Technical Appendix

This appendix outlines the assumptions and methodologies employed in devising the estimated reductions in greenhouse gas (GHG) emissions for the GAHP measure aimed at GHG reduction. We have demonstrated our process so that the U.S. Environmental Protection Agency (EPA) can follow the estimated GHG emission reductions calculations presented in the application. Included are the details of the methods utilized, models employed, key assumptions made, relevant outputs, and individual calculations supporting the estimates of GHG reduced. These estimates encompass both annual and cumulative GHG emission reductions, spanning 2025 through 2030 and 2025 through 2050. Please refer to GHGcalcs_SaltLakeCounty included in Other Attachments for specific calculations for the GHG reduction measure outlined in the application.

1. ***GHG Reduction Estimate Method****: Describe the methods used to arrive at the measure related activity data or other outputs and the GHG emission reduction estimate (e.g., engineering estimates, modeling, existing publicly available tool or calculator).*

We calculated the greenhouse gas (GHG) and local Nitrogen oxides (NOx) emissions benefits of all-electric multi-family housing located in Salt Lake County, Utah, compared to more traditional mixed-fuel housing, using gas for space and water heating, and clothes drying and cooking. We assumed 500 new units of multi-family housing and compared the emissions with more conventional mixed-fuel units of the same size. As described in the following sections, we used a variety of methods, including a publicly available report about building electrification in Utah, Salt Lake County-specific climate data, data from the Pacific Northwest National Laboratory (PNNL), and data from the National Renewable Energy Laboratory (NREL). Table 1 provides the comparative energy consumption data and GHG emissions per all-electric and mixed fuel housing units.

Table 1 – Energy and GHG Emissions by End-use.

All-Electric Units				Mixed Fuel Units			
Energy end-use	Electricity consump-tion (MMBtu/yr)	GHG emissions (kg CO_2/yr) average for 2025-2030	GHG emissions (kgCO2/yr) average for 2025-2050	Electricity consump-tion (MMBtu/yr)	Fuel (gas) consump-tion (MMBtu/yr)	GHG emissions (kg CO_2/yr) average for 2025-2030	GHG emissions (kg CO2/yr) average for 2025-2050
Space heating	5.3	836	492		26.4	1401	1401
Water heating	3.1	489	288		14.9	791	791
Cooking	2.3	363	213		4.3	228	228
Clothes dryer	2.4	379	223		3.8	202	202
Space cooling	1.6	252	148	2.7		426	251
Fans (air handling unit or mini-splits)	0.3	47	28	1.3		205	121
Total	**15.0**	**2,366**	**1,392**	**4.0**	**49.4**	**3,252**	**2,992**

As shown in Table 1, the total energy consumption for the all-electric unit (15.0 MMBtu/yr) is much less than the total for the mixed-fuel unit (53.4 MMBtu/yr). This is because the electric equipment, especially the cold-climate ductless mini-split heat pumps and heat pump water heaters, are so much more efficient than gas furnaces and gas water heaters. The specifications of the equipment are shown below in Table 3. These improvements in efficiency, together with the steadily declining electricity emission factors, lead to significant GHG emission reductions for all-electric units, highlighted in Table 5.

In addition to the substantial reductions in GHG emissions shown above, the all-electric units also significantly reduce local air pollutants, NOx, from gas combustion, as shown below in Table 2.

Table 2 – Reductions in NOx Emissions.

	All-Electric	Mixed Fuel
Annual NOx emissions per unit (kg NOx/yr)	0	113
Total NOx emissions per unit for 2025-2030 (kg NOx)	0	675
Total for 500 units (kg NOx) for 2025-2030	**0**	**337,633 (337 mt)**
Total NOx emissions per unit for 2025-2050 (kg NOx)	0	2,926
Total for 500 units (kg NOx) for 2020-2050	**0**	**1,463,075 (1,463 mt)**

2. ***Models/Tools Used***: *List or describe the specific models or tools used to develop the GHG emission reduction estimate; the name of the developer/provider of the model/tool (e.g., EPA); and any other detailed references (e.g., specific versions of the model or tool), as appropriate.*

The GAHP GHG reduction measure calculations were done using a variety of data sources. The following tools were used to develop the estimate. We used the estimated energy consumption values, for both the mixed-fuel and all-electric multi-family buildings, from Energy+Environmental Economics' (E3's) report, "Economics of All-Electric New Construction in Utah," Table 6.2 on p. 37 of the Appendix[1]. The values are site energy consumption, resented in MMBtu for both gas and electricity. E3's building energy consumption data for each building prototype was calculated using data from Pacific Northwest National Laboratory's (PNNL) database of Residential Prototype Building Models[2]. The E3 report, that was referenced for the GAHP calculations, used the U.S. Department of Energy's (DOE's) EnergyPlus[3] modeling software. The data from the E3 report is for the entire state of Utah, so the process was replicated with climate and energy data specific to Salt Lake County.

3. ***Measure Implementation Assumptions***: *Provide key assumptions related to the implementation of the GHG reduction measure (e.g., data supporting assumed rate of measure implementation, implementation milestones, measure lifetime, capital cost assumptions, operation and maintenance cost assumptions).*

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[1] Energy+Environmental Economics, Feb. 2022. "The Economics of All-Electric Construction in Utah." https://www.ethree.com/wp-content/uploads/2022/02/Economics-of-All-Electric-New-Construction-in-Utah-02.2022.pdf.

[2] https://www.energycodes.gov/prototype-building-models#Residential

[3] https://energyplus.net/

All 500 electric housing units will be implemented during the performance period of the grant, 2025-2030, with the majority of the all-electric units being online in Years 4 and 5 of the grant period. The implementation process will be divided into five project implementation phases, including 1) Design Phase: 6 month duration; 2) Outreach Phase: 1 year, 6 months duration; 3) Application Phase: 6 month duration, occurring simultaneously with the last 6 months of the Outreach Phase; 4) Funding Phase: 3 year duration; and 5) Evaluation Phase: 3 months duration, occurring simultaneously with the Funding Phase during the last 3 months of the project. This is described in depth in Section 3.c. of the Work Plan narrative. We anticipate that the GHG reduction measure will remain operational for a minimum of 10 years, considering the expected lifespan of the GAHP technology. For example, the HPWH may need to be replaced after twelve years, and the cold-climate mini-split heat pumps may need to be replaced after about fifteen years[4].

4. ***GHG Reduction Estimate Assumptions****: Provide key assumptions used as part of the method for estimating GHG emission reductions (e.g., emission rates; emission factors; input assumptions if modeling is used, such as cost and performance data, energy prices).*

The energy consumption values from E3's report are based on the equipment efficiencies shown below in Table 3. The equipment specifications and efficiencies for the all-electric and mixed-fuel units are shown on page 10 of the E3 report cited above. Note that for Salt Lake County, the all-electric units were modeled using the cold-climate mini-split heat pumps for heating and cooling.

Table 3 – Efficiencies of Equipment.

Equipment for all-electric units	Efficiency Specification	Equipment for mixed fuel	Efficiency Specification
Cold-climate mini-split HPs - heating	12.5 HSPF (COP of 3.7)	Gas furnace	80 AFUE
Mini-split HPs - cooling	25 SEER	Air conditioning	14 SEER
Heat pump water heater	3.0 UEF	Gas tank water heater	.63 UEF
ER cooking (0.74 EF)	.74 EF	Gas stove	.4 EF
ER clothes dryer (3.1 EF)	3.1 EF	Gas clothes dryer	2.75 EF

As an explanation of the emission factors taken into account: For gas, we used the accepted EPA emission factor of 117 lb CO_2/MMBtu (53.06 kg CO2/MMBtu). For electricity, we used the projected electricity emission factors for the State of Utah from the National Renewable Energy Laboratory (NREL).[5] With this data, NREL offers several scenarios, of which we chose the "Mid-Case 95 by 2050" scenario, which is closest to Utah's clean electricity goals. Within this scenario, for the short-term GHG benefits, we used the projected emission factors for 2025-2030; for the long-term GHG benefits, we used the projected emission factors for 2025-2050. For both time periods, we calculated the average emission factor for that period (6 years and 26 years). These average values are shown below in Table 4.

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[4] Twelve and fifteen years are average expected lives of heat pump water heaters and air-source heat pumps, respectively. For water heaters, see https://www.nachi.org/lifespan-water-heater.htm; for air-source heat pumps, see https://www.naturalhandyman.com/iip/infhvac/ASHRAE_Chart_HVAC_Life_Expectancy.pdf.

[5] "Cambium," NREL, 2021, https://scenarioviewer.nrel.gov/?project=a3e2f719-dd5a-4c3e-9bbff24fef563f45&mode=download&layout=Default.

NREL also offers several choices for GHG emission factors, and we chose the "annual average emission rate." The annual average emission rates (as opposed to for example, the "long-term marginal emission rates") are appropriate for analyzing the question, "what will be the emissions impact from this particular set of buildings?" (as opposed to analyzing a set of policies and programs, for which the long-term marginal rate would be more appropriate). The NREL projected annual average emission rates and the calculated averages for the two time periods are shown in the table below. Using the electricity and fuel consumption values provided in Table 1, and the GHG emission factors from above, we calculated the emissions for the mixed-fuel multi-family units and the all-electric multi-family units. The calculations are all provided in the attached spreadsheet.

Table 4 – Electricity GHG Emission Factors.

Year	Annual emission rate – load* (kg CO2e/MWh)
2024	516.5
2025	550.4
2026	584.2
2027	559.4
2028	534.6
2029	511.8
2030	488.9
2032	476.2
2034	461.2
2036	444.3
2038	389.3
2040	327
2042	200.3
2044	78.1
2046	67
2048	46.6
2050	18.9
Average emission factor for 2025 - 2030	**538.2**
Average emission factor for 2025 - 2050	**316.7**

*This means electricity generated to serve Utah's load. NREL also provides an annual average emission rate based on Utah's average generation, which is slightly lower, so we chose this one to be slightly more conservative. For NOx emissions, we used a NOx emission factor from EPA, 9.4 lb NOx/MMBtu, for commonly used residential gas furnaces.[6]

5. ***Reference Case Scenario (GHG Emissions or Activity Level)**: Describe the reference scenario that is used to quantify GHG emission reductions for each measure, as applicable. The type of reference scenario may differ depending upon the type of GHG reduction measure.*

[6] EPA Gas Emission Factors, https://gaftp.epa.gov/ap42/ch01/s04/final/c01s04_oct1996.pdf

As described above, we used the estimated energy consumption values, for both the mixed-fuel and all-electric multi-family buildings, from Energy+Environmental Economics' (E3's) report, "Economics of All-Electric New Construction in Utah," Table 6.2 on p. 37 of the Appendix[7].

6. ***Measure-Specific Activity Data**: Provide relevant activity data that is used for estimating GHG emission reductions for each measure. This may include data such as energy savings (e.g., MMBtu by fuel or MWh saved), electrical output (e.g., MWh), vehicle miles traveled, units of equipment installed, or other metrics used to track the implementation and/or effects of a GHG reduction measure. Applicants should use reasonable assumptions for measure implementation (e.g., market availability and level of use for a technology-related measure or level of participation for an activity-related measure).*

The only measure-specific activity data is the energy consumption values for the two buildings mixed-fuel and all-electric, as explained previously.

7. ***GHG Emissions Reduced**: For each GHG reduction measure, provide measure-specific estimated annual GHG emission reductions (e.g., absolute reduction in metric tons of CO2 equivalent [mtCO2e]) and cumulative GHG emission reductions for the periods 2025 through 2030, and 2025 through 2050.*

The cumulative GHG emission reductions for the 500 all-electric multi-family units in Salt Lake County for 2025-2030 are 2,660 metric tons of CO_2e (compared to the mixed fuel units). For the period of 2025-2030, the cumulative GHG emission reductions for 500 multi-family all-electric units in Salt Lake County are 20,800 metric tons of CO_2e. Because of the projected steady reductions in the GHG emissions from the electricity grid, the all-electric units produce much greater reductions in GHG emissions for the longer-term period (2025-2050) than for the shorter-term period (2025-2030).

Table 5 – Summary of GHG Emission Reductions, 2025-2030 and 2025-2030.

Total GAHP GHG Reductions 2025-2030	All-Electric	Mixed Fuel	GHG emission reductions for all-electric (kg CO2e)
Annual GHG emissions per unit (avg for 2025-2030) (kg CO_2e/yr)	2,366	3,252	
Total (Cumulative) GHG emissions per unit for 2025-2030 (kg CO_2e)	14,196	19,513	5,316
Percentage GHG emission reductions for all-electric: 2025-2030			**27.2%**
Total (Cumulative) GHG emissions for 500 units for 2025-2030 (kg CO_2e)	7,098,183	9,756,341	**2,658,158 (2,660 mt)**

[7] Energy+Environmental Economics, Feb. 2022. "The Economics of All-Electric Construction in Utah." https://www.ethree.com/wp-content/uploads/2022/02/Economics-of-All-Electric-New-Construction-in-Utah-02.2022.pdf.

Total GAHP GHG Reductions 2025-2050	**All-Electric**	**Mixed Fuel**	**GHG emission reductions for all-electric (kg CO2e)**
Annual GHG emissions per unit 2025-2050 (kg CO_2e /yr)	1,392	2,992	
Total (Cumulative) GHG emissions per unit for 2025-2050 (kg CO_2e)	36,195	77,802	41,607
Percentage GHG emission reductions for all-electric: 2025-2050			**53.5%**
Total (Cumulative) GHG emissions for 500 units for 2025-2050 (kg CO_2e)	18,097,597	38,901,158	**20,803,561 (20,800 mt)**