Appendix C

GHG Reduction Quantification Supporting Documentation

The following summary was developed by ICF Incorporated for the Air District to inform PCAP measure development and outline the approaches used by ICF to quantify the anticipated greenhouse gas emission reductions resulting from the two priority measures in the PCAP.

The quantification of GHG emission reductions from PCAP measures is subject to a data review and quality control process that is described in the Quality Assurance Project Plan (QAPP). This quantification is based on assumptions made on how the measure might be implemented as well as variables identified from existing literature and real-world data. As such, these GHG emission reduction estimates may be subject to an update in the CCAP process based on further QA of assumptions, best and worst case scenarios, and future improvements to data.

Memorandum

To: Monte DiPalma

From: Emily Adkins, Mollie Carroll, Adam Agalloco, Sam Pournazeri, ICF Incorporated

Date: February 29, 2024

Re: PCAP Measure Modeling Methodology

Overview

The U.S. Environmental Protection Agency's (EPA) Climate Pollution Reduction Grant (CPRG) program is one of the most flexible, fastest paced programs the federal government needs to deploy per the Inflation Reduction Act (IRA) of 2022. To support the Air District in development of a Priority Climate Action Plan (PCAP) covering the greater Bay Area, ICF quantified greenhouse gas (GHG) emissions reductions from building and transportation measures. This analysis is one component in support of a comprehensive climate planning effort the Air District is overseeing. The intent of this memo is to briefly summarize the results of this modeling effort and describe the underlying assumptions and methodologies used.

Brief Results Overview

Residential Building Decarbonization Measure

Table 1. Annual Emissions Mitigated by Buildings Measure (MT CO_2e)

	2025	2030	2035	2040	2045	2050
Air-source heat pump replaced for:						
Gas Boiler	571	6,827	13,301	17,375	18,284	18,297
Gas Furnace	4,259	50,910	99,170	129,409	136,086	136,183
Propane Furnace	155	1,858	3,617	4,705	4,938	4,941

	2025	2030	2035	2040	2045	2050
Electric Central Heat Pump replacement of Gas Hot Water Heater	3,361	37,081	66,701	81,106	85,389	85,567
Electric Oven and Induction Stovetop replacement of a Gas Oven and Range	272	3,420	7,411	10,847	12,395	12,611
ENERGY STAR Electric Dryer replacement for a Gas Dryer	97	1,240	2,544	3,864	5,117	5,641
Efficiency Measures (Thermostats and Lighting)	411	5,037	11,862	16,436	14,165	11,554
Weatherization and Deep Envelope Measures	819	10,195	22,873	34,608	44,322	53,061
Total Annual Emission Reductions	**9,945**	**116,567**	**227,479**	**298,351**	**320,695**	**327,857**

Table 2. Cumulative Emissions Mitigated by Buildings Measure (MT CO_2e)

	2025-2030	2025-2050
Air-source heat pump replaced for:		
Gas Boiler	20,464	336,784
Gas Furnace	152,592	2,508,472
Propane Furnace	5,568	91,219
Electric Central Heat Pump replacement of Gas Hot Water Heater	114,894	1,627,388
Electric Oven and Induction Stovetop replacement of a Gas Oven and Range	10,047	209,754
ENERGY STAR Electric Dryer replacement for a Gas Dryer	3,628	81,318
Efficiency Measures (Thermostats and Lighting)	14,902	274,436
Weatherization and Deep Envelope Measures	30,034	720,152
Total Cumulative Emission Reductions	**352,129**	**5,849,523**

Transportation Decarbonization Measure

Table 3. Cumulative Emissions Mitigated by Transportation Measure (MT CO_2e)

	Assumed Project Lifetime	2025-2030	2025-2050
Bike Infrastructure			
Light Rail	2027 - 2042	922	3,206
Commuter Rail	2027 - 2042	24,910	86,670
BRT	2027 - 2042	28	96
Pedestrian Infrastructure			
Light Rail	2027 - 2042	306	1,065

	Assumed Project Lifetime	2025-2030	2025-2050
Commuter Rail	2027 - 2042	11,064	38,497
BRT	2027 - 2042	8	28
E-Bike Share	2027 - 2039	1,352	3,069
E-Bike Incentive	2027 - 2039	3,484	7,911
EV Car Share	2027 - 2039	52,054	145,234
Transit Subsidy	2027 - 2032	31	87
EV Charging	2027 - 2037	77,525	184,819
Total Cumulative Emissions Reduction		**171,648**	**470,682**

Residential Building Decarbonization Measure

Building Energy Use

Building energy use and building GHG emissions projections are based on energy consumption from electricity, natural gas, fuel oil, and propane in existing residential buildings (both single family and multifamily). The base year and projections for energy consumption in existing buildings are built from the 2022 Annual Energy Outlook (AEO), which represented projected energy use prior to the passage of the Inflation Reduction Act, from the U.S. Energy Information Administration (EIA)[1]. AEO data is scaled to the Bay Area counties by scaling AEO census level data with census level ResStock building summary information. The tool uses a ratio of county proportional ResStock data, to apportion energy use to the various counties. Energy use values have been integrated with emissions factors for primary fuels (electricity, gas, propane and fuel oil) to provide total emissions. Results are provided every five years from 2020 to 2050 and interpolated for years in between.

CO_2Sight[2] is a strategic planning platform for decarbonization developed and maintained by ICF. This platform leverage's ICF's experience developing energy and climate policies and programs into a unified scenario analysis that allows users to assess future scenarios. The platform allows for a high degree of customization based on individual project needs. The modeling methodology for existing buildings utilizes ICF's Distributed Energy Resources Planner (DER Planner) model. Together the CO_2Sight platform and DER Planner estimate energy and GHG emissions changes from a range of decarbonization strategies including electrification retrofits and energy efficiency as presented in these results. In modeling buildings, ResStock[3] building characteristics and energy use data serve as a representation of each county's building portfolio. The ResStock energy use data are calibrated to match the EIA's AEO dataset. ResStock data was compiled by the National Renewable Energy Laboratory (NREL) including large public and private data sources, statistical sampling, detailed subhourly building simulations, and high-performance computing. By synthesizing multiple sources into a single resource, these data allow for a granular understanding of the housing stock and the impacts of building technologies in different

[1] https://www.eia.gov/outlooks/aeo/
[2] https://www.icf.com/technology/energy-decarbonization-platform-cosight
[3] https://www.nrel.gov/buildings/resstock.html

communities. These data are comprehensive and widely used across similar analyses and modeling efforts, and thus allow for development of comparable results.

DER Planner, informed by stock CO_2Sight measures data, has the capabilities to model more than 80 residential and commercial energy efficiency, electrification, and building envelope measures, in selected building types. ICF's program experience and available national data sources inform these measures' impacts on energy use. The modeling analysis was applied to the Bay Area counties building datasets, which CO_2Sight aggregates to estimate the changes in energy use.

DER Planner takes into account implementation rates of energy measures whereby individual building systems will be replaced in kind, switched to a more efficient technology, or switched to a comparable efficient electric technology, either as elective retrofits or at the time of natural replacement. For this work, adoption curves were developed specifically to represent the maximum adoption potential of new incentive programs for electrification and energy efficiency technologies. ICF worked with Air District staff to determine the correct CO_2Sight Strategy packages (DER Planner modeling result) to apply that best represents the alternative case needs. Core assumptions are outlined below.

- Zero NO_X standard implementation dates (applies to appliances manufactured after the noted date):
  - **Jan. 1, 2027** – Water heaters less than 75,000 BTU/hr (typically residential tank water heaters)
  - **Jan. 1, 2029** – Residential and commercial furnaces
  - **Jan. 1, 2031** – Water heaters between 75,000 and 2 million BTU/hr (commercial and multifamily)

Figure 1: Zero NOx standards implementation dates

Finally, ICF worked to post process the outputs to account for the Air District's zero NOx-emitting appliance regulations.[4] Beginning in 2027, as restrictions on NOx limits availability to install certain emitting technologies, ICF reduced number of retrofits in alignment with the useful life of the equipment. As an example, in 2040, 11 years after the change in rules, the number of modeled retrofits for a furnace to air source heat pump, equipment with an estimate 18 year lifecycle, was reduced by 61% (11 years/18 year useful life), to account for the fact that only 39% of the existing stock would have been installed prior to the rule change. Additional details and specific assumptions on this post processing are found in the NOx regulation section below.

Electricity Grid

CO_2Sight uses ICF's Integrated Planning Model[5] (IPM) tool to generate a trajectory of grid emissions factors associated with the electricity grid. The IPM model is populated with inputs from sector-specific analyses and solves for a least-cost mix of clean energy resources that are able to satisfy the resulting energy demand. IPM provides long-term projections of behaviors for existing, new commercial, and renewable power plants to meet electric generation demand while complying with specific limitations

[4] https://www.baaqmd.gov/rules-and-compliance/rule-development/building-appliances
[5] https://www.icf.com/technology/ipm

including regulation, transmission constraints, and operating constraints. IPM is a logically consistent framework through which to examine compliance outcomes in wholesale power market operation.

IPM includes a characterization of existing and potential incremental capacity. EPA assumptions are used to represent on and offshore wind generation. IPM includes solar (PV and thermal) resource potential varying in costs, generation profile, and contribution to reserve margin, which is modeled consistent with market operations for capacity requirements.

For this model, ICF used stock and available IPM modeling runs based on “on the books” policies to account for reductions in GHG emissions from grid-sourced electricity that are expected to occur regardless of whether any additional policy action is taken to encourage them (i.e., policies that are already on the books). These policies excluded the IRA, IIJA or CHIPS and Sciences Act. The “on the books” reductions through IPM were used to develop CALISO emissions factors which were then used to calibrate projections of electricity emissions factors for the Bay Areas based on a consumption emissions factor provided by the Air District.

Greenhouse Gas Emissions

Energy results were combined with emissions factors and scaling of frontline community households (discussed in further detail in this memo) to determine GHG emissions reductions. Equation 1, outlines the general approach.

Equation 1

GHG Emissions Reductions	=	Change in energy use per measure	x	Fuel and electricity emissions factors	x	Scaling to frontline community household prevalence

Emissions and Energy Modeling Assumptions

ICF used a range of assumptions regarding existing building stock and equipment efficiency. These were based in part on equipment available in the marketplace and certified as energy efficient through EPA’s ENERGY STAR[6] program and partially through previous program experience and published program result information. Together, ICF modeled 10 measures with retrofit curves. ICF worked with Air District staff and BAYREN to review assumptions on the efficiency levels for air-source heat pumps, gas furnace, gas boiler, electric central heat pumps and other equipment outlined below.

[6] https://www.energystar.gov/products

Table 4. Energy Change Assumptions by Measure

Efficient Measure	Baseline Measure	Fuel Type	Fuel Switch	Assumptions
Electric Central Heat Pump replacement of Gas Hot Water Heater	Gas Central hot water heater	Electricity & natural gas	Yes	Replace a Gas Hot Water Heater with 80% efficiency to a Heat Pump Water Heater with an energy factor (EF) of 2.
Electric Oven and Induction Stovetop replacement of a Gas Oven and Range	Gas Oven/stovetop	Electricity & natural gas	Yes	Replace a gas stovetop/oven with an induction stovetop/oven
ENERGY STAR Electric Dryer replacement for a Gas Dryer	Gas Dryer	Electricity & natural gas	Yes	Replace a gas dryer with an ENERGY STAR electric dryer.
Air-source Heat Pump (ASHP) replacement	Gas Furnace	Electricity & natural gas	Yes	Replace furnace with 80% efficiency with an ASHP that has a coefficient of performance (COP) of 2.8, also increased efficiency of AC from 2.5 COP
Air-source Heat Pump replacement	Propane Furnace	Electricity & propane	Yes	Replace furnace with 90% efficiency with an ASHP that has a 2.8 COP, also increased efficiency of AC from 2.5 COP
Air-source Heat Pump replacement	Gas Boiler	Electricity & natural gas	Yes	Replace boiler with 80% efficiency with an ASHP that has a COP of 2.8, also increased efficiency of AC from 2.5 COP
Smart Thermostat	Existing Thermostat	Electricity & natural Gas	No	8% reduction in gas, 10% reduction in electricity use from space heating and cooling
Building Envelope Sealing and Weatherization	Existing Building Envelope	Electricity & natural Gas	No	15% reduction in gas, 15% reduction in electricity use from space heating and cooling
Deep Building Envelope Sealing and Weatherization	Existing Building Envelope	Electricity & natural Gas	No	30% reduction in gas, 30% reduction in electricity use from space heating and cooling
Lighting Retrofit	Existing Lighting	Electricity	No	75% reduction in lighting energy use

Electricity Grid Emissions Factors

Grid emissions factors were developed using the methodology outlined above.

Table 5. Electricity Grid Emissions Factors (MT CO_2e/MWh)

2024	2025	2026	2027	2028	2029	2030	2035	2040	2045	2050
0.051	0.050	0.052	0.054	0.056	0.058	0.060	0.053	0.022	0.001	0.000

Natural Gas and Propane Emissions Factors

Values from EPA's Center for Corporate Climate Leadership GHG Emission Factors Hub were used.[7]

Table 6. Fuel Emission Factors (kg CO_2e/MMBTU)

Fuel	Emission Factors
Natural Gas	53.06
Propane	62.39

Scaling Results by Frontline Communities

To derive the portion of DER Planner results attributed to frontline communities, ICF scaled output results (which include energy change and participation) from single family and multifamily households at the County level. Total housing units in frontline communities by County were provided by the Air District,[8] while total housing units were taken from the U.S. Census.[9] Scaling of results combined the building typology (e.g., single family or multi-family) and measure specific County results with the proportional households from frontline communities. As an example: The Alameda County results from updating single family homes from a gas hot water heater to an electric central heat pump were scaled to match the proportion of single-family homes that are in frontline communities. Using this approach, the frontline community participation, GHG emissions, and energy savings for each measure is scaled proportionally to both the measure penetration[10] within the Counties, the household types in the Counties, and the proportion of frontline community housing units within each County. Using this approach, the model assumes that frontline community housing units have the same general characteristics (equipment types) as those within other parts of the counties and thus a retrofit program has the same results on a household basis.

[7] https://www.epa.gov/climateleadership/ghg-emission-factors-hub

[8] Based on EPA IRA Disadvantaged Communities, AB 617 communities, and Metropolitan Transportation Commission's Equity Priority Communities.

[9] https://www.census.gov/data/datasets/time-series/demo/popest/2020s-total-housing-units.html

[10] Measure penetration is a value used to determine the percentage of users or available stock that adopts something; in this case it refers to the percentage of measures adopted in eligible households. Measure penetration will vary based on the unique equipment and building characteristics of a given area.

Table 7. Percentage of Housing types by County that are in Frontline Communities

County	Units in 2-4 Unit Buildings	Units in 5+ Unit Buildings	Units in Single-Family, Townhome, Etc.
Alameda County	5.2%	13.1%	18.6%
Contra Costa County	3.2%	7.8%	20.3%
Marin County	1.0%	6.4%	3.8%
Napa County	2.2%	4.6%	14.3%
San Francisco County	7.4%	28.0%	15.4%
San Mateo County	3.4%	10.2%	13.6%
Santa Clara County	0.0%	0.0%	0.1%
Solano County	3.3%	5.2%	16.2%
Sonoma County	2.8%	6.5%	13.7%
Average Frontline Community Housing Type Within the Region (Regional Weighted Average)	**3.4%**	**9.8%**	**12.5%**

Participation Rates

To model participation rates, an S-curve is assumed for adoption to match the rate and shape of technology curves from NREL's Electrification Futures Study.[11] The maximum program participation rate was set separately for each retrofit program based on participation rates in similar programs.[12] In the current modeling, retrofit programs for air source heat pumps to provide both space and water heating were set at a maximum adoption rate of 2.5%. Programs for appliances (both gas-to-electric dryers and gas ovens/cooktops-to-electric and energy efficiency) achieved a maximum of a 1.6% program adoption rate. In both cases, programs would scale rapidly to the maximum adoption rate to reflect a program that scales quickly and assumes existing barriers that can slow participation have been addressed.

Scaled Results

Table 8. Annual Installations

	2025	2030	2035	2040	2045	2050
Air-source heat pump replaced for:						
Gas Boiler	457	1,233	860	455	128	-
Gas Furnace	3,195	8,618	6,015	3,182	897	-
Propane Furnace	91	246	172	91	26	-
Electric Central Heat Pump replacement of Gas Hot Water Heater	4,885	11,378	6,156	771	-	-
Electric Oven and Induction Stovetop replacement of a Gas Oven and Range	2,019	5,918	6,111	5,746	5,664	5,703
ENERGY STAR Electric Dryer replacement for a Gas Dryer	1,022	2,995	3,093	2,908	2,866	2,886
Efficiency Measures (Thermostats and Lighting)	5,678	16,640	17,182	16,085	15,520	15,216
Weatherization and Deep Envelope Measures	4,324	12,673	13,085	12,234	11,724	11,394
Total Annual Installations	**21,671**	**59,701**	**52,674**	**41,471**	**36,825**	**35,199**

[11] https://www.nrel.gov/analysis/electrification-futures.html
[12] https://eta-publications.lbl.gov/sites/default/files/ee_program_participation.pdf

Table 9. Cumulative Installations

	2025-2030	2025-2050
Air-source heat pump replaced for:		
Gas Boiler	5,554	15,113
Gas Furnace	38,833	105,670
Propane Furnace	1,109	3,018
Electric Central Heat Pump replacement of Gas Hot Water Heater	55,257	113,230
Electric Oven and Induction Stovetop replacement of a Gas Oven and Range	25,204	142,280
ENERGY STAR Electric Dryer replacement for a Gas Dryer	12,755	72,002
Efficiency Measures (Thermostats and Lighting)	70,868	395,354
Weatherization and Deep Envelope Measures	53,975	299,991
Total Cumulative Installations	**263,555**	**1,146,658**

Table 10. GHG emissions reductions and energy change per Installation in 2025 by measure

	MT CO_2e reduced per install	Change in kWh per install	Change in therms per install
Air-source heat pump replaced for:			
Gas Boiler	1.25	2146.7	-255.9
Gas Furnace	1.33	2242.0	-272.4
Propane Furnace	1.69	2679.4	-294.3
Electric Central Heat Pump replacement of Gas Hot Water Heater	0.68	1708.8	-145.8
Electric Oven and Induction Stovetop replacement of a Gas Oven and Range	0.14	318.2	-28.6
ENERGY STAR Electric Dryer replacement for a Gas Dryer	0.10	742.5	-25.3

	MT CO_2e reduced per install	Change in kWh per install	Change in therms per install
Thermostat	0.08	-132.4	-13.8
Lights	0.04	-828.3	0.0
Weatherization	0.14	-126.7	-25.9
Deep Energy	0.29	-253.5	-51.8

Zero NOx-Emitting Appliance Regulations

Given that the focus of this measure is on retrofit programs and not a replacement on burnout for equipment, model results were post processed to account for the Air District's zero NOx-emitting appliance regulations. The rules focus on replacement upon burnout and thereby decrease total participation levels in retrofit programs in later years when a smaller population of retrofit opportunities exist due to stock turnover. ICF used a set of assumptions to post process modeling results to account for a decreasing population of retrofittable stock for four of the retrofit types per the appliance regulation (Gas Boiler to ASHP, Gas Furnace to ASHP, Propane Furnace to ASHP and Gas Hot Water Heater to Electric Central Heat Pump). Useful life for each equipment is based on data provided to ICF by the Air District in alignment with NOx regulation modeling assumptions.[13]

Table 11. Assumptions used for zero NOx-emitting appliance regulations post processing of results

Equipment	Assumptions
Small Gas Hot Water Heaters (smaller than 75,000 BTU/hr)	• Available stock for small water heaters begins declining in 2027, using a 13 year useful life. • Small gas hot water heaters are assumed for all single family housing units, all multifamily housing units with less than 4 units, and half of all multifamily units with 5 or more units
Large Gas Water Heater (between 75,000 and 2 million BTU/hr)	• Available stock for large water heaters begins declining in 2031, using a 13 year useful life. • Large gas hot water heaters are assumed for half of all multifamily units with 5 or more units
Residential furnaces	• Available stock for residential furnaces begins declining in 2029, using an 18 year useful life.

While the useful life of equipment above were used in modeling, the actual implementation of this regulation may vary. There will be significant upfront cost to replace aging equipment, property owners may work to extend the life of their aging equipment (in lieu of replacing it), providing for a longer retrofit program effectiveness than shown in modeling.

[13] Equipment lifetimes are from data supporting the National Energy Modeling System (NEMS) and *Residential Building Electrification in California* (2019) by Energy and Environmental Economics. https://www.ethree.com/wp-content/uploads/2019/04/E3_Residential_Building_Electrification_in_California_April_2019.pdf

Additional Results Data

Table 12. Annual MMBTU Reduction by Measure

	2025	2030	2035	2040	2045	2050
Air-source heat pump replaced for:						
Gas Boiler	11,695	142,146	273,830	339,421	345,102	344,844
Gas Furnace	87,040	1,057,958	2,038,052	2,526,231	2,568,515	2,566,592
Propane Furnace	2,686	32,644	62,885	77,948	79,253	79,194
Electric Central Heat Pump replacement of Gas Hot Water Heater	71,227	805,645	1,425,471	1,607,710	1,612,655	1,612,655
Electric Oven and Induction Stovetop replacement of a Gas Oven and Range	5,770	72,025	159,805	230,266	245,061	238,152
ENERGY STAR Electric Dryer replacement for a Gas Dryer	2,589	32,322	71,715	103,336	109,976	106,875
Efficiency Measures (Thermostats and Lighting)	5,231	65,299	144,881	208,763	222,176	215,912
Weatherization and Deep Envelope Measures	14,713	183,652	408,480	621,610	818,501	999,147
Total Annual MMBTU Reduced	**200,952**	**2,391,691**	**4,585,119**	**5,715,285**	**6,001,239**	**6,163,370**

Table 13. Cumulative MMBTU Reduction by Measure

	2025-2030	2025-2050
Air-source heat pump replaced for:		
Gas Boiler	424,034	6,597,480
Gas Furnace	3,155,989	49,103,509
Propane Furnace	97,380	1,515,121

	2025-2030	2025-2050
Electric Central Heat Pump replacement of Gas Hot Water Heater	2,478,261	32,497,748
Electric Oven and Induction Stovetop replacement of a Gas Oven and Range	212,030	4,282,956
ENERGY STAR Electric Dryer replacement for a Gas Dryer	95,152	1,922,052
Efficiency Measures (Thermostats and Lighting)	192,229	3,882,984
Weatherization and Deep Envelope Measures	540,644	13,169,735
Total Cumulative MMBTU Reductions	**7,195,719**	**112,971,584**

Table 14. Annual MWh Reduction by Measure

	2025	2030	2035	2040	2045	2050
Air-source heat pump replaced for:						
Gas Boiler	(981)	(11,923)	(22,968)	(28,469)	(28,946)	(28,924)
Gas Furnace	(7,163)	(87,063)	(167,718)	(207,892)	(211,372)	(211,213)
Propane Furnace	(244)	(2,972)	(5,725)	(7,096)	(7,215)	(7,209)
Electric Central Heat Pump replacement of Gas Hot Water Heater	(8,348)	(94,422)	(167,065)	188,424)	(189,003)	(189,003)
Electric Oven and Induction Stovetop replacement of a Gas Oven and Range	(642)	(8,019)	(17,793)	(25,638)	(27,285)	(26,516)
ENERGY STAR Electric Dryer replacement for a Gas Dryer	(759)	(104,951)	(228,083)	(321,155)	(332,259)	(317,497)
Efficiency Measures (Thermostats and Lighting)	2,511	9,249	20,537	30,130	34,625	36,970
Weatherization and Deep Envelope Measures	720	8,982	19,978	30,401	40,031	48,865
Total Annual MWh Reductions	**(14,906)**	**(291,119)**	**(568,837)**	**(718,142)**	**(721,424)**	**(694,527)**

Table 15. Cumulative MWh Reduction by Measure

	2025-2030	2025-2050
Air-source heat pump replaced for:		
Gas Boiler	(35,566)	(553,366)
Gas Furnace	(259,717)	(4,040,889)
Propane Furnace	(8,865)	(137,927)
Electric Central Heat Pump replacement of Gas Hot Water Heater	(290,452)	(3,808,736)
Electric Oven and Induction Stovetop replacement of a Gas Oven and Range	(23,607)	(476,864)
ENERGY STAR Electric Dryer replacement for a Gas Dryer	(302,633)	(5,925,903)
Efficiency Measures (Thermostats and Lighting)	28,997	588,400
Weatherization and Deep Envelope Measures	26,441	644,093
Total Cumulative MWh Reductions	**(865,402)**	**(13,711,192)**

Costs Estimates

Results

ICF estimated costs for implementation of the residential buildings measure using a bottom-up methodology; multiplying the number of units retrofitted (found in Table 8. Annual Installations) by costs and incentives developed on a per retrofit basis. Costs and incentives were both provided by the Air District and gathered from a range of different sources as outlined in Table 16 below. All cost estimates are shown in 2022 dollars.

Several costs are estimated:

- ***Total cost of installation*,** which is the average total cost of the appliance or equipment plus construction/installation costs and enabling upgrades.
- ***Total cost to customer,*** which is the potential cost of installation minus regional[14] and state, and with and without federal incentives to show the range of price a customer might pay.
- ***Total program costs,*** which is inclusive of the cost of regional incentives, program administration, and marketing associated with a retrofit program.
- ***Potential remaining funding need after state and federal incentives are applied,*** was estimated as total cost of installation minus federal and state incentives. Regional incentives are considered separately as reducing customer cost, but increasing the program cost for the regional agencies and community choice aggregators (CCAs) who administer them.

Summaries of outputs from this analysis can be found below in Table 16, Table 17, Table 18, Table 19, Table 20, Table 21, and Table 22 below.

[14] Regional incentives refer to BayREN incentives. Local incentives and CCA incentives are not included in this estimate.

Table 16. Cost Summary for each equipment installation or retrofit

Equipment/ Retrofit	Cost of Installed Equipment[15]	Program Cost per Install[16]	Total State and Federal Incentives [17]	Total Cost to Customer per Install with Regional and State Incentives [18]	Total Cost to Customer per Install with Regional, State, and Federal Incentives	Total Remaining Funding Need Per Install after State and Federal Incentives (excludes Regional incentives))[19]
Air Source Heat Pump	$18,465	$787	$8,000	$17,852	$9,852	$10,465
Hot Water Heat Pump	$8,042	$735	$2,650	$6,568	$4,818	$5,392
Electric Oven and Induction Stovetop	$2,481	$471	$840	$2,112	$1,272	$1,641
Electric Dryer	$992	$304	$0	$755	$755	$992
Smart Thermostat	$222	$96	$75	$72	$72	$147
Household LED Lighting Retrofit	$251	$128	$0	$151	$151	$251
Household Weatherization	$7,322	$388	$1,600	$7,021	$5,421	$5,722
Household Deep Energy Retrofit	$23,051	$1,251	$8,000	$22,076	$14,076	$15,051

[15] The average cost of appliance or equipment plus construction/installation costs and enabling upgrades.

[16] Program cost per install equals average program administration cost plus average regional rebates (which are administered by BayREN). This does not include local incentives and incentives from CCAs. (see Table 28).

[17] State incentives included are Golden State Rebates (TECH Clean CA and CEC Equitable Building Decarbonization are not included) Federal incentives included are: HEEHRA and HOMES programs (WAP and LIHEAP are not included).

[18] Total cost to customer without federal incentives equals cost of installed equipment minus state incentives and regional rebates (see Table 25 and Table 26).

[19] Total remaining funding need per install after state and federal incentives equals cost of installed equipment (including construction costs) minus federal and state incentives.

Table 17: Total Installation Costs *(without incentives)*	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Air-source heat pump replaced for:						
Gas Boiler	$8,437,383	$22,760,192	$15,885,287	$8,402,572	$2,370,123	$0
Gas Furnace	$58,993,223	$159,136,674	$111,068,120	$58,749,828	$16,571,627	$0
Propane Furnace	$1,684,856	$4,544,969	$3,172,123	$1,677,904	$473,288	$0
Electric Central Heat Pump replacement of Gas Hot Water Heater	$39,284,947	$91,496,264	$49,504,566	$6,196,647	$0	$0
Electric Oven and Induction Stovetop replacement of a Gas Oven and Range	$5,008,801	$14,679,676	$15,159,517	$14,253,784	$14,049,109	$14,146,837
ENERGY STAR Electric Dryer replacement for a Gas Dryer	$1,013,900	$2,971,514	$3,068,645	$2,885,303	$2,843,872	$2,863,655
Efficiency Measures (Thermostats and Lighting)	$1,314,468	$3,852,413	$3,977,815	$3,722,581	$3,585,418	$3,507,119
Weatherization and Deep Envelope Measures	$69,909,657	$204,889,568	$211,571,613	$198,417,565	$193,123,109	$191,450,686
Total Annual Costs	$185,647,236	$504,331,269	$413,407,686	$294,306,185	$233,016,546	$211,968,297

Table 18: Cumulative Installation Costs (without incentives)

	2025-2030	2025-2050
Air-source heat pump replaced for:		
Gas Boiler	$102,555,066	$279,067,427
Gas Furnace	$717,053,365	$1,951,207,727
Propane Furnace	$20,479,158	$55,726,803
Electric Central Heat Pump replacement of Gas Hot Water Heater	$444,348,406	$910,540,764
Electric Oven and Induction Stovetop replacement of a Gas Oven and Range	$62,520,386	$352,932,438
ENERGY STAR Electric Dryer replacement for a Gas Dryer	$12,655,606	$71,441,880
Efficiency Measures (Thermostats and Lighting)	$16,407,332	$91,441,711
Weatherization and Deep Envelope Measures	$872,619,722	$4,891,566,745
Total Cumulative Costs	**$2,248,639,043**	**$8,603,925,496**

Table 19. Annual Program Implementation Costs

	2025	2030
Air-source heat pump replaced for:		
Gas Boiler	$359,492	$969,745
Gas Furnace	$2,513,528	$6,780,347
Propane Furnace	$71,787	$193,648
Electric Central Heat Pump replacement of Gas Hot Water Heater	$3,592,356	$8,366,746
Electric Oven and Induction Stovetop replacement of a Gas Oven and Range	$951,032	$2,787,262
ENERGY STAR Electric Dryer replacement for a Gas Dryer	$310,639	$910,414
Efficiency Measures (Thermostats and Lighting)	$607,615	$1,780,783
Weatherization and Deep Envelope Measures	$3,776,854	$11,069,114
Total Annual Costs	**$12,183,303**	**$32,858,058**

Table 20. Cumulative Program Implementation Costs

	2025-2030
Air-source heat pump replaced for:	
Gas Boiler	$4,369,570
Gas Furnace	$30,551,539
Propane Furnace	$872,557
Electric Central Heat Pump replacement of Gas Hot Water Heater	$40,632,809
Electric Oven and Induction Stovetop replacement of a Gas Oven and Range	$11,870,882
ENERGY STAR Electric Dryer replacement for a Gas Dryer	$3,877,430
Efficiency Measures (Thermostats and Lighting)	$7,584,311
Weatherization and Deep Envelope Measures	$47,143,088
Total Cumulative Costs	**$146,902,187**

Table 21. Annual Potential Funding Need After State and Federal Incentives Applied

	2025	2030
Air-source heat pump replaced for:		
Gas Boiler	$4,781,878	$12,899,315
Gas Furnace	$33,434,348	$90,190,545
Propane Furnace	$954,890	$2,575,856
Electric Central Heat Pump replacement of Gas Hot Water Heater	$26,339,019	$61,344,661
Electric Oven and Induction Stovetop replacement of a Gas Oven and Range	$3,312,652	$9,708,641
ENERGY STAR Electric Dryer replacement for a Gas Dryer	$1,013,900	$2,971,514
Efficiency Measures (Thermostats and Lighting)	$1,030,589	$3,020,425
Weatherization and Deep Envelope Measures	$47,428,190	$139,001,418
Total Annual Funding Need	**$118,295,466**	**$321,712,376**

Table 22. Cumulative Potential Funding Need After State and Federal Incentives Applied

	2025-2030
Air-source heat pump replaced for:	
Gas Boiler	$58,122,978
Gas Furnace	$406,389,254
Propane Furnace	$11,606,542
Electric Central Heat Pump replacement of Gas Hot Water Heater	$297,918,203
Electric Oven and Induction Stovetop replacement of a Gas Oven and Range	$41,348,869
ENERGY STAR Electric Dryer replacement for a Gas Dryer	$12,655,606
Efficiency Measures (Thermostats and Lighting)	$12,863,915
Weatherization and Deep Envelope Measures	$592,003,682
Total Cumulative Funding Need	**$1,432,909,050**

Costs Modeling Assumptions

Methodology

Where possible, ICF sourced the cost of installed equipment from data provided by the Air District including data from an analysis by Rincon based on data provided by BayREN, Bay Area community choice aggregators, and TECH Clean CA. Where gaps remained, ICF primarily sourced data from NREL's Residential Efficiency Measures Database,[20] which lists a range of national average costs data inclusive of equipment, installation, and a range of other factors. When the NREL's Residential Efficiency Measures Database was used, ICF increased costs for specific retrofits in line with the RSMean's City Cost Index.[21] ICF used an average of San Francisco, San Jose, and Oakland's cost index to develop a regional cost increase for items from NREL's Residential Efficiency Measures Database. For the housing lighting retrofit, weatherization, and deep energy retrofit measures, ICF layered on industry assumptions to develop costs outlining what type of retrofit would be completed.

Table 23. Energy Efficiency Retrofit Cost Assumptions

Retrofit	Assumptions
Lighting	Assumed costs of a full LED changeout of lighting from incandescent.
Weatherization	Assumed costs associated with Air Sealing from 15 ACH to 1 ACH for 1,790 square foot single family home (a typical household size in California) Assumed 1/3 of that cost for each multifamily housing unit.
Deep Energy Retrofit	Assumed Costs associated with Air Sealing from 15 ACH to 1 ACH for 1,790 square foot single family home (a typical household size in California), Roof and wall insulation for a 30x30 two floor housing with 288 sqft of windows for single family housing units and assumed 1/3 of that cost for each multifamily housing unit.

Table 24. Assumed Cost of Installed Equipment/Retrofit

	Cost	Source
Air Source Heat Pump	$18,465	BAAQMD Rincon cost data weighted between single family and multifamily
Hot Water Heat Pump	$8,042	BAAQMD Rincon cost data weighted between single family and multifamily
Electric Oven and Induction Stovetop	$2,481	NREL National Residential Efficiency Measures Database, with regional cost adder derived from RS Means
Electric Dryer	$992	NREL National Residential Efficiency Measures Database, with regional cost adder derived from RS Means

[20] https://remdb.nrel.gov/
[21] https://www.rsmeans.com/rsmeans-city-cost-index

	Cost	Source
Smart Thermostat	$222	NREL National Residential Efficiency Measures Database, with regional cost adder derived from RS Means
Household LED Lighting Retrofit	$251	ICF Assumptions on typical household, with regional cost adder derived from RS Means
Household Weatherization[22]	$7,322	Derived from NREL's National Residential Efficiency Measures Database, with regional cost adder derived from RS Means
Household Deep Energy Retrofit[23]	$23,051	Derived from NREL's National Residential Efficiency Measures Database and ICF Assumptions, with regional cost adder derived from RS Means

ICF used online rebate calculators to determine available State and Federal rebates for installed equipment.[24, 25] ICF identified state rebates available to homeowners and renters in single and multi-family buildings from the Golden State Rebate.[26] ICF assumed that all participants would be eligible to receive the low-income qualifying rebate value for all installation types where available from the federal government (rebates include the High-Efficiency Electric Home Rebate Act (HEEHRA) and HOMES Program).[27] ICF did not assume any tax credits, as they can be difficult to monetize for low-income households, and did not include assumptions related to the Weatherization Assistance Program (WAP) or Low-Income Home Energy Assistance Program (LIHEAP).

Table 25. Assumed State and Federal Incentives for Equipment/Retrofit

	State Incentive	Federal Incentive	Total	Details
Air Source Heat Pump	$0	$8,000	$8,000	HEEHRA's rebate
Hot Water Heat Pump	$900	$1,750	$2,650	Golden State Rebate and HEEHRA's rebate

[22] Weatherization varies from home to home, but typically includes a diagnostic assessment of air leakage and targeted air sealing throughout the building envelope to reduce air leakage throughout a home. This can include caulk around windows, weather stripping and other repairs aimed at lowering energy costs and increasing energy efficiency.
[23] Deep Energy retrofits vary from household to household and are developed based on a diagnostic assessment. Cost information was assumed to include improved roof insulation, foam insulation on all exterior walls, and upgraded windows. Window upgrades are the largest cost improvement within deep energy retrofits.
[24] Federal rebates identified using: https://www.rewiringamerica.org/app/ira-calculator
[25] State rebates identified using: https://goldenstaterebates.com/
[26] TECH Clean CA incentives are not including as it is difficult to predict the fraction of installations modeled that would be able to successfully place a reservation for a Single Family Equity or Multifamily Equity Unitary Hot Water Heat Pumps or other equipment based on available remaining or future funding. Excluding this rebate for now is a more conservative estimate. https://switchison.org/contractors/incentive-resources/
[27] Readers can find out more about HEEHRA and HOMES online at: https://building-performance.org/ira/

	State Incentive	Federal Incentive	Total	Details
Electric Oven and Induction Stovetop	$0	$840	$840	HEEHRA's rebate
Electric Dryer	$0	$0	$0	
Smart Thermostat	$75	$0	$75	Golden State Rebate
Household LED Lighting Retrofit	$0	$0	$0	
Household Weatherization	$0	$1,600	$1,600	HEEHRA's rebate
Household Deep Energy Retrofit	$0	$8,000	$8,000	HOMES rebate

ICF assumed a rebate program run by an area implementer and sought to match rebate costs to existing programs including BAYREN's Home+ and BAMBE programs where available.[28] ICF assumed a rebate of program rebate of $200 for electric dryers, $75 for smart thermostats (to match the state rebate) and $100 for lighting retrofits.

Table 26. Assumed Program Rebates by Installed Equipment/Retrofit per Unit

	Single Family	Multifamily	Weight Average Rebate	Sources
Air Source Heat Pump	$400	$1,000	$613	BAYREN Homes+ and BAMBE rebates
Hot Water Heat Pump	$400	$1,000	$574	BAYREN Homes+ and BAMBE rebates
Electric Oven and Induction Stovetop	$250	$750	$369	BAYREN Homes+ and BAMBE rebates
Electric Dryer	$200	$375	$237	BAYREN BAMBE rebates and ICF assumption
Smart Thermostat	$75	$75	$75	ICF Assumption
Household LED Lighting Retrofit	$100	$100	$100	ICF Assumption
Household Weatherization	$150	$500	$302	BAYREN Homes+ and BAMBE rebates
Household Deep Energy Retrofit	$1,000	$1,500	$974	BAYREN Homes+ and BAMBE rebates

[28] https://www.bayren.org/rebates-financing

Finally, ICF estimated program implementation costs building from BAYREN's existing costs for Home+ and BAMBE.[29] Costs include administration and marketing and were derived by reviewing the total incentive and direct install program costs as a ratio of the total marketing and administration costs for each program.

Table 27. Assumed Program Implementation Costs by Source

Program	Total Program Admin Costs	Total Incentive and Direct Install Costs	Cost Ratio (Admin Costs/ Incentive Costs)
Home+	$2,014,916	$8,119,122	.25
BAMBE	$701,769	$2,250,120	.31

ICF weighted each measure based on the single family/multi-family housing need and applied the cost ratio derived from BAYREN actual costs for Home+ and BAMBE programs to derive the Total Program Costs by equipment/retrofit per unit.

Table 28. Assumed Program Implementer Costs by Installed Equipment/Retrofit per Unit

	Weighted average rebate	Weighted Average Program Administration Cost	Total Program Costs per install
Air Source Heat Pump	$613	$174	$787
Hot Water Heat Pump	$574	$174	$735
Electric Oven and Induction Stovetop	$369	$174	$471
Electric Dryer	$237	$161	$304
Smart Thermostat	$75	$102	$96
Household LED Lighting Retrofit	$100	$67	$128
Household Weatherization	$302	$21	$388
Household Deep Energy Retrofit	$974	$28	$1,251

[29] https://www.bayren.org/sites/default/files/2023-05/BayREN%20AR%2011x17.pdf

Transportation Sector Measures

Measure Specific Methodologies

Bike Facility within 3 miles of a Mobility Hub

Description

The addition of bicycle facilities in the vicinity of mobility hubs is a critical step towards enhancing the overall experience of bicycling. The most significant impact of this initiative is the displacement of vehicle travel, as it promotes bicycling as a preferable alternative to driving. This shift not only advances healthier commuting options but also plays a crucial role in reducing carbon emissions. Moreover, improving accessibility to transit hubs through these facilities leads to an increase in transit ridership, further contributing to the reduction of Vehicle Miles Traveled (VMT) and associated emissions. The range of bicycle facilities includes off-road bicycle paths or shared use paths, on-road bicycle lanes like side paths or designated bicycling lanes, and protected bicycle lanes or cycle tracks, which offer a safer and more segregated space from vehicular traffic.

Quantification Methodology

The calculation of GHG emission reduction attributed to a new bike facility takes into account two key factors: the decrease in GHG emissions from reduced single-occupancy vehicle (SOV) trips to the transit hub and the further GHG emission reductions brought about by increased transit ridership.

Equation 2

$$GHG = GHG_{SOV} + GHG_{MS}$$

Table 29. Variables Included in Equation 2

ID	Variable	Value	Notes
GHG	Cumulative GHG emissions reductions	N/A	Calculated in Metric Tons
GHG_{SOV}	GHG emissions reductions due to a reduction in SOV trips to the transit hub	N/A	Calculated in Metric Tons
GHG_{MS}	GHG emissions reductions due to mode shift	N/A	Calculated in Metric Tons

Reduced SOV trips to the Transit Hub

The first part of the GHG emission reduction from a new bicycle facility near a transit hub is estimated by calculating the reduction in SOV trips to the transit hub:

Equation 3

$$\mathrm{GHG_{SOV}} = \mathrm{R} \times \mathrm{Frac_3} \times \mathrm{Frac_{bike}} \times \mathrm{Dist_{bike}} \times \mathrm{EF_{LDV}}$$

Table 30. Variables Included in Equation 3

ID	Variable	Value	Notes
GHG_{SOV}	GHG emissions reductions due to a reduction in SOV trips to the transit hub (metric tons)	N/A	Calculated in Metric Tons
R	Average annual ridership per station	Varies by transit mode	From Clipper Boarding Data[30]
$Frac_3$	Fraction of transit riders within 3 miles of the transit hub	65%	Based on trip data ending in transit from Replica[31]
$Frac_{bike}$	Fraction of transit riders within 3 miles of the transit hub who will transition to biking	50%	In the absence of project-specific information, the project team made an engineering judgment and assume a conservative shift from SOV to biking. This assumption is also supported by a survey data from WMATA. [32]
$Dist_{bike}$	Average biking distance to the transit hub	1.5 miles	Given that the bike facility will be developed within 3 miles, the project team is assuming an average trip length of 1.5 miles (half of the radius to transit hub)
EF_{LDV}	Cumulative light duty vehicle emission factor	Sum of grams per mile emission rates over the project lifetime. The longer the project lifetime, the higher the emission rate.	Based on CARB'S EMFAC2021 model (California Air Resource Board, 2021)

Increased Transit Ridership (i.e., Mode Shift)

The second part of the GHG emission reduction from a new bicycle facility is estimated by calculating the estimated increased transit ridership:

Equation 4

$$GHG_{MS} = R \times Frac_R \times Dist_{trip} \times D_{transit} \times EF_{LDV}$$

[30] https://mtc.ca.gov/operations/traveler-services/clipper

[31] https://replicahq.com/

[32] In 2010, Washington Metropolitan Area Transit Authority (WMATA) conducted a survey of individuals who currently drive to Metrorail Stations. The survey results revealed that over half would contemplate alternative modes of transportation if certain conditions were met. Specifically, 55% expressed willingness to walk to the stations, while 67% considered biking to the stations a viable option. Regarding the return journey, 60% were open to walking from the stations, and 50% would consider biking from them. This indicates a significant potential for increased walking and biking to and from Metrorail Stations if appropriate biking and walking facilities are being built near transit hubs. Available at: https://planitmetro.com/wp-content/uploads/2010/12/Metrorail-Bicycle-Pedestrian-Access-Improvements-Study-_Final.pdf

Table 31. Variables Included in Equation 4

ID	Variable	Value	Notes
GHG_{MS}	GHG emissions reductions due to mode shift	N/A	Calculated in Metric Tons
R	Average annual ridership per station	Varies by transit mode	From Clipper Boarding Data[33]
$Frac_{R}$	Increased ridership	10%	In the absence of project-specific information, the project team made an engineering judgment and assumed 10% increase in ridership
$Dist_{trip}$	Average transit trip distance	Varies by transit mode	Based on CARB's AHSC Benefits Calculator Tool (California Air Resource Board, 2021)
$D_{transit}$	Transit dependency (i.e., vehicle ownership)	Varies by transit mode	Based on CARB's AHSC Benefits Calculator Tool (California Air Resource Board, 2021)
EF_{LDV}	Cumulative light duty vehicle emission factor	Sum of grams per mile emission rates over the project lifetime. The longer the project lifetime, the higher the emission rate.	Based on CARB'S EMFAC2021 model (California Air Resource Board, 2021)

Example Project Quantification

For Bus Rapid Transit with an average transit trip distance of 4.61 miles per trip and transit dependency of 0.54, and a project starting in 2025 with a lifetime of 15 years, the calculations are:

Reduced SOV Trips to the Transit Hub

$$\frac{6{,}757\ trip}{year} \times 0.65\ x\ 0.5 \times \frac{1.5\ mile}{trip} \times \frac{3{,}954\ gCO_2.year}{mile} \times \frac{1\ MT\ CO_2}{1000000\ g\ CO_2} = \mathbf{13.0\ MTCO_2}$$

Increased Transit Ridership (i.e., Mode Shift)

$$\frac{6{,}757\ trip}{year} \times 0.1 \times \frac{4.61\ mile}{trip} \times 0.54 \times \frac{3{,}954\ gCO_2.year}{mile} \times \frac{1\ MT\ CO_2}{1000000\ g\ CO_2} = \mathbf{6.7\ MTCO_2}$$

Total GHG Reductions

$$13.0\ MTCO_2 + 6.7\ MTCO_2 = \mathbf{19.7\ MTCO_2}$$

[33] https://mtc.ca.gov/operations/traveler-services/clipper

Pedestrian Facility within 1 mile of a Mobility Hub

Description

The introduction of pedestrian facilities near mobility hubs significantly enhances the walkability of an area, which in turn plays a pivotal role in reducing vehicle travel by encouraging modal shifts towards walking. This shift from vehicular to pedestrian modes of travel is instrumental in lowering overall transportation-related carbon emissions. Furthermore, by improving accessibility to transit hubs, these pedestrian facilities indirectly boost transit ridership, leading to a further reduction in VMT and associated GHG emissions. The spectrum of pedestrian infrastructure is broad and includes elements like sidewalks and curb ramps, which provide safe and accessible walking routes; shared use paths that cater to both pedestrians and cyclists; crosswalks that ensure safe crossing over streets; and various street crossing treatments such as signals and signs that enhance pedestrian safety and visibility.

Quantification Methodology

The process of calculating the GHG emission reduction resulting from a new pedestrian facility involves the summation of two distinct components. Firstly, it accounts for the decrease in GHG emissions that results from a reduction in SOV trips to the transit hub. This reduction is primarily attributed to more people choosing to walk instead of driving, thereby decreasing the number of car trips. Secondly, the calculation includes the GHG emissions savings due to increased transit ridership, a ripple effect of enhanced accessibility to transit hubs. This increase in the use of public transit contributes to further GHG emission reductions.

Equation 5

$$\mathrm{GHG} = \mathrm{GHG}_{\mathrm{SOV}} + \mathrm{GHG}_{\mathrm{MS}}$$

Table 32. Variables Included in Equation 5

ID	Variable	Value	Notes
GHG	Annual GHG emissions reductions	N/A	Calculated in Metric Tons
$\mathrm{GHG}_{\mathrm{SOV}}$	GHG emissions reductions due to a reduction in SOV trips to the transit hub (metric tons)	N/A	Calculated in Metric Tons
$\mathrm{GHG}_{\mathrm{MS}}$	GHG emissions reductions due to mode shift (metric tons)	N/A	Calculated in Metric Tons

Reduced SOV Trips to the Transit Hub

The first part of the GHG emission reduction from a new pedestrian facility is estimated by calculating the reduction in SOV trips to the transit hub:

Equation 6

$$\mathrm{GHG}_{\mathrm{SOV}} = \mathrm{R} \times \mathrm{Frac}_1 \times \mathrm{Frac}_{\mathrm{walk}} \times \mathrm{Dist}_{\mathrm{walk}} \times \mathrm{EF}_{\mathrm{LDV}}$$

Table 33. Variables Included in Equation 6

ID	Variable	Value	Notes
GHG_{SOV}	GHG emissions reductions due to a reduction in SOV trips to the transit hub	N/A	Calculated in Metric Tons
R	Average annual ridership per station	Varies by transit mode	From Clipper Boarding Data[34]
$Frac_1$	Fraction of transit riders within 1 mile of the transit hub	37%	Based on trip data ending in transit from Replica[35]
$Frac_{walk}$	Fraction of transit riders within 1 mile of the transit hub who will transition to walking	50%	In the absence of project-specific information, the project team assumed this value. This assumption is also supported by a survey data from WMATA. [36]
$Dist_{walk}$	Average walking distance to the transit hub	0.5 miles	Given that the pedestrian facility will be developed within 1 miles, the project team is assuming an average trip length of 0.5 miles (half of the radius to transit hub)
EF_{LDV}	Cumulative light duty vehicle emission factor	Sum of grams per mile emission rates over the project lifetime. The longer the project lifetime, the higher the emission rate.	Based on CARB'S EMFAC2021 model (California Air Resource Board, 2021)

Increased Transit Ridership (i.e., Mode Shift)

The second part of the GHG emission reduction from a new bicycle facility is estimated by calculating the estimated increased transit ridership:

Equation 7

$$GHG_{MS} = R \times Frac_R \times Dist_{trip} \times D_{transit} \times EF_{LDV}$$

34 https://mtc.ca.gov/operations/traveler-services/clipper

35 https://replicahq.com/

36 In 2010, Washington Metropolitan Area Transit Authority (WMATA) conducted a survey of individuals who currently drive to Metrorail Stations. The survey results revealed that over half would contemplate alternative modes of transportation if certain conditions were met. Specifically, 55% expressed willingness to walk to the stations, while 67% considered biking to the stations a viable option. Regarding the return journey, 60% were open to walking from the stations, and 50% would consider biking from them. This indicates a significant potential for increased walking and biking to and from Metrorail Stations if appropriate biking and walking facilities are being built near transit hubs. Available at: https://planitmetro.com/wp-content/uploads/2010/12/Metrorail-Bicycle-Pedestrian-Access-Improvements-Study-_Final.pdf

Table 34. Variables Included in Equation 7

ID	Variable	Value	Notes
GHG_{MS}	GHG emissions reductions due to mode shift	N/A	Calculated in Metric Tons
R	Average annual ridership per station	Varies by transit mode	From Clipper Boarding Data
$Frac_R$	Increased ridership	5%	In the absence of project-specific information, the project team assumed this value.
$Dist_{trip}$	Average transit trip distance	Varies by transit mode	Based on CARB's AHSC Benefits Calculator Tool (California Air Resource Board, 2021)
$D_{transit}$	Transit dependency (i.e., vehicle ownership)	Varies by transit mode	Based on CARB's AHSC Benefits Calculator Tool (California Air Resource Board, 2021)
EF_{LDV}	Cumulative light duty vehicle emission factor	Sum of grams per mile emission rates over the project lifetime. The longer the project lifetime, the higher the emission rate.	Based on CARB'S EMFAC2021 model (California Air Resource Board, 2021)

Example Project Quantification

For Bus Rapid Transit with an average transit trip distance of 4.61 miles per trip, transit dependency of 0.54, and a project starting in 2025 with a lifetime of 15 years, the calculations are:

Reduced SOV Trips to the Transit Hub

$$\frac{6{,}757\ trip}{year} \times 0.37 \times 0.5 \times \frac{0.5\ mile}{trip} \times \frac{3{,}954\ gCO_2.year}{mile} \times \frac{1\ MT\ CO_2}{1000000\ g\ CO_2} = \mathbf{2.5\ MTCO_2}$$

Increased Transit Ridership (i.e., Mode Shift)

$$\frac{6{,}757\ trip}{year} \times 0.05 \times \frac{4.61\ mile}{trip} \times 0.54 \times \frac{3{,}954\ gCO_2.year}{mile} \times \frac{1\ MT\ CO_2}{1000000\ g\ CO_2} = \mathbf{3.3\ MTCO_2}$$

Total GHG Reductions

$$2.5\ \frac{MT\ CO_2}{year} + 3.3\ \frac{MT\ CO_2}{year} = \mathbf{5.8\ MTCO_2}$$

E-Bike Share

Description

E-Bike share represents a micromobility initiative that operates with minimal to no emissions, playing a crucial role in reducing carbon emissions through modal shift. By offering a zero-emission alternative to traditional transportation methods, e-bike sharing encourages individuals to switch from high-emission vehicles to electric bikes for their travel needs. E-Bike share serves as a complementary option for the first and last miles of a journey, thereby making transit systems more convenient, reliable, and efficient for users. In assessing the GHG emission reduction potential of establishing or expanding e-bike share programs, the primary focus is on the displacement of SOV VMT. However, it is important to note that this methodology does not take into account any potential impacts on existing transit activities.

Quantification Methodology

The GHG emission reduction from E-Bike share is estimated by calculating the GHG emission reductions from displaced VMT:

Equation 8

$$GHG = n_{ebike} \; x \; n_{trips} \; x \; VMT_d \; x \; EF_{LDV}$$

Table 35. Variables Included in Equation 8

ID	Variable	Value	Notes
GHG	GHG emissions reductions	N/A	Calculated in Metric Tons
n_{ebike}	Number of e-Bikes in bike share	1200 e-Bikes	In the absence of project-specific information, the project team assumed this value.[37]
n_{trips}	Number of trips per bike per day	621 trips per bike per day	(National Association of City Transportation Officials, 2019)
VMT_d	VMT displaced per e-Bike trip	1.30 miles	Based on (Rzepecki, 2019) applying the adjustment factor from (Volker, Handy, Kendall, & Barbour, 2020)
EF_{LDV}	Cumulative light duty vehicle emission factor	Sum of grams per mile emission rates over the project lifetime. The longer the project lifetime, the higher the emission rate.	Based on CARB'S EMFAC2021 model (California Air Resource Board, 2021)

Example Project Quantification

For a project starting in 2025 with a lifetime of 12 years, the calculations are:

$$1{,}200\; bikes \; x \; \frac{621\; trips}{bike * day} \; x \; \frac{365\; day}{year} \; x \; \frac{1.3\; miles}{trip} \; x \; \frac{3{,}224\; gCO_2.year}{mile} \; x \; \frac{1\; MT\; CO_2}{1{,}000{,}000\; g\; CO_2} = \mathbf{3{,}120\; MTCO_2}$$

[37] From July 2022 to July 2023, San Francisco recorded an average of 6,200 daily bike trips. Based on the National Association of City Transportation Officials' 2017 data (https://nacto.org/bike-share-statistics-2017/), which suggests that each bike is typically used for 1.7 trips per day, it can be estimated that approximately 3,700 bikes are in operation in the area. This data supports the hypothesis that a bike-share program with an initial fleet of 500 bikes could be a reasonable starting point. Bike Share Systemwide Activity available at: https://transtat-public.sfmta.com/t/public/views/FordGoBike/BikeShareSystemwideActivity?%3Aembed=y#2

E-Bike Incentive

Description

E-bikes, with their electric assistance, are more accessible to a wider range of users, including those who may find physical exertion challenging. This feature makes longer distances or hilly terrains more manageable, thus appealing to a broader demographic who might otherwise rely on cars for such trips. The implementation of incentives for e-bikes is a strategic approach that can lead to substantial emissions reduction by encouraging modal shifts. Furthermore, e-bikes are adept at facilitating smoother integration with existing transit systems. They provide efficient solutions for covering the first and last miles of trips, effectively bridging the gap between public transit stops and the final destination. This enhancement not only makes transit systems more convenient and reliable but also potentially increases their use, thereby contributing to further GHG emission reductions, however the GHG emission reductions that could result from an increase in transit use due to the e-bike incentive is not calculated in this methodology. While the primary benefit of e-bike incentives is the direct reduction in SOV trips, leading to lower VMT, it is also worth noting that the broader impacts on overall travel patterns and public transit usage contribute significantly to a more sustainable transportation ecosystem. The GHG emissions reduction from e-bike incentives is estimated by calculating the emission reductions from displaced VMT:

Equation 9

$$GHG = n_{\ ebike} x\ VMT_d\ x\ EF_{LDV}$$

Table 36. Variables Included in Equation 9

ID	Variable	Value	Notes
GHG	GHG emissions reductions	N/A	Calculated in Metric Tons
n_{ebike}	Number of e-Bikes incentivized	2,500	In the absence of project-specific information, the project team assumed this value.[38]
VMT_d	Daily VMT displaced per e-Bike	2.73 miles	Based on (Johnson, Fitch-Polse, & Handy, 2023)
EF_{LDV}	Cumulative light duty vehicle emission factor	Sum of grams per mile emission rates over the project lifetime. The longer the project lifetime, the higher the emission rate.	Based on CARB'S EMFAC2021 model (California Air Resource Board, 2021)

Example Project Quantification

For a project starting in 2025 with a lifetime of 12 years, the calculations are:

[38] Assuming a rebate of approximately $2,000 per bike, the maximum offered by the California Air Resources Board's (CARB) statewide e-bike incentive program, the total incentives for this program would amount to around $2 million. This represents about one-sixth of the total funds allocated to the statewide e-bike program.

$$5{,}000\ ebikes\ x\ \frac{2.73\ miles}{day}\ x\ \frac{365\ day}{year}\ x\ \frac{3{,}224\ gCO_2.year}{mile}\ x\ \frac{1\ MT\ CO_2}{1{,}000{,}000\ g\ CO_2} = \mathbf{16{,}091}\boldsymbol{MTCO_2}$$

EV Car Share

Description

Electric vehicle (EV) car-sharing programs represent a transformative approach in urban mobility, with the potential to promote shared ridership and reduce reliance on gasoline vehicles. By providing convenient access to EV for short-term use, these programs make it easier for individuals to choose EVs over traditional gasoline-powered cars for their transportation needs. This accessibility is particularly impactful in urban areas where car ownership may be less practical or desirable. There are different models of car sharing, including traditional services like Zipcar, which require returning the vehicle to a specific location, and one-way services like Gig, which offer more flexibility. These services, often membership-based, cover costs like fuel, maintenance, parking, and insurance. Partnerships with transit agencies, like Gig's with BART, enhance multimodal travel. The shift to EV car-sharing helps in multiple ways: it not only reduces the number of gasoline vehicles on the road, thereby directly cutting down on emissions from conventional fuel sources, but also decreases driving frequency. Moreover, EV car-sharing can complement public transit systems by providing a flexible, zero emission option for trips that are not easily covered by existing transit routes.

Quantification Methodology

The GHG emission reduction resulting from EV car share programs is calculated by combining the reductions in emissions from decreased SOV trips with those achieved by shifting to EVs.

Equation 10

$$\mathrm{GHG} = \mathrm{GHG_{SOV}} + \mathrm{GHG_{MS}}$$

Table 37. Variables Included in Equation 10

ID	Variable	Notes
GHG	Cumulative GHG emissions reductions	Calculated in Metric Tons
GHG_{SOV}	GHG emissions reductions due to a reduction in SOV VMT	Calculated in Metric Tons
GHG_{MS}	GHG emissions reductions due to mode shift	Calculated in Metric Tons

Reduced SOV VMT

The first part of the GHG emission reduction from EV car share is estimated by calculating the reduction in single occupancy vehicle trips:

Equation 11

$$\mathrm{GHG_{SOV}} = \mathrm{EF_{LDV}} \times \mathrm{n}_{cars} \times \mathrm{m}_{car}\ \left((\mathrm{Frac}_{tcs} \times \mathrm{VMT}_{r,tcs}) + (\mathrm{Frac}_{owcs} \times \mathrm{VMT}_{r,owcs})\right) \times d_{travel}$$

Table 38. Variables Included in Equation 11

ID	Variable	Value	Notes
GHG_{SOV}	GHG emissions reductions due to a reduction in SOV VMT	N/A	Calculated in Metric Tons
EF_{LDV}	Cumulative light duty vehicle emission factor	Sum of grams per mile emission rates over the project lifetime. The longer the project lifetime, the higher the emission rate.	Based on CARB'S EMFAC2021 model (California Air Resource Board, 2021)
n_{cars}	Number of EV cars to be funded	650 cars	In the absence of project-specific information, the project team assumed this value.[39]
m_{car}	Average number of members per car	19 people	(San Francisco Municipal Transportation Agency, 2017)
$Frac_{tcs}$	Fraction of traditional car share members	81%	(Metropolitan Transportation Commission, 2018)
$VMT_{r,tcs}$	VMT reduction for traditional car share program	7 miles	(Martin, Stocker, Nichols, & Shaheen, 2021)
$Frac_{owcs}$	Fraction of one-way car share members	19%	(Metropolitan Transportation Commission, 2018)
$VMT_{r,owcs}$	VMT reduction for one-way car sharing	1.07 miles	(Martin, Elliot, & Shaheen, 2016)
d_{travel}	Number of travel days per year	347	Standard state assumption

VMT Shift to EVs

The second part of the GHG emission reduction from EV car share is estimated by calculating the shift in gasoline vehicle VMT to EV VMT:

Equation 12

$$\mathrm{GHG_{MS}} = \mathrm{EF_{LDV}} \times \mathrm{n}_{cars} \times \mathrm{m}_{car} \ \left(\left(\mathrm{Frac}_{tcs} \times \mathrm{VMT}_{tcs}\right) + \left(\mathrm{Frac}_{owcs} \times \mathrm{VMT}_{owcs}\right)\right) \mathrm{x}\ d_{travel}$$

[39] Based on the information in the On-Street Car Sharing Pilot Program evaluation report, in 2016, Getaround maintained a fleet of 700 vehicles while Zipcar operated 800 vehicles. Therefore, it seems reasonable to estimate a fleet size of approximately 400 vehicles for a car share program. Link to SFTMA On-Street Car Sharing Pilot Program evaluation report: https://www.sfmta.com/sites/default/files/projects/2017/Carshare_eval_final.pdf

Table 39. Variables Included in Equation 12

ID	Variable	Value	Notes
GHG_{MS}	GHG emissions reductions due to mode shift	N/A	Calculated in Metric Tons
EF_{LDV}	Cumulative light duty vehicle emission factor	Sum of grams per mile emission rates over the project lifetime. The longer the project lifetime, the higher the emission rate.	Based on CARB'S EMFAC2021 model (California Air Resource Board, 2021)
n_{cars}	Number of EV cars to be funded	650 cars	In the absence of project-specific information, the project team assumed this value.
m_{car}	Average number of members per car	19 people	(San Francisco Municipal Transportation Agency, 2017)
$Frac_{tcs}$	Fraction of traditional car share members	80.6%	(Metropolitan Transportation Commission, 2018)
VMT_{tcs}	Average daily VMT in traditional car share vehicles by members	3.46 miles	(Martin, Elliot, and Susan Shaheen, 2016)
$Frac_{owcs}$	Fraction of one-way car share members	19.4%	(Metropolitan Transportation Commission, 2018)
VMT_{owcs}	Average daily VMT in one-way car share vehicles by members	0.3 miles	(Martin, Elliot, and Susan Shaheen, 2016)
d_{travel}	Number of travel days per year	347	Standard state assumption

Example Project Quantification

For a project starting in 2025 with a lifetime of 15 years, the calculations are:

Reduced SOV VMT

$$\frac{3{,}896.4\ gCO_2.year}{mile} \times \frac{1\ MT\ CO_2}{1000000\ g\ CO_2} \times 650\ cars \times \frac{19\ members}{car} \times \times \left(\left(80.6\% \times \frac{7\ miles}{member.day} \right) + \left(19.4\% \times \frac{1.07\ miles}{member.day} \right) \right) \times \frac{347\ days}{year} = \mathbf{97{,}706\ MTCO_2}$$

VMT Shift to EVs

$$\frac{3{,}896.4\ gCO_2.year}{mile} \times \frac{1\ MT\ CO_2}{1000000\ g\ CO_2} \times 650\ cars \times \frac{19\ members}{car} \times \times \left(\left(80.6\% \times \frac{3.46\ miles}{member.day} \right) + \left(19.4\% \times \frac{0.3\ miles}{member.day} \right) \right) \times \frac{347\ days}{year} = \mathbf{47{,}528\ MTCO_2}$$

Total GHG Reductions

$$97,706\ MTCO_2 + 47,528\ MTCO_2 = 145,234\ MTCO_2$$

Transit Subsidy

Description

Transit subsidies represent a strategic approach to promote public transportation use, resulting in significant modal shifts and fostering both equity and GHG emission benefits. By reducing the cost barrier associated with transit use, subsidies make it more accessible and financially viable for a broader segment of the population. This increased affordability can lead to an increase in transit ridership, as more individuals opt for buses, trains, or other public transportation modes over private vehicles. Furthermore, transit subsidies have a pronounced impact on promoting social equity. They provide lower-income communities, who often rely more on public transportation, with greater mobility and access to essential services and opportunities.

Quantification Methodology

The GHG emission reduction from a transit subsidy is estimated by calculating the mode shift from light-duty vehicles (LDV) to increased transit ridership and reduction in LDV VMT:

Equation 13

$$GHG_{MS} = R_{total} \times Frac_{eligible} \times Frac_{fare} \times e_{rf} \times Dist_{trip} \times D_{transit} \times EF_{LDV}$$

Table 40. Variables Included in Equation 13

ID	Variable	Value	Notes
GHG_{MS}	GHG emissions reductions due to mode shift	N/A	Calculated in Metric Tons
R_{total}	Total annual transit ridership across the region	Varies by transit mode	From Clipper Boarding Data[40]
$Frac_{eligible}$	Percent of people eligible for transit subsidy	18%	From (Metropolitan Transportation Commission, 2021)
$Frac_{fare}$	Percent change in transit fare	-50%	Based on Clipper START program.[41]
e_{rf}	Elasticity between total ridership and transit fare	-43%	From (Handy, Lovejoy, Boarnet, & Spears, 2013)
$Dist_{trip}$	Average transit trip distance	Varies by transit mode	Based on CARB's AHSC Benefits Calculator Tool (California Air Resource Board, 2021)

[40] https://mtc.ca.gov/operations/traveler-services/clipper

[41] Clipper START is a pilot program offering a 50% discount on single rides for eligible participants across various services including AC Transit, Marin Transit, SolTrans, BART, Muni, and others.

ID	Variable	Value	Notes
$D_{transit}$	Transit dependency (i.e., vehicle ownership)	Varies by transit mode	Based on CARB's AHSC Benefits Calculator Tool (California Air Resource Board, 2021)
EF_{LDV}	Cumulative light duty vehicle emission factor	Sum of grams per mile emission rates over the project lifetime. The longer the project lifetime, the higher the emission rate.	Based on CARB'S EMFAC2021 model (California Air Resource Board, 2021)

Example Project Quantification

For BRT, which has a transit dependency of 0.54, and with a project start year in 2025 and a project lifetime of 15 years, the calculation is:

$$\frac{229{,}752\ trips}{year} \times 0.18 \times (-0.5) \times (-0.43) \times \frac{4.61\ mile}{trip} \times 0.54\ x\ \frac{3954.9\ gCO_2 . year}{mile} \times \frac{1\ MT\ CO_2}{10^6\ gCO_2} = \mathbf{87.5\ MTCO_2}$$

Public EV Charging Infrastructure

Description

The deployment of public EV charging stations (EVCS) is a critical factor in accelerating the adoption and usage of EVs, subsequently leading to reduction in emissions. By ensuring that drivers have reliable and convenient places to charge their vehicles, especially in urban and high-traffic areas, the attractiveness of owning an EV increases. This enhanced infrastructure not only encourages more consumers to transition from traditional gasoline vehicles to EVs, but it also supports existing EV owners in using their vehicles more frequently and for longer trips, further contributing to a decrease in carbon emissions from transportation. Additionally, the equitable expansion of the EV charging network is essential in ensuring that all communities, including underserved and lower-income areas, have equal access to EV technology. This inclusive approach to infrastructure development is crucial in avoiding a transportation divide and ensures that the environmental and economic benefits of EV adoption are shared widely.

Quantification Methodology

The GHG emission reduction is calculated by estimating the total displaced VMT from gasoline LDVs to EVs, using total electricity or energy consumed by EVCS.

Equation 14

$$GHG = \sum N_i P_i U_i H_i \div \eta_{EV,LDV} \times EF_{LDV}$$

Table 41. Variables Included in Equation 14

ID	Variable	Value	Notes
GHG	GHG emissions reductions	N/A	Calculated in Metric Tons
$\mathbf{N_i}$	Number of chargers of a certain power level	250	In the absence of available data, we assumed 50 Level 2 and 50 DCFC chargers
$\mathbf{P_i}$	Charger power level	L2: 19.2 kW; DCFC: 150 kW.	19.2 and 150 kW are typical power level for public Level 2 and DCFC
$\mathbf{U_i}$	Average charger utilization rate	L2: 10% DCFC: 5%	Estimated using current national average (Bauer, Hsu, Nicholas, & Lutsey, 2021) (Fitzgerald & Nelder, 2019); can be replaced with project-specific input using total time a charger is actively used divided by the evaluation period[42].
$\mathbf{H_i}$	Total annual hours in use	8,760 hour/year	Assuming charger in use 24/7.
$\boldsymbol{\eta_{EV,LDV}}$	Average EV energy efficiency	0.294 kWh/mile	Average EV efficiency published by the Argonne National Laboratory in 2022 (David, Yan, Xinyi, & Calista, 2022); to be updated with future EV model characteristics.
$\mathbf{EF_{LDV}}$	Cumulative light duty vehicle emission factor	Sum of grams per mile emission rates over the project lifetime. The longer the project lifetime, the higher the emission rate.	Based on CARB'S EMFAC2021 model (California Air Resource Board, 2021)

Example Project Quantification

For a public EVCS site with fifty 19.2 kW and fifty 150 kW DCFC stations lasting over 10 years (typical lifetime of chargers) the cumulative carbon reduction would be:

$$\frac{[(250 \times 19.2\ kW \times 10\% + 250 \times 150\ kW \times 5\%]}{\frac{0.294\ kWh}{mile}} \times 2{,}727 \frac{gCO2.year}{mile} \times \frac{8760\ hour}{year} \times \frac{1\ MT\ CO_2}{10^6\ gCO_2}$$
$$= 191{,}352\ \boldsymbol{MTCO_2}$$

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[42] For example, if a charger is actively used 2 hours in a day, the daily utilization rate would be $2\ \mathrm{h}/24\ \mathrm{h} = 8.3\%$.

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