

Workplan – Greater Boston Affordable Housing Decarbonization Accelerator

This appendix details the methodology and assumptions for developing the estimated GHG reductions for each measure in this application.

Measure 1 – Kickstart decarbonization retrofits

GHG Reduction Estimate Method: We use energy modeling in a representative multifamily building to estimate the annual energy reductions in the targeted properties from the decarbonization retrofits. Pre- and post-retrofit energy consumption estimates are used to estimate GHG reductions, using representative emissions factors for gas and electricity. We assume increasing year-on-year reductions in electricity emissions based on Massachusetts policies and Housing Authority electricity purchasing, which are detailed further below.

Models/Tools Used: Energy modeling was completed in eQUEST (developed by James J. Hirsch and Associates in collaboration with Lawrence Berkeley National Labs under U.S. Dept. of Energy Funding) for Boston Housing Authority in a Dec. 2023 study by Andelman and Lelek Engineering to estimate energy reductions at a prototype multifamily building representative of the buildings targeted for retrofit through this grant. The eQUEST modeling uses the latest DOE-2.3 building energy analysis software. The model was compiled using information obtained from the original 1950s drawings, plans from renovation projects, assumed building usage schedules, and TMY3 weather data for Boston – Logan Airport. The existing building model was created and calibrated to metered electric and gas consumption for 2021. The retrofit building model integrates envelope and HVAC measures with no changes to other existing conditions and usage schedules beyond those described below.

Measure Implementation Assumptions: For each component affected, we describe the baseline and measure assumptions used:

Component	Existing Condition	Measure Assumption
Envelope – Wall (above grade)	R-4.2: Existing conditions include exterior walls original to 1950s construction with a single wythe of face brick, an estimated 3” air gap, 8” hollow concrete masonry unit, and 1/2” gypsum board with no added insulation	R-23.8: Retrofit adds new exterior insulation and cladding, including a fiber cement panel (R-0.21), structural insulated panels (R-13.4), and 1.5” mineral wool insulation (R-6). Floor slabs insulated with spray foam (R-5) and 1’ section at grade insulated with addition 1.25” XPS insulation and masonry veneer
Envelope – Wall (below grade)	R-2.1: Uninsulated concrete masonry unit	R-2.3 (area-weighted average of exposed and below-grade basement walls): Exposed basement wall insulated with 6.5” XPS insulation; 2” XPS up to 2’ depth below grade
Envelope – Windows	U-0.76: Windows approximately 30 years old with double glazing and non-thermally broken aluminum frames	U-0.229 (fixed), U-0.143 (operable): All windows replaced with new thermally broken aluminum framing and insulated triple glazing with SHGC-0.36
Envelope – Roof	R-18.2: Roof renovated in 2005 with four ply cold-process roofing system, 0.75” wood fiber (est. R-5.4), 2” polyisocyanurate	R-34.5: New roof assembly built up from concrete slab with 6” extruded XPS insulation

	insulation (R-11.2), and 8" concrete slab	
HVAC	Two gas-fired boilers (10-15 years old, 660 MBtu/h max output), thermal efficiency of 83%, fixed setpoint of 180°F; Window AC units with cooling EER 8.5 Heating setpoint of 75°F, cooling setpoint of 78°F	Cold climate air source heat pumps (based on Mitsubishi SUZ-KA**NAHZ-TH, avg. COP 3.67, EER 13.42) of 1.5-3.5 ton nominal outdoor unit capacity; supplemental electric resistance used below 5°F; electric resistance heaters in stairwells and basement; three new ERVs with energy recovery effectiveness of 72-75% Heating setpoint of 70-72°F (evening setback) and cooling 78-80°F (daytime setback) to reflect higher unit control
Domestic Hot Water (fixed setpoint of 135 °F)	Two gas-fired condensing water heaters (15-20 years old), 400 MBtu/h capacity at 400 GPH, thermal efficiency of 95%	Three CO ₂ heat pump water heaters with 136 MBtu/h capacity and COP at 80.6°F 4.11 (Mitsubishi QAHV)
Lighting	Mixture of fluorescent and LED lighting. Assumed lighting power density (LPD) of 1.25 W/SF in apartments, 0.75 W/SF in stairwells, and 0.5 W/SF in basement	LED fixtures for common spaces of building, assumed 0.45 W/SF lighting power
Cooking	Gas stove/oven, assumed peak load of 1.5 MBtu/h and approx. 1 therm usage per month per apartment	Electric stove/oven, approx. 700 kWh/year per apartment
Solar PV	N/A	28.4 kW _{dc} capacity. Est. annual production of 32,983 kWh

In total, measures are assumed to cost approximately \$110,000-170,000 per housing unit, based on previous construction bids and a cost study completed on behalf of BHA by Arup in 2024. Additional state and utility incentives are expected to account for 25% of the measure capital cost, with the remaining 75% provided by CPRG. A detailed discussion of the expected cost for each project site is provided in the Budget Narrative (Budget_MAPC.pdf) and the accompanying budget spreadsheet (Budgetcalcs_MAPC.xlsx).

GHG Reduction Assumptions: GHG emissions reductions assumed are tied to changes in gas and electricity usage, as well as reduction in electricity emissions intensity over time and reduction in methane leakage:

- **Gas:** Assumed emission factor of **53.11 kg CO_{2e}/MMBtu**, using the EPA 2023 Emission Factors for Greenhouse Gas Inventories and 100-year GWP from 2013 IPCC AR5 Fifth Assessment Report. Massachusetts law and regulatory proceedings currently have no provisions to increase usage of renewable natural gas injected into the gas network. This emission factor is assumed to remain constant through 2030 and 2050.
- **Electric:** We use statewide electricity GHG emission factors based on the Massachusetts analysis completed for the MA Department of Environmental Protection's annual GHG emission inventories for compliance with the Global Warming Solutions Act. The DEP approach tracks New England Power Pool Generation Information System (NEPOOL GIS) certificates across state lines within ISO-NE and from Massachusetts imports from outside of ISO-NE to estimate state emissions and emissions rates from non-biogenic and biogenic generation sources that supply Massachusetts customers. As of 2020, state emissions rates were estimated at **337.38 kg**

CO_{2e}/MMBtu (Mass Dept. of Environmental Protection Greenhouse Gas Baseline & Inventory, Appendix W: 2020 Emissions from Electricity Consumed in Massachusetts).

- Massachusetts has aggressive targets for eliminating emissions from electricity generation by 2050. These targets are represented in law by the combination of the Commonwealth's Renewable Portfolio Standard, Alternative Portfolio Standard, and an overarching Clean Energy Standard, which require retail sales of electricity to use a certain percentage of clean energy, increasing annually.
- In 2020 (the baseline year for the MA DEP electricity emissions estimate), the percentage requirement was 20%. By 2030, the requirement will be approximately 90% (which includes 60% from new generation units) in 2030 and reach 100% by 2050.
- We assume that electricity emissions decline from the 2020 baseline year-on-year in accordance with the Clean Energy Standard to achieve the 2030 and 2050 requirements. The electricity emissions factor assumed by year is detailed in the "Emissions Factors" tab of the GHG calculations spreadsheet (GHGcalcs_MAPC.xlsx).
- Boston and Chelsea HA purchase electricity from the grid or from competitive energy suppliers meeting state minimum requirements and are thus assumed to have an electricity emissions rate that matches the state emissions rate. Lowell HA purchases all electricity from a 7.4 MW solar net metering contract and is assumed to have zero electricity emissions.
- **Methane:** Increasing evidence indicates that gas cooking equipment leaks methane even when off. A recent study published in *Environmental Science and Technology* estimated each natural gas stove/oven leaks approximately 0.65 kg of methane annually.¹ We assume this leakage is eliminated through removal of gas cooking equipment and capping gas lines to electrified buildings. We assume a 100-year GWP of 28 for methane leakage avoided, in accordance with the 2013 IPCC AR5 Fifth Assessment values.

Reference Case Scenario: In the "business as usual" (BAU) scenario, we assume that the targeted buildings continue making end-of-life, like-for-like replacements to existing gas equipment. This includes a higher efficiency gas boiler replacement upon end-of-life (est. 2040). Electricity emissions continue to decline year-on-year based on the assumptions above.

Measure-Specific Activity Data: As all buildings targeted by decarbonization retrofits through this grant have a similar vintage, construction, size (i.e. all 2- or 3-story walk-up buildings with 8-24 units), HVAC/appliance conditions, and retrofit needs, we assume that all buildings will pursue the same measures and thus apply the same assumptions for pre- and post-retrofit energy consumption, scaled to the number of housing units in each building. For example, the modeled building has 19 housing units. For buildings with 15 housing units, we scale down all pre- and post-retrofit energy consumption by 21% (including solar PV generation). As described in the timeline in Section 3c of the workplan, we assume all retrofits will be completed within 27 months of contracting and begin providing GHG emissions reductions as of January 1, 2027.

GHG Emissions Reduced: Cumulative GHG emission reductions estimated are reduced by 25% to reflect state and utility incentives that will support the retrofits under Measure 1.

- Cumulative GHG Emission Reductions (2025-2030): 6,357.9 MTCO_{2e}

¹ Lebel, Eric D., Finnegan, Colin J., Ouyang, Zutao, and Jackson, Robert B. (2022) Methane and NO_x Emissions from Natural Gas Stoves, Cooktops and Ovens in Residential Homes. *Environmental Science & Technology*, 56(4), 2529-2539. DOI: 10.1021/acs.est.1c04707

- Cumulative GHG Emission Reductions (2025-2050): 38,299.2 MTCO_{2e}
- Annual GHG Emission Reductions: See the “2030 and 2050 GHG Projections” tab in the GHG calculations spreadsheet (GHGcalcs_MAPC.xlsx) for annual GHG emission reductions (“Adjusted Total”).

Measure 2 – Establish technical assistance program

GHG Reduction Estimate Method: As discussed in Section 3b of the workplan, GHG reductions are attributable to Measure 2 when TA grant awardees implement decarbonization retrofits as a direct result of the TA provided. To estimate GHG reductions, we use the same assumptions as Measure 1, using the modeled multifamily building to represent all affordable multifamily buildings that would be retrofitted as a result of Measure 2 activities. Pre- and post-retrofit energy consumption estimates are used to estimate GHG reductions, using representative emissions factors for gas and electricity. We assume increasing year-on-year reductions in electricity emissions based on Massachusetts policies and Housing Authority electricity purchasing, which are detailed further below.

Models/Tools Used: See Measure 1.

Measure Implementation Assumptions: We assume that all units of affordable housing retrofitted as a result of Measure 2 have the same existing conditions and measure assumptions as the modeled building used for Measure 1.

GHG Reduction Assumptions: We use the same assumptions for Measure 2 as Measure 1 for gas, electricity, and methane emissions. To determine the GHG reductions resulting from the TA provided to affordable housing owners and managers:

- We estimate that we will be able to make awards to 40 affordable building housing owners and managers through the TA Program (approx. \$50,000 awards on average).
- We estimate that TA awards will enable 15% of the 40 awardees to proceed with projects by 2030 and 40% by 2040.
- We assume that each project will involve 15 units of affordable housing with similar retrofit measures and energy usage characteristics to the model building (i.e. 240 units decarbonized by 2040).
- We attribute 20% of the GHG emissions achieved from each project to the TA award under Measure 2 due to the critical need for enabling TA to proceed with accessing other affordable housing decarbonization programs.

Reference Case Scenario: In the “business as usual” (BAU) scenario, we assume that the targeted buildings continue making end-of-life, like-for-like replacements to existing gas equipment. This includes a higher efficiency gas boiler replacement upon end-of-life (est. 2040). Electricity emissions continue to decline year-on-year based on the assumptions above. In the accompanying spreadsheet, we establish the BAU scenario as the GHG emissions from the 240 housing units (that are expected to be decarbonized) in the absence of additional retrofits beyond a higher efficiency boiler replacement.

Measure-Specific Activity Data: We assume that all units of affordable housing decarbonized through Measure 2 pursue the same measures as the building model described in Measure 1, and that all units have the same per-unit pre- and post-retrofit energy consumption as in the building model. In the accompanying spreadsheet, we estimate the cumulative number of units decarbonized by year.

GHG Emissions Reduced: As noted above, we attribute 20% of the estimated GHG emission reductions from implemented decarbonization retrofits to the TA awards provided through Measure 2.

- Cumulative GHG Emission Reductions (2025-2030): 177.2 MTCO_{2e}
- Cumulative GHG Emission Reductions (2025-2050): 4,224.2 MTCO_{2e}
- Annual GHG Emission Reductions: See the “2030 and 2050 GHG Projections” tab in the accompanying spreadsheet (GHGcalcs_MAPC.xlsx) for annual GHG emission reductions (“Adjusted Total”).

Measure 3 – Streamline decarbonization procurement

GHG Reduction Estimate Method: As discussed in Section 3b of the workplan, GHG reductions are attributable to Measure 3 when streamlined procurement vehicles and procurement reforms lead to cost reductions for procuring entities, which enable additional projects to be completed given limited financial resources.

To estimate GHG reductions, we use the same assumptions as Measure 1, using the modeled multifamily building to represent all public housing buildings retrofitted using procurement pathways established or modified through Measure 3 activities. Pre- and post-retrofit energy consumption estimates are used to estimate GHG reductions, using representative emissions factors for gas and electricity. We assume increasing year-on-year reductions in electricity emissions based on Massachusetts policies, which are detailed further below.

Models/Tools Used: See Measure 1.

Measure Implementation Assumptions: We assume that all units of public housing retrofitted that benefit from Measure 3 activities have the same existing conditions and measure assumptions as the modeled building used for Measure 1.

GHG Reduction Assumptions: We use the same assumptions for Measure 3 as Measure 1 for gas, electricity, and methane emissions. To determine the GHG reductions resulting from Measure 3 procurement activities:

- While activities that will be completed under Measure 3 will be dependent on research and the input of stakeholders engaged (see Section 3b of the workplan for additional discussion on Outputs and Outcomes for Measure 3), we assume that a combination of streamlined aggregated procurement vehicles and procurement reforms will contribute to an overall decarbonization retrofit cost reduction of 3%.
- Housing authorities and other public entities that are pursuing decarbonization will benefit from procurement activities completed through Measure 3. We estimate that the cost reductions provided through Measure 3 will lead to 100 additional units of public housing undergoing decarbonization retrofits by 2030 and 600 units by 2050.
- As a result of these cost reductions, we attribute 3% of the GHG emissions achieved from these decarbonization retrofit projects to Measure 3.

Reference Case Scenario: In the “business as usual” (BAU) scenario, we assume that the targeted buildings continue making end-of-life, like-for-like replacements to existing gas equipment. This includes a higher efficiency gas boiler replacement upon end-of-life (est. 2040). Electricity emissions continue to

decline year-on-year based on the assumptions above. In the accompanying spreadsheet, we establish the BAU scenario as the GHG emissions from the 600 housing units (that are expected to be decarbonized) by 2050 in the absence of additional retrofits beyond a higher efficiency boiler replacement.

Measure-Specific Activity Data: We assume that all units of affordable housing decarbonized using procurement pathways affected by Measure 3 will pursue the same measures as the building model described in Measure 1, and that all units have the same per-unit pre- and post-retrofit energy consumption as in the building model. In the accompanying spreadsheet, we estimate the cumulative number of units decarbonized by year.

GHG Emissions Reduced: As noted above, we attribute 3% of the estimated GHG emission reductions from implemented decarbonization retrofits to the cost reductions provided through Measure 3:

- Cumulative GHG Emission Reductions (2025-2030): 31.0 MTCO_{2e}
- Cumulative GHG Emission Reductions (2025-2050): 1,022.1 MTCO_{2e}
- Annual GHG Emission Reductions: See the “2030 and 2050 GHG Projections” tab in the accompanying spreadsheet (GHGcalcs_MAPC.xlsx) for annual GHG emission reductions (“Adjusted Total”).

Measure 4 – Expand regional community of practice

The expanded Energy Cohort in Measure 4 will provide affordable housing owners, managers, and professionals with valuable insights, resources, and capacity building to facilitate decarbonization project implementation.

GHG Reduction Estimate Method: As discussed in Section 3b of the workplan, GHG reductions are attributable to Measure 4 when participants in the Energy Cohort implement decarbonization retrofits as a result of support from the Energy Cohort.

To estimate GHG reductions, we use the same assumptions as Measure 1, using the modeled multifamily building to represent all affordable multifamily buildings retrofitted as a result of Measure 4 activities. Pre- and post-retrofit energy consumption estimates are used to estimate GHG reductions, using representative emissions factors for gas and electricity. We assume increasing year-on-year reductions in electricity emissions based on Massachusetts policies and Housing Authority electricity purchasing, which are detailed further below.

Models/Tools Used: See Measure 1.

Measure Implementation Assumptions: We assume that all units of AH retrofitted as a result of Measure 4 have the same existing conditions and measure assumptions as the modeled building used for Measure 1.

GHG Reduction Assumptions: We use the same assumptions for Measure 4 as Measure 1 for gas, electricity, and methane emissions. To determine the GHG reductions resulting from the TA provided to AH owners and managers:

- We estimate that we will be able to grow membership in the Energy Cohort from 500 members to 1,000 by the end of the grant.

- We assume that building owners participating in the Energy Cohort will pursue additional decarbonization retrofits that they otherwise would not have without support from the Energy Cohort.
- We estimate that the incremental increase in AH units receiving decarbonization retrofits will be 200 units by 2030, 700 units by 2040, and 1,300 units by 2050.
- We attribute 1% of the GHG emissions achieved from each project to the Energy Cohort.

Reference Case Scenario: In the “business as usual” (BAU) scenario, we assume that the targeted buildings continue making end-of-life, like-for-like replacements to existing gas equipment. This includes a higher efficiency gas boiler replacement upon end-of-life (est. 2040). Electricity emissions continue to decline year-on-year based on the assumptions above. In the accompanying spreadsheet, we establish the BAU scenario as the GHG emissions from the 1,300 housing units (expected to be decarbonized) in the absence of additional retrofits beyond a higher efficiency boiler replacement.

Measure-Specific Activity Data: We assume that all units of AH decarbonized through Measure 4 pursue the same measures as the building model described in Measure 1, and that all units have the same per-unit pre- and post-retrofit energy consumption as in the building model. In the accompanying spreadsheet, we estimate the cumulative number of units decarbonized by year.

GHG Emissions Reduced: As noted above, we attribute 1% of the estimated GHG emission reductions from implemented decarbonization retrofits to the TA awards provided through Measure 4.

- Cumulative GHG Emission Reductions (2025-2030): 24.5 MTCO_{2e}
- Cumulative GHG Emission Reductions (2025-2050): 761.1 MTCO_{2e}
- Annual GHG Emission Reductions: See the “2030 and 2050 GHG Projections” tab in the accompanying spreadsheet (GHGcalcs_MAPC.xlsx) for annual GHG emission reductions (“Adjusted Total”).