington, DC: ACEEE. https://www.aceee.org/white-paper/2023/09/equity-andelectrification-driven-rate-policy-options.