Memorandum

Community Energy and Emissions Modeling Technical Methodology

To: City of Portland, City of South Portland, & Linnean Solutions
From: Integral Group & Daybreak Climate Consulting
Date: August 2020
Re: Methodology for One Climate Future Community Energy and Emissions Modeling, 2017-2050

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1 Model Overview

One Climate Future sets a goal of reducing citywide greenhouse gas (GHG) emissions 80% by 2050, with an interim goal of 35% by 2030. To analyze options to achieve that goal, subconsultants Integral Group and Daybreak Climate Consulting developed an Excel-based GHG emissions model to inform and model plan actions for all quantified sources of GHG emissions in Portland and South Portland.

The model is built on, and aligned with, the 2017 GHG inventories conducted by Integral Group and Daybreak Climate Consulting that were completed for the Cities of Portland and South Portland in 2019-2020. Those inventories follow the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC).[1] Wherever possible, modeling of future emissions has been aligned with standards in the GHG inventories to allow the cities to more easily track progress over time. Because the One Climate Future plan is for both cities, the results of the two inventories were combined and input into a single model, and baseline and projected numbers will appear larger than would be expected for either city on its own. The inventories show that both the scale and distribution of emissions between different fuels and sectors are extremely similar in both cities, with a few small exceptions: the industrial sector is larger in South Portland, and Portland has more non-road transportation infrastructure (e.g., Harbor, Jetport). Overall, combining the

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[1] GHG Protocol, Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) Washington, DC: World Resources Institute. Retrieved from https://ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities

two inventories into a single baseline and model simplifies planning while still yielding results applicable to each city.

The consultant team used the model to estimate future energy and emissions under a business-as-usual (BAU) scenario, and to quantify the potential impact various actions could have on different sectors. Actions are compared against a “no action” BAU scenario, which assumes growth in economic activity and population, but does not include energy efficiency or renewable energy policies at the city, state, or federal levels. The model is intended to inform the Cities on how they can achieve the One Climate Future 2050 climate target; it is not meant to quantify all actions or assign savings to specific actions. The team quantified specific programs and policies where actions are more directly quantifiable, such as new construction codes. In other cases, where actions are more difficult to tie to specific savings, the team focused on determining the scale of action required to achieve the climate and energy targets, looking either at feasible levels of market transformation, or achieving specific sectoral targets. All data in the model is annualized, and the model does not account for hourly or seasonal variation in energy use or emissions.

The model is not intended to be a predictive tool and does not account for costs or externalities other than GHG emissions. The intent of the One Climate Future plan is to provide the cities with a roadmap for how the two cities can achieve their GHG reduction targets. The plan provides this roadmap through a package of policy and program recommendations, with additional information and recommendations regarding the design and implementation of such actions based on available research and experiences in other leading jurisdictions. The specific design and implementation of many of these actions will take further analysis, including understanding the potential cost-effectiveness and relative feasibility of program and policy approaches and designs. The model also shows one way of achieving the goals of One Climate Future; other paths may also be feasible.

This memo is divided up into four major sectors: Energy Supply, Buildings and Industry, Transportation, and Waste. For each sector, the baseline and BAU assumptions are discussed first, and then the policy scenario assumptions. The titles of the policy scenario sections correspond to the titles in the wedge charts depicting GHG savings by policy. Table 1 shows how actions are aggregated into plan sections, and which plan actions each wedge most relates to.

Table 1: Action Grouping

Plan Section	Plan Sub-section	Wedge	Plan Actions	Methodology Memo Section
BE	BE 1: Municipal Buildings and Energy	Municipal Renewable Energy	BE 1.1	2.2.3
		Municipal Building Efficiency	BE 1.2, 1.3	3.2.4
	BE 2: New Construction Energy Efficiency & Decarbonization	New Construction Policies	BE 2.1, 2.3	3.2.1
	BE 3: Existing Buildings Energy Efficiency & Decarbonization	Existing Building Efficiency	BE 3.1, 3.2, 3.3	3.2.2
		Existing Building Decarbonization	BE 3.4, 3.5, 5.4, 5.6	3.2.3
	BE 4: Industrial Energy Efficiency & Decarbonization	Industrial Decarbonization	BE 4.1, 4.2	3.2.5
	BE 5: Clean and Renewable Energy	Renewable Portfolio Standard	BE 5.1	2.2.1
		Local Solar	BE 2.2, 3.5, 3.6, 5.1	2.2.2
TLU	TLU 1: Mode Shift & Land Use	Mode Shift and Land Use Policies	TLU 1 (all)	4.2.1
	TLU 2 & 3: Vehicle Electrification and Infrastructure	Bus Electrification	TLU 2.3	4.2.2
		Fuel Economy Standards	N/A	4.2.3
		Electric Vehicle Adoption	TLU 2.1, 2.2, 2.4, 2.5	4.2.4
		Ferry and Ship Electrification	TLU 3.3, 3.4	4.2.5
WR	WR 1 & 2: Waste Reduction	Solid Waste Reduction	WR 1 (all)	5.2.1
		Wastewater Efficiency	WR 2.3	5.2.2

2 Energy Supply and Emissions Intensities

The assessment models greenhouse gas emissions from all sectors from now through 2050, accounting for all energy use, energy sources, and emissions factors. The business-as-usual scenario assumes that the 2017 baseline emission factors all stay constant. Further, the BAU discounts the existing impact of renewable energy in order to capture the full effect of renewable energy in the policy wedge. The model then assesses the greenhouse gas emissions avoided between now and 2050, considering the implementation of a set of state and local policies for renewable electricity supply.

2.1 Baseline GHG Emissions Intensities

GHG intensity factors were applied to energy use by fuel type to calculate total GHG emissions. In the model, the GHG intensity of electricity accounted for losses from generation, but not from transmission and distribution (T&D), because T&D losses are not included in the GHG inventories. The model used the

Northeast Power Coordinating Council (NPCC) New England sub-region factor from EPA's eGRID database of regional GHG intensities for 2016; this region is aligned with ISO New England. However, in order to fully capture the impact of the renewable portfolio standard (RPS), the BAU GHG intensity of electricity was calculated by removing renewables from the BAU grid mix.

We kept the GHG intensity ($tCO_2e/kBtu$) of all energy types constant in the BAU scenario. This was done to capture and communicate the impact of state policy for renewable energy and carbon pricing, most notably the RPS. The BAU model does not assume additional declines due to the federal regulation or electricity generation plant closures and replacements. To avoid overly optimistic assumptions about declining electricity emissions, these external forces were assumed not to decrease the electricity emissions factor. This means deeper emissions reductions from changes in electricity supply are very likely to occur than is modeled for the BAU scenario.

Table 2: Electricity BAU GHG Intensity

	Baseline from eGRID (tCO2/kBtu)	Baseline without Renewable Energy (tCO2/kBtu)	Trajectory
Electricity GHG Emissions Factor	7.75E-05	9.04E-05	Declines due to renewable energy policies
Carbon dioxide factor	7.75E-05	9.04E-05	
Methane factor	3.35E-07	3.91E-07	
Nitrous oxide factor	4.23E-07	4.93E-07	

The emissions factors for natural gas, fuel oil, gasoline, and diesel are a function of their carbon content and are constant over time. For simplicity, all fuel oil use is assumed to be No. 2 Fuel Oil, and all diesel use is assumed to be standard diesel. In reality, there is likely some marginal use of Fuel Oil Nos. 1, 4, 5, & 6; however, the data collected for the inventory and the model does not allow the disaggregation of fuel oils, and the marginal differences in GHG emissions would not have a significant effect on the modeling. (The differences in criteria pollutants among fuel oils is more significant, but non-GHG air pollutants are not within the scope of the modeling.) Marine diesel does have a slightly different composition and GHG factor than the diesel fuel used in land vehicles; this difference is accounted for the inventory, but it is minor and in the interest of simplicity was not included in the modeling.

Our analysis did not include fugitive emissions from transmission and distribution of natural gas, because these losses are not included in GHG inventories, in alignment with the GPC BASIC protocol.

Table 3: Fossil fuel GHG intensities.

	Emissions Factor (tCO2e/kBtu)	Trajectory
Natural Gas GHG Emissions Factor	5.31E-05	Constant over time in all scenarios
Fuel Oil No. 2 GHG Emissions Factor	7.44E-05	
Gasoline GHG Emissions Factor	7.22E-05	
Diesel GHG Emissions Factor	7.41E-05	

2.2 Avoided Energy Supply Sector Emissions Due to Policies

2.2.1 Renewable Portfolio Standard

Renewable electricity currently supplies 16% of electricity in the ISO-NE region. Maine's new renewable energy portfolio (RPS) standard calls for 80% of electricity supply to come from renewable sources by 2030, and 100% of the electricity supply to come from renewable power by 2050.

To fully show the impact of the recently updated RPS, the BAU assumes that 16% of electricity comes from renewable sources from now until 2050. The policy scenario then increases the renewable portion of electricity, beginning at 16% in 2017 (to align with the inventory), and rising to 80% by 2030 and 100% by 2050.

These GHG savings show up in the Renewable Portfolio Standard wedge. As the actions in section BE 5 of the One Climate Future plan most directly relate to the RPS and statewide renewable energy, these savings are counted towards BE 5.

Table 4: Electricity GHG intensity projections under Maine RPS, 2017-2050.

Year	% Renewable	GHG Intensity (tCO2e/kBtu)
2017	16%	7.832E-05
2018	21%	7.373E-05
2019	26%	6.914E-05
2020	31%	6.455E-05
2021	36%	5.996E-05
2022	41%	5.537E-05
2023	46%	5.078E-05
2024	50%	4.619E-05
2025	55%	4.160E-05
2026	60%	3.701E-05
2027	65%	3.242E-05
2028	70%	2.783E-05
2029	75%	2.324E-05
2030	80%	1.865E-05
2031	81%	1.771E-05
2032	82%	1.678E-05
2033	83%	1.585E-05
2034	84%	1.492E-05
2035	85%	1.398E-05
2036	86%	1.305E-05

2037	87%	1.212E-05
2038	88%	1.119E-05
2039	89%	1.025E-05
2040	90%	9.321E-06
2041	91%	8.389E-06
2042	92%	7.457E-06
2043	93%	6.525E-06
2044	94%	5.593E-06
2045	95%	4.661E-06
2046	96%	3.728E-06
2047	97%	2.796E-06
2048	98%	1.864E-06
2049	99%	9.321E-07
2050	100%	0.000E+00

2.2.2 Local Solar

Locally generated solar power counts towards the state RPS, and most-to-all of the Solar Renewable Energy Credits (SRECs) generated from locally produced solar are expected to be sold to entities that have to comply with the state RPS mandates. Therefore, local solar generation in the model does not increase overall renewable power in the model, but merely reassigns energy from the RPS wedge to the local solar wedge.

Local solar is assumed to supply a negligible (effectively 0%) amount of power today and to increase linearly over time until 2050.

Analysis done by GridSolar indicates the following as the full capacity for solar within Portland and South Portland in 2050, with solar PV installed to the fullest technical and economic extent.

Table 5: Maximum local solar PV capacity (GridSolar).

City	Number of PV Panels	MWh Annual Generation	MW Capacity[2]
Portland	698,895	401,699	252
South Portland	343,703	197,793	123
Both	1,042,598	599,492	375

Solar built out to this capacity would provide 29% of all electricity needed in both cities, even with electrification of buildings. In reality, not all building owners will install solar, for a variety of reasons, even if it is both technologically and economically feasible. (For example, shading, structural integrity of roof space, owner desires, property turnover, planned demolition, the ratio of solar potential to on-site electricity use, etc.

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[2] In line with GridSolar's assumptions of 360 watts/panel.

all factor into that decision.) Rather, the GridSolar estimate for full capacity represents proof that a significant supply of solar can be locally sourced.

Based on our work in other jurisdictions and experience with what can be considered a reasonable expectation, for the modeling we assumed that 14.5% of all electricity would be met by local solar, or half as much as included in GridSolar's analysis.

Avoided GHG emissions from renewable energy generated from solar PV systems within the Cities shows up in the Local Solar wedge. The One Climate Future actions that will most increase local solar are those that will expand solar installs on existing buildings included in plan section BE 3. However, as local solar will count towards the state RPS, the amount of renewable energy needed for Portland and South Portland that the RPS needs to supply from outside the Cities decreases as more local solar is installed. Thus, the savings from the RPS and from local solar cannot be looked at independently. Therefore, the savings from local solar are grouped with the other RPS savings under BE 5.

2.2.3 Municipal Renewable Energy

The model assumes that both Portland and South Portland procure 75% of their electricity supply from renewable sources starting in 2022, and 100% by 2032. The two municipal governments make up 1.9% of electricity consumption, so this initially decreases citywide electricity emissions by almost 2%; this relative impact declines over time, however, as municipal buildings undergo energy efficiency retrofits.

The savings from municipal renewable energy procurement show up in the Municipal Renewable Energy wedge and are counted with the other municipal buildings and energy actions in BE 1.

3 Buildings and Industry

The assessment models greenhouse gas emissions for buildings and industry from now through 2050, accounting for all energy use by buildings as well as industrial process loads. The business-as-usual scenario assumes energy use intensities stay constant, while accounting for projected growth in the cities. The model then assesses the greenhouse gas emissions avoided between now and 2050 if we were to implement a set of policy scenarios that focus on buildings and industry energy efficiency and decarbonization.

3.1 Baseline and Business-as-Usual Building Assumptions

3.1.1 Building Floor Area and Growth Rate

To address the growth in buildings, the consultant team used a stock turnover model based on tax parcel data provided by both cities. Buildings were aggregated into 12 broad categories based on their use classifications in the parcel data and the classifications available from the U.S Department of Energy, as shown in Table 6.

Portland, and to a lesser extent, South Portland, are experiencing a period of rapid growth in population and buildings. The population of Portland and South Portland is expected to grow by 1.5% per year. The model accounts for this growth through a change in floor area growth by sector. Because no official city estimates for floor area growth by sector were available, average annual growth rate (AAGR) assumptions were made based on Integral Group experience with similar sized cities on similar growth trajectories. These construction rates should not be seen as indicative of any official estimate by either city government or as endorsements of any given policy goal.

Table 6: Building floor areas.

Sector/Subsector	Gross Floor Area	AAGR%
Residential	54,141,052	
Single Family	28,441,359	0.45%
2-4-unit Multi-family	10,261,092	0.62%
5+ unit Multi-family	15,438,601	0.80%
Institutional and Government	7,971,690	
Education and Institutional	4,438,537	0.20%
Government - City	1,364,081	0.05%
Government - Other	2,169,072	0.05%
Commercial	43,428,233	
Office	9,984,137	0.43%
Healthcare	3,482,279	0.17%
Warehouse and Storage	6,948,374	0.17%
Other Commercial, including hotels	23,013,443	0.17%
Industrial	3,951,460	N/A[3]
Parking	770,661	0%
Total	105,540,975	

3.1.2 Energy Use Intensity of Residential and Commercial Buildings

Electricity consumption data for Portland and South Portland for 2017 and 2018 was provided by CMP, broken out between commercial, residential, and industrial sectors, including total consumption and number of accounts. Natural gas consumption data for Portland and South Portland was provided by Unitil for 2017 and 2018, broken down into residential and commercial, including both total consumption and number of units. While the GHG inventories were completed for calendar year 2017, the consultant team noted significant differences in industrial energy use between the 2017 and 2018 data and opted to use 2018 electricity and natural gas data to inform the energy use intensity assumptions for the modeling. Other than the consumption of fuel oil in city-owned buildings, fuel oil consumption data was not available. While using fuel oil for heating is very common in Maine, there is an ongoing process of converting buildings to natural

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[3] Forward projections for industrial loads in Southern Maine were not available, and industrial energy use is largely uncorrelated with floor area, and so no industrial floor area growth rates were developed.

gas in Portland and South Portland. Therefore, state gas consumption numbers could not be considered as a reliable reference, proportionally, for either city.

As part of conducting the GHG inventory, Integral developed estimates of electricity, natural gas, and fuel oil consumption for each building category. This then could be divided by floor area to calculate the EUI, or the total amount of energy a building uses per year divided by total building area (e.g. kBtu/ft^2/yr.). To allocate a specific energy consumption to the various building categories, a set of preliminary energy use intensities were developed based on EIA's nationwide building energy surveys--the Commercial Building Energy Consumption Survey (CBECS) for 2012 and the Residential Energy Consumption Survey (RECS) from 2015.[4,5]

Electricity EUIs for commercial buildings were developed for each building type from the 2012 CBECS data for the Northeast or New England region, depending on data availability. Electricity EUIs for residential buildings were developed from the RECS data and models for ASHRAE Climate Zone 6A. Estimated EUIs for each type were multiplied by the floor area and compared to the total consumption for that building type. EUIs were adjusted by maintaining the same energy consumption ratio seen with the preliminary EUIs and shifting the EUI to match total energy consumption; only minor adjustments were needed.

Natural gas use and fuel oil use in residential buildings were estimated using energy models from the Residential Prototype Building Models from the U.S. Department of Energy and Pacific Northwest National Laboratory (LBNL) for the state of Maine.[6] Natural gas and fuel oil use in commercial buildings used the 2012 CBECS for New England. These models were used to develop EUI estimates for heating loads by fuel type. The assignment of residential buildings to heating fuel types built on a prior analysis for both cities done by Meister Consultants Group (MCG), which was provided to the consultant team by the Cities. Once floor area and unit counts had been determined for building and fuel type, EUI per square foot or per unit were assigned. In the case of natural gas, these values were then adjusted to true up the totals with the citywide natural gas consumption data; only minor adjustments were needed. Since the residential and commercial building code data showed that the heating EUI of a building with the same equipment and efficiency is equivalent for natural gas and fuel oil, the adjustments to local EUIs made to the natural gas consumption were also applied to the fuel oil consumption.

All analysis was done using site EUIs, that is, the energy use as consumed at the building. Source energy, which accounts for losses in generation and transmission was not included. This aligns with the data sources above, which all use site EUI, and the GPC BASIC GHG Inventory standards, which apply GHG intensities to site energy use. Electricity generation losses are captured in the GHG intensities applied to electricity. Per the BASIC inventory standards, transmission and distribution losses are not included. The final energy use and EUI assumptions for the OCF modeling are as follows:

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[4] U.S Department of Energy. 2012 CBECS Survey Data https://www.eia.gov/consumption/commercial/data/2012/index.php?view=consumption

[5] U.S Department of Energy 2015 RECS Survey Data https://www.eia.gov/consumption/residential/data/2015/

[6] .S Department of Energy. Residential Prototype Building Models. https://www.energycodes.gov/development/residential/iecc_models

Table 7: Energy use and energy use intensity assumptions.

Building Type	Total Site EUI (kBtu/ft^2)	Electric EUI (kBtu/ft^2)	Natural Gas EUI (kBtu/ft^2)	Fuel Oil EUI (kBtu/ft^2)	Total Energy Use (MMBtu)	Total Electricity Use (MMBtu)	Total Natural Gas Use (MMBtu)	Total Fuel Oil Use (MMBtu)
Residential					3,762,504	828,044	1,163,524	1,770,936
Single Family	64.6	12.5	10.0	42.1	1,837,317	355,519	284,906	1,196,892
Apt 2-4	77.0	17.4	30.1	29.4	789,908	178,455	309,309	302,144
Multi-family	73.5	19.0	36.9	17.6	1,135,279	294,070	569,308	271,900
Institutional/ Government					854,628	284,672	383,525	195,409
Education/ Institutional	107.3	30.4	53.0	23.4	476,443	134,968	235,242	103,862
Government - City	73.9	41.1	42.0	0.4	100,821	56,053	57,249	514
Government - Other	127.9	43.2	42.0	42.0	277,364	93,651	91,034	91,034
Commercial					4,827,479	1,711,446	2,088,353	934,735
Office	115.0	43.2	46.1	23.4	1,148,515	431,070	460,527	233,629
Other Commercial	115.4	43.5	46.1	23.4	2,654,821	1,000,980	1,061,516	538,515
Healthcare	127.1	55.5	70.6	-	442,639	193,431	245,810	0
Warehouse and Storage	83.7	12.4	46.1	23.4	581,504	85,965	320,500	162,592
Parking	20	20	0	0	15,412	15,412	0	0
Total					9,444,611	2,824,162	3,635,402	2,901,080

3.1.3 Industrial Energy Use

Both cities have substantial industrial sectors. The CMP electricity data broke out industrial use; 2018 industrial use was notably higher than in 2017, and so was used as a base for the modeling. However, Unitil does not have a separate rate classification for industrial users; industrial gas use was grouped into the commercial data. To estimate industrial gas use, the commercial gas data was apportioned between commercial and industrial sectors based on the ratio of commercial and industrial electricity use in each city. Industrial fuel oil loads were estimated using a combination of the MCG data on gas and oil service, and the ratio of industrial to commercial use found in the electricity consumption data.

The major drivers of energy use in industrial buildings are industrial process loads, which are uncorrelated with floor area. For private industry, process load data was not available, and the available data on industrial job growth projections and its relation to energy use was too inconclusive for the purposes of long-term planning. For these reasons, industrial energy use was held flat for the baseline and BAU and does not rise with floor area. The following BAU assumptions were made for industrial energy use across the two cities.

Table 8. Private industrial energy use.

	EUI (kBtu/ft2)	Total Energy Use (MMBtu)	Total Electricity Use (MMBtu)	Total Natural Gas Use (MMBtu)	Total Fuel Oil Use (MMBtu)
Private Industry	696	2,813,087	859,729	993,746	959,613

3.2 Avoided Buildings Sector Emissions Due to Policies

3.2.1 New Construction Policies

The model uses modeled building codes to affect the energy performance of new and rehabilitated buildings. Two sets of building codes are applied: one targeting single-family and small (2-4-unit) multifamily buildings, and another targeting commercial and large (5-unit or larger) multifamily buildings.

When a new energy code is adopted, buildings in the process of permitting and construction can be completed under the prior code, which creates a lag between code adoption and code impact. For residential buildings, the impact of new codes is modeled as occurring two years after code adoption; for commercial and large multifamily buildings, the impact of new codes is modeled as occurring three years after code adoption (e.g., a code adopted in 2021 impacts energy use of new buildings in 2024). These delays are drawn from Integral Group field experience. Each code adoption impacts building energy performance by reducing the EUI of the building type. PNNL models were used to compare the modeled EUIs under the new codes to the existing average EUIs of buildings, as listed above. Due to a low baseline efficiency of buildings, this results in the appearance of much deeper savings than the codes actually will be requiring.

Table 9: Energy code assumptions.

Adoption Year	Code	Residential	Commercial
Current/2020	IECC 2015	30% reduction in EUI	35-65% reduction in EUI, depending on building type
2023	Next Stretch Code	45% reduction in EUI 100% reduction in fuel oil use	45-75% reduction in EUI, depending on building type 100% reduction in fuel oil use
2030	Net Zero Stretch Code	65% reduction in electricity use intensity 100% reduction in natural gas and fuel oil use	65-85% reduction in electricity use intensity 100% reduction in natural gas and fuel oil use

The high-performance stretch code update for commercial and large multifamily buildings is assumed to reduce the EUI of new buildings to approximately halfway between the EUI required under the 2018 code update and the net-zero stretch code for 2030. Buildings constructed under net-zero codes are assumed to have EUIs that would allow the building to be supplied with on-site energy. However, the specific EUI and fuel source requirements will vary by building type and size, as well as other characteristics, and the EUIs used in the model should not be seen as a “net-zero level EUI” for purposes beyond this broad modeling exercise.

The model assumes code compliance of 75% for the first two years of each code, 80% for the year after that, and 85% thereafter. Based on the structure of the model, an 85% code compliance rate means achieving 100% of the code’s energy and GHG reduction potential from 85% of the affected building square footage, and no energy or GHG reductions from the remaining 15%. In reality, the 15% non-compliant buildings would very likely still achieve some energy use and GHG reductions from partial code compliance. This means the GHG reductions attributed to new construction may be underestimated.

The savings from new construction show up in the New Construction Policies wedge and are associated with BE 2.

3.2.2 Existing Building Efficiency

For existing buildings, the model includes several overlapping programs. These programs in the model represent the impact of a suite of actions recommended in the plan and are not a one-for-one match to any specific BE action. Three policies were modeled for energy efficiency in existing buildings—benchmarking, energy efficiency retrofits, and gut-rehab renovations. Each policy is also applied to municipal buildings at differing levels, as discussed in Section 2.2.4.

3.2.2.1 Benchmarking

The model includes projected effects from expansions to the Cities’ mandatory benchmarking programs. Benchmarking is the act of tracking and publicly reporting the energy performance of buildings, usually using the ENERGY STAR Portfolio Manager platform. Benchmarking does not itself save energy, but it reveals low-cost and no-cost opportunities for savings.

Benchmarking is assumed to be fully implemented in both cities as of 2025. Based on a survey of results from other cities, we assumed a 80% compliance rate once the benchmarking programs are fully implemented, applied only to the percent of floor area for each building type that is over the size thresholds for the Cities’ current programs (but assuming, in South Portland’s case, an expansion from the current limited geography to the whole city). We estimated cumulative 10% savings per benchmarked building over 5 years, which is a composite of multiple studies that find energy savings of 7% to 14%, over periods of 3 to 5 years.[7,8]

3.2.2.2 Energy Retrofits

The retrofits assumed in the model are intended to provide a sense of the scale of action required in the existing building sector to achieve the 2050 GHG reduction target, while being realistic enough to achieve and sustain. The scale of retrofits assumed for private buildings is equivalent to achieving a 40-50% energy

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[7] Mims, N. et. al. 2017. Evaluation of U.S. Benchmarking and Transparency Programs; Attributes, Impacts, and Best Practices. Berkley, CA: Lawrence Berkley National Laboratory. Pp 60- 62 https://emp.lbl.gov/sites/default/files/lbnl_benchmarking_final_050417_0.pdf

[8] Meng, T., D. Hsu, and D. Han. 2016. “Measuring Energy Savings from Benchmarking Policies in New York City.” Proceedings of the 2016 ACEEE Summer Study on Energy Efficiency in Buildings. https://aceee.org/files/proceedings/2016/data/papers/9_988.pdf,

use reduction across 1% to 2% of the building stock each year (or, in practice, a lower average energy use reduction across a larger portion of existing buildings). The term retrofit in this regard is a bit of a misnomer; in reality, the modeled retrofits will include a variety of building interventions focused on reducing energy and/or emissions, ranging from lighting upgrades to full envelope and HVAC system replacements. For this retrofit program, energy reductions are applied across all fuel types in equal measure.

For municipal government buildings, the penetration rate is calculated to achieve retrofits of all municipally owned buildings by 2050, as discussed below. State and county government buildings are modeled as being retrofitted to the same energy performance, but across only 25% as much floor area. For other building types, the assumed retrofit rates are based on national and global best practices and Integral Group field experience.

Table 10: Retrofit assumptions.

Sector	Years	% EUI Reduction	Penetration Rate Per Year
Local Government	2021-2025	10%	1%
Local Government	2026-2030	30%	3%
Local Government	2031-2050	80%	3%
State/County Government	2021-2025	10%	0.25%
State/County Government	2026-2030	30%	1%
State/County Government	2031-2050	80%	1%
Single Family & Apt 2-4	2022-2030	40%	1.5%
Single Family & Apt 2-4	2031-2050	50%	1.5%
Multifamily	2022-2030	40%	1.5%
Multifamily	2031-2050	50%	1.5%
Commercial	2020-2030	40%	2%
Commercial	2030-2050	50%	2%

3.2.2.3 Gut-Rehabs

Additionally, the model assumes that a portion of existing buildings would go through a renovation each year, triggering the requirement to comply with the most recent building codes for the portion of the building undergoing a rehab. We assumed that the rehabs would result in the average building improving its energy performance by half as much as if the entire building was required to meet the latest code, because gut retrofits may not address all aspects of a building, such as building envelope; these assumptions are based on Integral Group field experience.

The savings from these three policies show up in the Existing Building Efficiency wedge and are grouped with other existing building actions in BE 3.

3.2.3 Existing Building Decarbonization

Given the high penetration of natural gas and fuel oil heating in Maine, Portland and South Portland will not be able to achieve an 80% GHG reduction—let along carbon neutrality—without switching most residential and commercial buildings to carbon-neutral sources of heating, such as high-efficiency cold-climate air-source heat pumps (ASHP) or ground-source heat pumps (GSHP) for heating and cooling, and converting other process loads such as domestic hot water and cooking to electricity as well. Electrifying these systems will have immediate benefits for health and safety and important ripple effects in terms of GHG reductions.

Electric heat pump systems are significantly more efficient than traditional combustion-based systems. With few exceptions, the efficiency gains from using heat pumps will lead to immediate reductions in GHG emissions. Moreover, electric systems create more dispatchable load—load that can be intelligently managed and timed throughout the day to reduce peak demand on the grid or to coincide with peak periods of renewable energy generation. This alignment can help make it more beneficial and cost-effective to add more renewable energy to the grid.

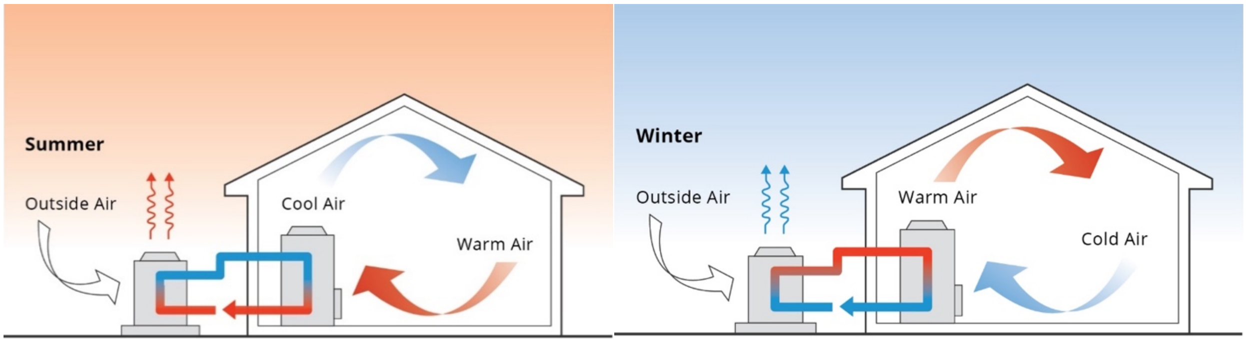

Figure 1: Heat pump diagram.

Modern cold climate air-source heat pumps are capable of supplying heating even when it is below freezing, albeit with decreasing efficiency. A study of the ASHP and GSHP potential in Portland and South Portland by Meister Consultants Group found that most buildings in Portland and South Portland are good candidates for heat pump systems.

The efficiency of a heat pump is measured using a coefficient of performance (COP), which represents the amount of usable heating or cooling produced per unit of electricity consumed. Because heat pumps move heat rather than directly generate it, most have COPs ranging from 2.0 to 3.0, which is to say they are 200% to 300% efficient. While best practice heat pumps have theoretical COPs of 3.0, in the context of cold Maine winters, a COP assumption of 2.5 is more reasonable.[9] To make a further conservative assumption, we assumed that 20% of natural gas use would not be able to be replaced with heat pumps, though this may not remain true as technology continues to improve.

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[9] Schoenbauer, B. and M. Kushler. 2016. “Field Assessment of Cold Climate Air Source Heat Pumps.” Proceedings of the 2016 ACEEE Summer Study on Energy Efficiency in Buildings. https://www.aceee.org/files/proceedings/2016/data/papers/1_700.pdf

The model makes the following assumptions for system efficiencies. The fuel switch factors are the amount of additional electricity required to make up for the removed fossil fuel. For example, a natural gas fuel switch factor of 0.377 for single-family homes means that for every unit of natural gas consumption reduced/removed, 0.377 units of electricity consumption will be added; a building that formerly used 5,000 kBtu of electricity and 10,000 kBtu of natural gas, after a fuel switch, uses 8,770 kBtu of electricity and 0 kBtu natural gas. These factors are a function of the relative efficiency assumptions, and also the distribution of fuel use in each building type

Table 11: Fuel switching assumptions for natural gas (NG) and fuel oil (FO).

Sector	Sub-Sector	Natural Gas / Fuel Oil Baseline Efficiency				New Electric System Efficiencies			NG Fuel Switch Factor	FO Fuel Switch Factor
		NG Space Heat	FO Space Heat	NG/FO DHW*	NG Cooking/ Other	Space Heat	DHW*	Cooking / Other		
Residential	Single Family	75%	75%	63%	75%	250%	200%	75%	0.377	0.438
	Apt 2-4	75%	75%	63%	75%	250%	200%	75%	0.377	0.438
	Multi-family	85%	75%	63%	75%	250%	200%	75%	0.403	0.30
Inst./Gov.	Educational Institutional	85%	75%	63%	75%	250%	200%	75%	0.410	0.360
	Gov't City	85%	75%	63%	75%	250%	200%	75%	0.437	0.346
	Gov't Other	85%	75%	63%	75%	250%	200%	75%	0.437	0.346
Commercial	Office	85%	75%	63%	75%	250%	200%	75%	0.440	0.346
	Other Commercial	85%	75%	63%	75%	250%	200%	75%	0.390	0.303
	Healthcare	85%	75%	63%	75%	250%	125%	100%	0.590	0.345
	Warehouse	85%	75%	63%	75%	250%	125%	100%	0.610	0.330

*DHW = domestic hot water

With some sectoral exceptions, the modeling assumes that 100% of all residential and commercial buildings that use natural gas or fuel oil are electrified by 2050—a rate of over 3% per year, starting in 2024. No fuel switching is assumed for healthcare and state/county government buildings; the high energy demand of healthcare facilities makes retrofits in this sector more challenging, and it is assumed that state and county buildings would not be covered by any city government retrofit programs or requirements.

The savings from these decarbonization efforts show up in the Existing Building Decarbonization wedge and are grouped with other existing building actions in BE 3.

3.2.4 Municipal Buildings Policies

All energy savings from municipal buildings are grouped under the Municipal Buildings Policies wedge. Together with savings from Municipal Renewable Energy, it provides the assumed savings for plan section BE 1. In the short-term, most of the savings under BE 1 come from Municipal Renewable Energy (see section

4.2.3) but buildings policies become the dominant source of municipal GHG savings as the municipal buildings become more energy efficient, and as the difference between the RPS and the municipal renewable energy becomes less significant after 2030. The Municipal Buildings Policies wedge has the same subcomponents as rest of the building policy actions discussed above.

New municipal buildings are assumed to be built to the same stretch energy code as other new buildings, but to reflect the Cities leading by example, new municipal buildings are assumed to follow a net-zero-energy-ready path beginning in 2026.

At the same time, all municipal buildings are modeled as undergoing retrofits to become highly energy efficient and all-electric. For municipal buildings, the penetration rate is calculated to achieve retrofits of all municipally owned buildings by 2050, at 3% per year. The municipal buildings follow the same fuel switching efficiencies as buildings owned by other governments, per the above. To avoid double-counting savings between retrofits and gut-rehabs, no municipal building energy savings are assumed from gut-rehabs.

Table 12: Municipal retrofit assumptions.

Sector	Years	% EUI Reduction	Penetration Rate Per Year
Local Government	2021-2025	10%	1%
Local Government	2026-2030	30%	3%
Local Government	2031-2050	80%	3%

3.2.5 Industrial Decarbonization

Industrial efficiency can be highly cost-effective, and in states like Maine where there has been a limited focus on industrial savings to date, large savings are reasonable to expect. At the same time, the high energy demands of industry, particularly the need for very high temperatures in many industries, make direct electrification a challenge. Three initiatives were modeled for private industry.[10] These savings were assumed to begin in 2028, the timeline for the increase in industrial programs, through ending the opt-out.

First, the model assumes that almost all (90%) of industrial space would be affected by efficiency measures. Of these, we assume 60% (54% of all industrial space, or 1.86% per year) would undertake an efficiency project that reduces their energy use by 35%, based on a median efficiency savings in industrial projects nationwide for various sectors identified in studies by the American Council for an Energy Efficiency Economy.[11] A study would need to be commissioned to determine if these values are achievable for the industries and industrial users located in Portland and South Portland.

Secondly, we modeled that 40% of the industrial spaces that undertake any efficiency project would undertake a combined heat and power (CHP) conversion by 2050 (36% of all facilities, or 1.24% per year), to leverage excess thermal energy and offset electric demand. A CHP conversion is estimated at reducing grid-

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[10] Kelly, M. and E. Rodgers. 2016. Communicating the Value of Industrial Energy Efficiency Programs. Washington, DC: American Council for an Energy-Efficiency Economy. https://www.aceee.org/sites/default/files/value-industrial-ee-programs.pdf

[11] Elliot, N. 2017. Energy efficiency and industry: the national trend. Washington, DC: American Council for an Energy-Efficiency Economy. https://www.aceee.org/blog/2017/08/energy-efficiency-and-industry

supplied electricity use by 90% while increasing natural gas use by 54%, based on findings from the U.S. Environmental Protection Agency.[12] These are average numbers—the actual energy savings for CHP will vary greatly by facility.

Finally, we estimated that 95`% of facilities that use fuel oil will convert to using natural gas or a biofuel. We estimate that 33% of facilities that use fuel oil will convert to using biofuels, such as renewable fuel oil (RFO) or biogas, 33% will electrify, and the remainder will switch to natural gas.

The savings from these three policies show up in the Industrial Decarbonization wedge and make up the savings for BE 4.

4 Transportation

The assessment models greenhouse gas emissions for all mobile transportation within the boundaries of Portland and South Portland from 2020 through 2050. For on-road transportation, the business-as-usual scenario assumes that vehicle miles traveled continues to increase at historical rates, with the current levels of vehicle fuel economy. For waterborne transportation, the business-as-usual scenario holds energy use constant. The policy scenario models GHG emissions avoided as a result of the implementation of transportation and land use policies that encourage mode shift and vehicle electrification.

4.1 Baseline and Business-as-Usual Transportation Assumptions

4.1.1 On-Road Emissions

Baseline and business-as-usual transportation demand are based on the greenhouse gas inventories that were conducted for Portland and South Portland for this project. The GHG emissions for vehicles were based on the vehicle miles traveled (VMT) and the GHG intensities of fuel sources. As is standard for calculating VMT and tracking transportation sector emissions, VMT numbers were based on the miles traveled within the boundaries of the city, regardless of whether the vehicle owners reside in either city or whether the vehicles are purchased at dealers within the city limits. Because sport utility vehicles (SUVs) and pickup trucks are a common mode of transit in Maine, passenger vehicle VMT was broken out between passenger vehicles and light-duty trucks.

Maine Department of Transportation data was used to calculate the total VMT on each road segment in each city, and from this, we can estimate that a total 748,773,000 vehicle miles were traveled across the two cities in the baseline year (2017). This extremely granular data does not tell us which vehicles traveled on which roads, however. To estimate this, vehicle registration data was used to look at the registered vehicle stock within each city. U.S. Department of Transportation and U.S. Energy Information Administration data for the fuel economy of vehicles sold in each class and model year were matched to the registered vehicle stock,

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[12] U.S. Environmental Protection Agency. 2015. Fuel and Carbon Dioxide Emissions Savings Calculation Methodology for Combined Heat and Power Systems. Washington, DC: U.S. Environmental Protection Agency https://www.epa.gov/sites/production/files/2015-07/documents/fuel_and_carbon_dioxide_emissions_savings_calculation_methodology_for_combined_heat_and_power_systems.pdf

and from this, weighted average fuel economy calculations were created for each city and each vehicle class. Looking across both cities for the modeling, this data can be aggregated as follows.

Table 13. On-road energy use by fuel type.

Fuel Type	Vehicles	VMT	MPG (Weighted)	Fuel Use (MMBTU)	GHG (MTCO$_2$e)	GHG Intensity (MTCO$_2$e/VMT)
Diesel	2,689	27,244,599	6.4	591,848	43,917	1.61E-03
Gasoline	68,753	696,596,483	21.6	4,487,117	316,176	4.54E-04
Hybrid Electric	2,110	21,378,246	31.1	95,464	6,727	3.15E-04
CNG	33	334,352	3.4	11,700	622	1.86E-03
Electric	59	597,780	37.0	344,780	92	1.54E-04

Table 14. On-road emissions by vehicle type.

Vehicle Type	Baseline VMT	Baseline GHGs	Portion of VMT	Portion of GHGs from VMT
Passenger Cars	3.59E+08	1.07E+05	48.0%	29.1%
Passenger Trucks	2.94E+08	1.68E+05	39.3%	45.6%
Electric Passenger Vehicles	5.98E+05	9.21E+01	0.1%	0.0%
Buses	1.88E+06	5.45E+03	0.3%	1.5%
Other Light- & Medium-Duty Vehicles	6.32E+07	3.61E+04	8.4%	9.8%
Heavy Duty Trucks	2.68E+07	5.15E+04	3.6%	14.0%

Mode share numbers come from the Portland Comprehensive Plan (Portland's Plan 2030) and American Community Survey data on commute modes in Portland and South Portland.[13] Because these mode share numbers come from commute data, they likely inflate the use of transit, walking, and biking, relative to all travel, but better data for all passenger trips was not available.

Preliminary modeling by PACTS and AECOM for the ongoing "Transit Tomorrow" regional analysis was shared with the consultant team, and it indicates that VMT in southern Maine can be expected to increase in the business-as-usual scenario by 16% between 2020 and 2040—which works out to 0.74% per year on average. Passenger ridership on buses is increasing faster, however. Greater Portland METRO reported in 2019 that their system has seen a 45% increase in use between 2013 and 2019—which works out to 5.45% per year.[14] Limited data was available on the growth rates for walking and biking, and so a growth rate similar to the growth in overall VMT was assumed, keeping the percentage of walking/biking constant at 9%. While any shift to walking and biking from other modes is captured in the modeling as VMT reductions, the explicit

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[13] City of Portland. Portland's Plan 2030. Retrieved from https://www.portlandmaine.gov/DocumentCenter/View/18269/Portlands-Plan-2030-with-Appendices

[14] McGuire, P. 2020. "Portland Metro got a record 2.1 million riders on the bus in 2019." Portland Press Herald. January 8, 2020. https://www.pressherald.com/2020/01/08/portland-metro-bus-ridership-hits-record-2-1-million-in-2019/

growth of walking and biking under a business-as-usual scenario due to population growth, for example, is not included in the modeling as those trips have no emissions.

Table 15. Passenger mode share BAU.

Mode	Baseline Mode Share	BAU Average Annual Growth Rate	2050 BAU Mode Share
Passenger Vehicle	88%	0.75%	80%
Transit Buses	3%	5.45%	10%
Walking and Biking	9%	1%	10%

Heavy-duty trucks are not included in the mode share numbers. Due to insufficient data on their growth rates, the VMT, fuel consumption, and emissions for heavy-duty vehicles (other than transit buses) are held flat over time. While the plan contains actions that will help mitigate emissions from heavy trucks, the magnitude of impact of these actions is uncertain and was not modeled.

4.1.2 Non-Road Transport Emissions

Emissions from cruise ships were estimated using the cruise ship visit schedule for 2017 from the City of Portland, and calculated based on the number of hours each cruise ship was docked in Portland, the size of each ship, and whether more than one ship was docked at any one time.[15] To estimate emissions from the docked cruise ships, we reviewed two studies of docked ship emissions from Los Angeles (Port of Los Angeles) and Seattle, Washington (Puget Sound Maritime Air Forum).[16,17] See section 4.6 of the GHG Inventory Methodology for the assumptions that went into this modeling.

The Casco Bay Lines ferry system travels between the Portland peninsula and Portland's islands; these trips are included within the GHG inventory and One Climate Future modeling, as these routes are within the City of Portland. Casco Bay Lines staff estimated that their ferries consume 240,000 gallons of marine diesel fuel every year. No increase in ferry travel was assumed over time. While cruise ship visits are increasing, the scale of the increase is difficult to forecast, and so no increase was assumed in the BAU or policy scenarios.

Table 16. Waterborne transportation BAU.

Waterborne Transportation	Annual Diesel Use (units variable)	Annual Energy Consumption (kBtu)	Annual GHG Emissions ($MTCO_2e$)
Cruise Ship Auxiliary Engines	6,004,611 kWh-e	20,487,733	4,167
Cruise Ship Boilers	250,192 kWh-e	853,656	231
Casco Bay Lines Ferry	240,000 gallons	33,120,000	2,479

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[15] https://www.portlandmaine.gov/DocumentCenter/View/27428/2017-Cruise-Schedule

[16] Starcrest Consulting Group. 2018. "Inventory of Air Emissions for Calendar Year 2017." Port of Los Angeles. https://kentico.portoflosangeles.org/getmedia/880bc597-84bc-4ae6-94e2-59a2e6027f42/2017_Air_Emissions_Inventory

[17] Starcrest Consulting Group. 2018. "2016 Puget Sound Maritime Emissions Inventory, Revised October 2018" Puget Sound Maritime Air Forum. https://pugetsoundmaritimeairforum.files.wordpress.com/2018/10/final-2016-psei-report-19-oct-2018-scg.pdf

Emissions from passenger and freight rail and intracity aircraft were not included in either the inventory or the model due to limited data availability. As discussed in the GHG Inventories Memorandum, transboundary ship, train, and plane emissions are not included in the GPC BASIC protocol.

4.2 Avoided Transportation Sector Emissions Due to Policies

4.2.1 Mode Shift & Land Use Policies

Land use policies are crucial to reducing GHG emissions by encouraging a shift in travel modes away from driving passenger vehicles. However, modeling the effects of a variety of individual land use policies on mode shift and vehicle miles traveled (VMT) is a complex and intensive modeling process that was not within the scope of this project. Given that constraint, the consultant team modeled the VMT changes, and the correlated GHG emissions reductions, that result from reaching a set of mode share thresholds, defined as part of the modeling process.

As shown in Table 17, the selected mode share thresholds include: 60% of trips completed by passenger vehicles (down from 88% currently); 20% of trips completed by public transit (up from 3% currently), and 20% of trips completed by walking or biking (up from 9% currently).[18] These thresholds were selected through discussions with Portland and South Portland City staff, and the Climate Planning Process Committee. These targets are informed by mode-shift targets being set in other cities with a similar current level of transit ridership (including Richmond, Virginia and Oakland, CA).[19] The targets are also informed by the more aggressive mode share targets being set by cities with robust transit systems, like Boston, MA or Washington, DC, which aim to reduce trips by passenger vehicles to 25% of all trips by 2030 and 2032, respectively.[20,21]

Table 17. Mode share targets.

Mode	Current Mode Share	BAU Annual Growth Rate	BAU 2050 mode share projection	Target Mode Share	Target Annual Growth Rate	Change in Growth Rate from BAU to Target
Passenger Vehicle	88%	0.74%	80%	60%	-0.42%	-156%
Transit Buses	3%	5.45%	10%	20%	7.43%	36%
Walking and Biking	9%	1.0%	10%	20%	3.45%	255%

While these targets may seem aggressive, they are both in line with planning efforts elsewhere and a reasonable shift from the current rates of change. Doubling walking and biking trips (9% to 20%) is well within

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[18] It is important to note that the current mode share breakdown is based on commuting trips, which is used as a proxy for all trips, given the lack of better mode share data.

[19] City of Oakland. 2020. Oakland Equitable Climate Action Plan. https://cao-94612.s3.amazonaws.com/documents/Oakland-ECAP-07-24.pdf

[20] City of Boston. 2019.Boston Climate Action Plan https://www.boston.gov/sites/default/files/imce-uploads/2019-10/city_of_boston_2019_climate_action_plan_update_2.pdf

[21] District of Columbia. 2019. Sustainable DC 2.0. http://www.sustainabledc.org/wp-content/uploads/2019/04/sdc-2.0-Edits-V5_web.pdf

the norm for most sustainability plans. Increasing transit ridership to 20% of trips does represent a transformation of the transit system and a more difficult challenge. However, Greater Portland METRO ridership is increasing at over 5% per year, while overall passenger VMT is increasing at 0.745% per year; at those rates, bus ridership will represent approximately 10% of passenger miles traveled by 2050. To reach the target mode share, the growth rate will need to be 7.4% per year, a 36% increase in the annual ridership growth rate relative to the recent past.

In order to model the full potential of greenhouse gas emissions reductions created due to mode shift, mode shift greenhouse gas emissions savings were calculated using the energy efficiency and emissions intensity of the current vehicle stock, prior to accounting for fuel economy standards and a transition to electric vehicles.

With transit ridership increasing, the total VMT and emissions from the bus fleet will also increase, though not in direct proportion, since some existing bus routes are under-utilized today. The modeling assumes that total VMT from buses will increase by 6.4% per year, or a six-fold increase by 2050. For the purposes of looking at savings specifically from mode shift, the model assumes the bus fleet continues to be diesel buses. (The GHG reductions from bus electrification are captured in another wedge, discussed in section 4.2.2.) Thus, the total GHG emissions savings achieved through lower passenger vehicle miles traveled are reduced by 12.8%, due to increased emissions from diesel buses.

Table 18. Mode share net emissions savings.

Action	2050 GHG Savings ($MTCO_2e$)	Cumulative GHG savings, 2020-2050 ($MTCO_2e$)
Reduced Passenger Vehicle Use	109,698	1,997,310
Increased Bus Use	-13,309	-256,831
Net Mode Shift Impact	96,388	1,742,479

To fully capture the potential for GHG savings from mode shift, the buses need to be battery electric buses, which are modeled below. The savings from this mode shift show up in the Mode Shift & Land Use Policies wedge and constitute the savings for TLU 1.

4.2.2 Bus Electrification

The transit buses of Greater Portland METRO and South Portland Bus Service (SPBS) are treated as a single fleet for modeling purposes, in line with the overall modeling approach of combining data for both cities. Based on the increases in transit ridership, we project the combined bus fleets of METRO and SPBS will need to grow by 6.4% per year, rising from 51 buses in 2019 to 350 buses by 2050. Both bus services have set a goal of having a zero-emissions bus fleet by 2040. As buses have an average 15-year lifespan, all new bus purchases must therefore be battery-electric vehicle (BEV) buses starting in 2025. For simplicity, we modeled the bus fleet as increasing in size and electrifying linearly: starting in 2026, all public transit bus retirements (3 per year) are diesel, and all new buses (14 per year) are BEV buses, reaching a fully electric fleet by 2040. The bus fleets produce no direct emissions as of 2040, and once the RPS is 100% renewable in 2050, no operational emissions at all.

The One Climate Future plan also calls for the electrification of school buses, with all new school bus purchases being BEV buses by 2030. However, insufficient data was available to estimate the savings specifically from electrifying the school bus fleet, and so no savings for this transition are incorporated in the model. Transportation GHG savings are underestimated in this respect.

The savings from BEV transit buses show up in the Bus Electrification wedge and are grouped with other vehicle electrification actions in TLU 2 & 3.

4.2.3 Fuel Economy Standards

As the passenger vehicle stock grows, existing vehicles in the stock are retired and new vehicles are purchased each year. As a result, the average fuel efficiency of the vehicle stock and the vehicles that comprise it change. Each year, 6.67% of the existing passenger vehicle stock is replaced by new vehicles.[22] New vehicles entering the stock have a higher fuel efficiency rating due to the federal Corporate Average Fuel Economy (CAFE) Standard, which results in an increase in the average fuel efficiency of the entire stock.[23] The GHG and energy use reduction impacts of the CAFE Standard were included in the analysis to make its impact explicit. Because it is a federal regulation already in place, the CAFE Standard will achieve GHG reductions regardless of actions taken in the Cities of Portland and South Portland.

The current Federal administration has proposed a rollback of the CAFE standards; however, Maine is one of the states that follows the California standards, which are aligned with the CAFE standards set under President Obama. The model assumes that that lawsuits to end California's higher standards fail to have an impact, and that California and other states (including Maine) continue to use higher fuel standards and that the auto industry does not market different cars in adjoining states. CAFE thresholds would continue to get stricter out to 2025, and then remain constant. Savings would continue to grow as older cars are replaced. Because of the current low weighted average fuel economy of the vehicle fleet in southern Maine, the impact of the CAFE Standards is significant on its own. The blended fuel economy numbers assume that 45% of passenger vehicle VMT continues to be from light trucks, as it is today, as shown in Table 19.

Table 19. Corporate Average Fuel Economy (CAFE) assumptions (kBtu/mile).

Year	Baseline (2017)	2020	2021	2022	2023	2024	2025 (and thereafter)
Conventional Passenger Car (kBtu/mi)	4.22	3.22	3.08	3.02	2.93	2.83	2.79
Conventional Passenger Light Truck (kBtu/mi)	8.08	4.75	4.46	4.25	4.07	3.88	3.86
Blended Conventional Passenger Vehicle (kBtu/mi)	6.54	4.14	3.91	3.76	3.61	3.46	3.43
Battery Electric Passenger Vehicle (kBtu/mi)	1.72	1.62	1.56	1.55	1.55	1.52	1.50

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[22] Based on the number of new vehicle sales versus the number of total registered vehicles in the United States over the past several years (https://www.statista.com/statistics/185198/age-of-us-automobiles-and-trucks-since-1990/), with approximately 70% of vehicles on the road after 15 years, and some longer (http://www-nrd.nhtsa.dot.gov/Pubs/809952.pdf); Total registered vehicles in 2015 - https://www.statista.com/statistics/183505/number-of-vehicles-in-the-united-states-since-1990/; Light vehicle retail sales: https://www.statista.com/statistics/199983/us-vehicle-sales-since-1951/

[23] CAFE Standard fuel efficiency values are based on modeling from the U.S. Energy Information Administration's Annual Energy Outlook 2015.

Fuel economy standards is the only policy action modeled that cannot be linked to any specific One Climate Future plan action. However, it is a crucial part of reducing GHG emissions. By joining the strong California standards, Maine has taken statewide action to ensure these GHG savings are realized, regardless of federal action. The savings from these standards show up in the Fuel Economy Standards wedge and are grouped with other vehicle electrification actions in TLU 2 & 3.

4.2.4 Electric Vehicle Adoption

Electric vehicle (EV) adoption is rapidly increasing around the world, driven by technological changes, decreasing prices, and EV-supportive policies, including EV-readiness requirements and the build-out of charging infrastructure. The model includes battery electric vehicles, powered entirely by electricity from the grid, and plug-in hybrid electric vehicles, initially powered by a battery and then by a petroleum fuel-based engine when the battery is depleted.[24] The model assumes the breakdown of battery electric vehicles (EVs) to plug-in hybrid electric vehicles (PHEVs) starts at 50/50, and steadily shifts towards EVs with a 60/40 breakdown in 2030, a 91/9 breakdown in 2040, and a 97/3 breakdown in 2050.

The model also assumes that the EV market share for new vehicles (the share of new vehicles sold that are electric vehicles) will increase over time. Due to continually accelerating market trends plus stronger local and/or state incentives, and increasing federal regulations, we make the assumption that EV adoption will exceed currently predicted global trends, with EVs being 60% of new car sales by 2040 and 100% by 2050 (which would happen if the U.S. were to follow the lead of the United Kingdom, France, Norway, Sweden, India, and China in restricting the sale of gasoline- and diesel-powered cars in the 2040-2050 timeframe). This projection is in line with extrapolating forward projections from Bloomberg New Energy Finance (see Figure 2).

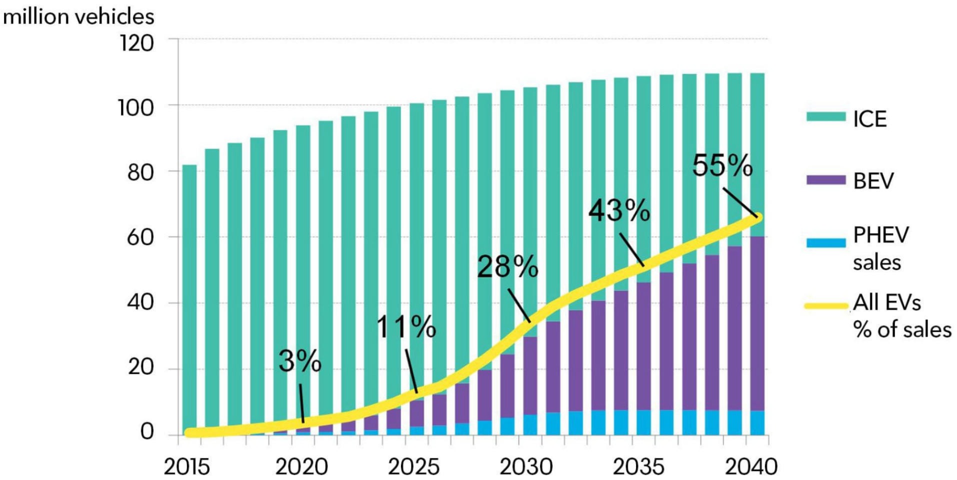

Figure 2: EV adoption projections (courtesy of Bloomberg New Energy Finance, 2019); ICE: Internal Combustion Engine, BEV: Battery Electric Vehicle, PHEV: Plug-in Hybrid Electric Vehicle, EV: Electric Vehicle

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[24] The model assumes plug-in hybrid electric vehicles operate on electricity 66% of the time and gasoline 34% of the time, based on Marshall, B.M., Kelly, J.C., Lee, T.-K., Keoleian, G.A., Filipi, Z., 2013. Environmental assessment of plug-in hybrid electric vehicles using naturalistic drive cycles and vehicle travel patterns: A Michigan case study. Energy Policy 58, 358–370; Kelly, J.C., MacDonald, J.S., Keoleian, G. a., 2012. Time-dependent plug-in hybrid electric vehicle charging based on national driving patterns and demographics. Appl. Energy 94, 395–405.

Insufficient data was available to calculate specific savings from electrifying the light-duty fleet vehicles owned and operated by both cities. However, these vehicles are included in the total vehicle counts, and so their electrification is captured within this action (albeit on a less aggressive timeline than called for in the plan, which calls for all new municipal light-duty vehicle purchases to be EVs by 2028). The savings from private and municipal passenger EV adoption show up in the Electric Vehicle Adoption wedge and are grouped with other vehicle electrification actions in TLU 2 & 3.

4.2.5 Ferry & Ship Electrification

The model assumes that all new Casco Bay Lines ferries are hybrid-electric ferries, which will be more energy-efficient, and, once sufficient shore power resources are provided, run on 100% electric power. All ferry conversions are completed by 2045. While there will be marginal short-term emissions reductions due to the efficiency of a hybrid-electric engine even without shore power hookups, these savings are not included in the model.

In line with the One Climate Future strategy for shore power, the model includes the effects of shore power hookups installed by 2040. Cruise ship auxiliary engines and boilers are assumed to be 50% efficient, while electric power is 100% efficient, so hooking up to shore power decreases not only emissions, but also energy consumption. Once the grid is 100% renewable in 2050, the electricity provided through shore power will have no associated emissions.

Table 20. Shore power assumptions.

Type of Vessel Energy Use	Annual Energy Consumption (kBtu)	Peak Electrical Demand (MW)
BAU Cruise Ship Auxiliary Engines, Diesel	20,487,733	N/A
BAU Cruise Ship Boilers, Diesel	853,656	N/A
BAU Ferry Diesel	33,120,000	N/A
Total Shore Power Demand	27,230,694	31.8
Shore Power Demand for Cruise Ships	10,670,694	27.0
Shore Power Demand for Ferries	16,560,000	4.8

The savings from shore power show up in the Ferry & Ship Electrification wedge and are grouped with other vehicle electrification actions in TLU 2 & 3.

5 Waste

The assessment models greenhouse gas emissions from waste from now through 2050, looking at the direct emissions from breaking down waste and the energy used to process the waste. The business-as-usual scenario assumes increases in waste emissions based on population growth. The model then assesses the greenhouse gas emissions avoided between now and 2050, considering the implementation of policies to divert waste from incineration and to reduce the energy intensity of wastewater processing.

5.1 Baseline and Business-as-Usual Waste Assumptions

5.1.1 Solid Waste

All waste in Portland and South Portland is collected and processed by ecomaine. Waste that is not recycled or sent to an anaerobic digester is incinerated at the ecomaine incinerator in Portland. The emissions from the plant are prorated to only capture the portion attributable to Portland and South Portland waste streams (along with the relatively small amount of energy and emissions needed for ecomaine operations, which are attributed to Portland because of the plant's location). In accordance with the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC), emissions from the incineration of biogenic waste (e.g. paper, food waste, wood products) are considered carbon-neutral—whether this is appropriate is an active political debate; however, modeling must follow current GHG inventory standards.

The BAU for waste increases proportionally to population in the model. BAU diversion rates were held at current documented levels: 32.4% for residential; 12% for commercial, institutional, and industrial waste; and 0% for drop-off. A small food waste collection program is currently operating in South Portland; 77% of the waste collected through that program goes to an anaerobic digester; the remaining 23% are contaminants that are incinerated. The quantity of construction and demolition waste is unknown and not included in the GHG inventory or modeling at this time. The emissions intensity of the incineration was calculated based on data collected and shared by ecomaine, equivalent to 0.33685 $MTCO_2e$/tonne of waste. The anaerobic digester has an emissions intensity of 0.02239 $MTCO_2e$/tonne of organic waste.

Table 21. Solid waste baseline.

Category/Sub-Category	Baseline (2017) Waste Volume (tonnes)	Baseline Emissions ($MTCO_2e$)	2050 Waste Volume (tonnes)	2050 Emissions ($MTCO_2e$)
Residential Disposed Waste Total	16,400	5,525	26,802	9,029
Residential MSW*	15,402		25,170	
Residential Bulky	999		1,632	
Commercial Disposed Waste Total	65,820	22,172	107,566	36,234
Commercial MSW*	54,454		88,993	
Commercial Bulky	11,365		18,574	
Food Waste	5,396	515	8,819	836
Food Waste Digested	4,143		6,771	
Food Waste Contaminates	1,253		2,031	

Waste not producing GHGs	38,461		62,855	
Inert Ash [no GHG]	21,979		35,919	
Residential Recycling [no GHG]	7,843		12,817	
Commercial Recycling [no GHG]	8,639		14,119	
Total MSW including recycling	126,077		206,026	
Total MSW* producing GHGs	87,616	28,211	143,188	46,099

*MSW: Municipal Solid Waste

5.1.2 Wastewater

Wastewater energy use and process emissions are assumed to increase at a rate of 1.5% per year, proportional to population growth.

Table 22. Wastewater energy use baseline.

	Wastewater EUI in kBtu/gal/day	Annual Energy Use (MMBtu)	Annual Electricity Use (MMBtu)	Annual Natural Gas Use (MMBtu)	Annual Fuel Oil Use (MMBtu)
Wastewater Treatment	1.71	29,418	20,764	8,308	346

Wastewater process emissions were modeled using data provided by the Portland Water District and the South Portland Water Resource Protection Department, and the “CIRIS Wastewater Emissions Calculator.” Wastewater process emissions for the 2017 baseline were estimated at 3,959 MTCO$_2$e and increase to 6,471 MTCO$_2$e by 2050.

5.2 Avoided Waste Emissions Due to Policies

5.2.1 Solid Waste Reduction

The modeling for solid waste reduction was oriented towards achieving “zero waste” by 2050. As some products cannot be recycled or composted, the model targets an 80%-90% reduction in waste, which is in line with common definitions for zero waste targets. Waste emissions are reduced in the model through several measures. Due to source reduction, total waste generated is reduced by 20% relative to the BAU case. However, due to population growth, total waste generated still grows by 81% relative to 2017. The model assumes that through a combination of recycling and composting, 90% of residential and commercial waste that is generated is diverted from incineration by 2050. Greenhouse gas emissions from waste decrease from 28,221 MTCO$_2$e in 2017 to 4,133 MTCO$_2$e in 2050—an 85% decrease. The savings from solid waste show up in the Solid Waste Reduction wedge and are grouped with other waste policies in WR.

5.2.2 Wastewater Efficiency

All water/wastewater actions were calculated assuming energy reductions per gallon of water/wastewater, with the quantity of water/wastewater increasing in proportion to population growth. The model assumes natural gas and fossil fuel use at the wastewater treatment plant would be met with biodigester gas, beginning implementation in 2035 and completing by 2040. We also assumed a 10% reduction in electricity consumption per gallon treated due to plant efficiency efforts. Improvements were calculated to occur over a five-year timeframe starting in 2030.

No policy interventions were assumed to reduce wastewater process emissions, as insufficient information was gathered on current process emissions to be able to recommend appropriate interventions and potential reductions.

The savings from the wastewater plants show up in the Wastewater Efficiency wedge and are grouped with other waste policies in WR.

6 Results

The following section summarizes the results of the model, including the effects on greenhouse gas emissions reductions as well as energy savings driven by the implementation of strategies in the One Climate Future plan.

6.1 Greenhouse Gas Results

6.1.1 GHG Emission Reductions from Policies

The modeling shows that Portland and South Portland can reduce citywide greenhouse gas emissions by over 81% by 2050, relative to 2017. Many of the assumptions in the model are conservative, and greater savings may well be possible with additional state and federal support.

Recognizing the scale of the global climate crisis and the need to take aggressive action, many actions have been front-loaded. Almost half of all the plan's actions occur in the next decade. The Cities are projected to achieve a 33% reduction in GHG emissions by 2030, and a 50% reduction by 2036, relative to 2017.

The following actions are some of the critical "front-loaded" actions; because they are implemented early, they make up a higher percentage of cumulative savings than 2050 savings.

- New Construction: The stretch code will require new buildings to be net-zero energy (NZE)-ready by 2030, if implemented as planned.
- Renewable Portfolio Standard: The state renewable portfolio standard will require electricity to be 80% renewable by 2030, thus achieving most of the GHG savings from electricity generation within the next ten years.

- Fuel Economy Standards: Federal fuel economy standards for cars level off after 2025, with most of the savings locked in early.
- Municipal Renewable Energy: The municipal government electricity supply will be 100% renewable by 2032.
- Municipal Building Policies: Municipal government building retrofits will be net-zero energy by 2030.
- Bus Electrification: All transit buses and school buses will be electric vehicles by 2040.

Conversely, the following actions are key actions that require ramp up or are phased in over a longer period. Consequently, these actions make up a higher percentage of 2050 annual savings than 2030 or 2040 annual savings, or cumulative savings.

- Existing Building Decarbonization: Fuel switching retrofits do not begin in earnest until 2025, because the program requires further study and will take a few years to ramp up.
- Electric Vehicle Adoption: EV adoption is limited by the rate of new vehicle purchases and the available types of electric vehicles, but is accelerating over time; the model results show most emissions savings from EV adoption coming after 2035.
- Mode Shift and Land Use Policies: Transit system expansion and land use changes require a large number of infrastructure and development projects before we begin to see the aggregated effects, primarily after 2030.
- Industrial Decarbonization: Industrial energy efficiency and decarbonization efforts are not forecast to take off until 2030, due to the need for sector-specific energy efficiency and decarbonization potential studies, regulatory changes that support greater investment in this sector, and technological innovation.

The five biggest areas of GHG emission savings in the plan modeling are as follows:

1. Renewable Portfolio Standard and Local Solar—40% of all cumulative savings.
2. Existing Building Efficiency and Existing Building Decarbonization—23% of all cumulative savings.
3. Electric Vehicle Adoption and Fuel Economy Standards—17% of all cumulative savings.
4. Mode Shift and Land Use Policies—6% of all cumulative savings.
5. Industrial Decarbonization—4% of all cumulative savings.

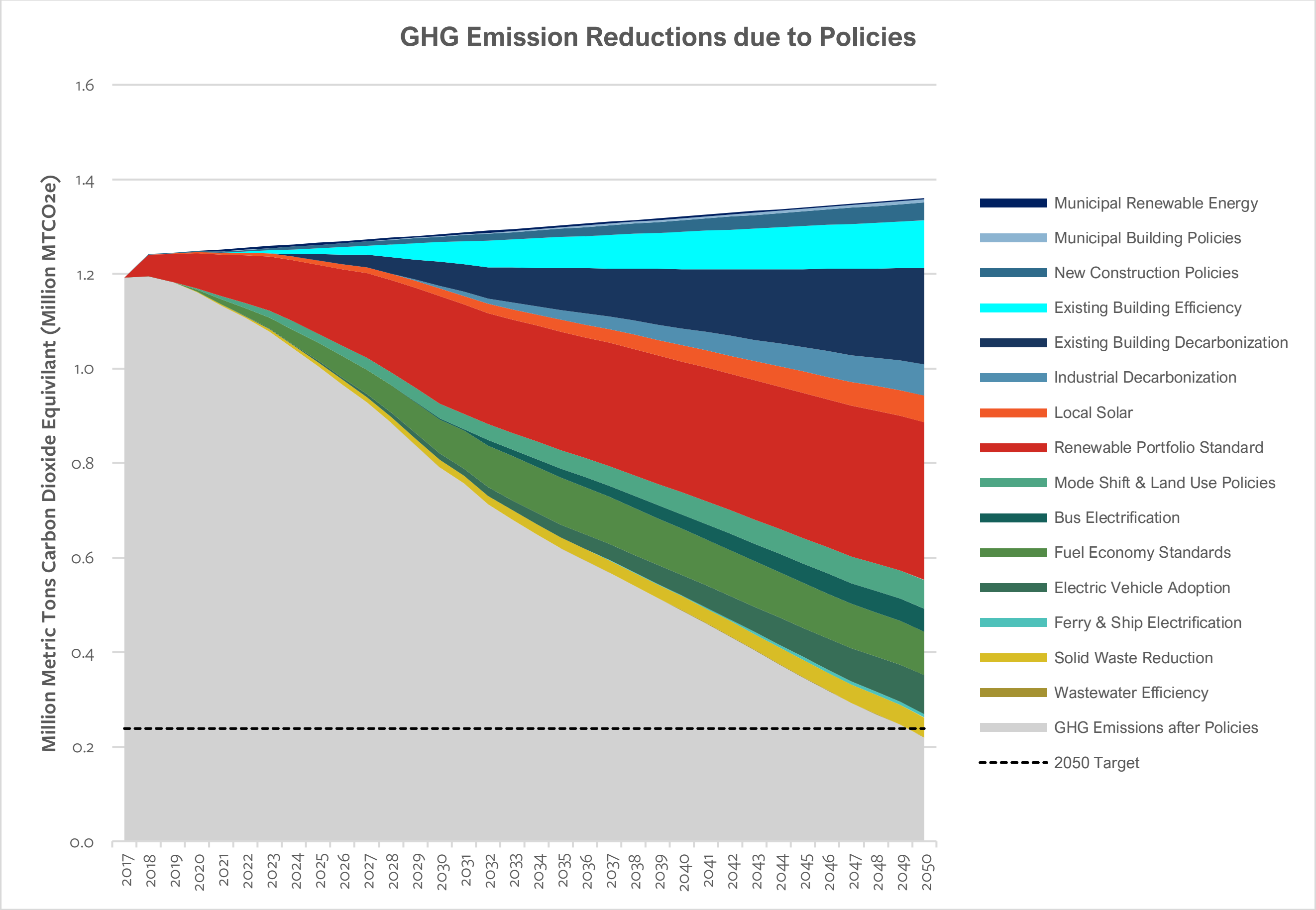

Figure 4 shows what the wedge chart looks like if we were to “take out” the two wedges related mostly to state and federal action—the Maine Renewable Portfolio Standard (RPS) and the Federal Corporate Average Fuel Economy (CAFE) Standards. By doing this, we are incorporating these policies into the “business-as-usual” scenario, and assuming that we can be relatively sure that these policies will continue to exist and be implemented as planned. By contrast, by including the RPS and CAFE Standards, Figure 3 illustrates how important these components are to achieving our carbon reduction goals.

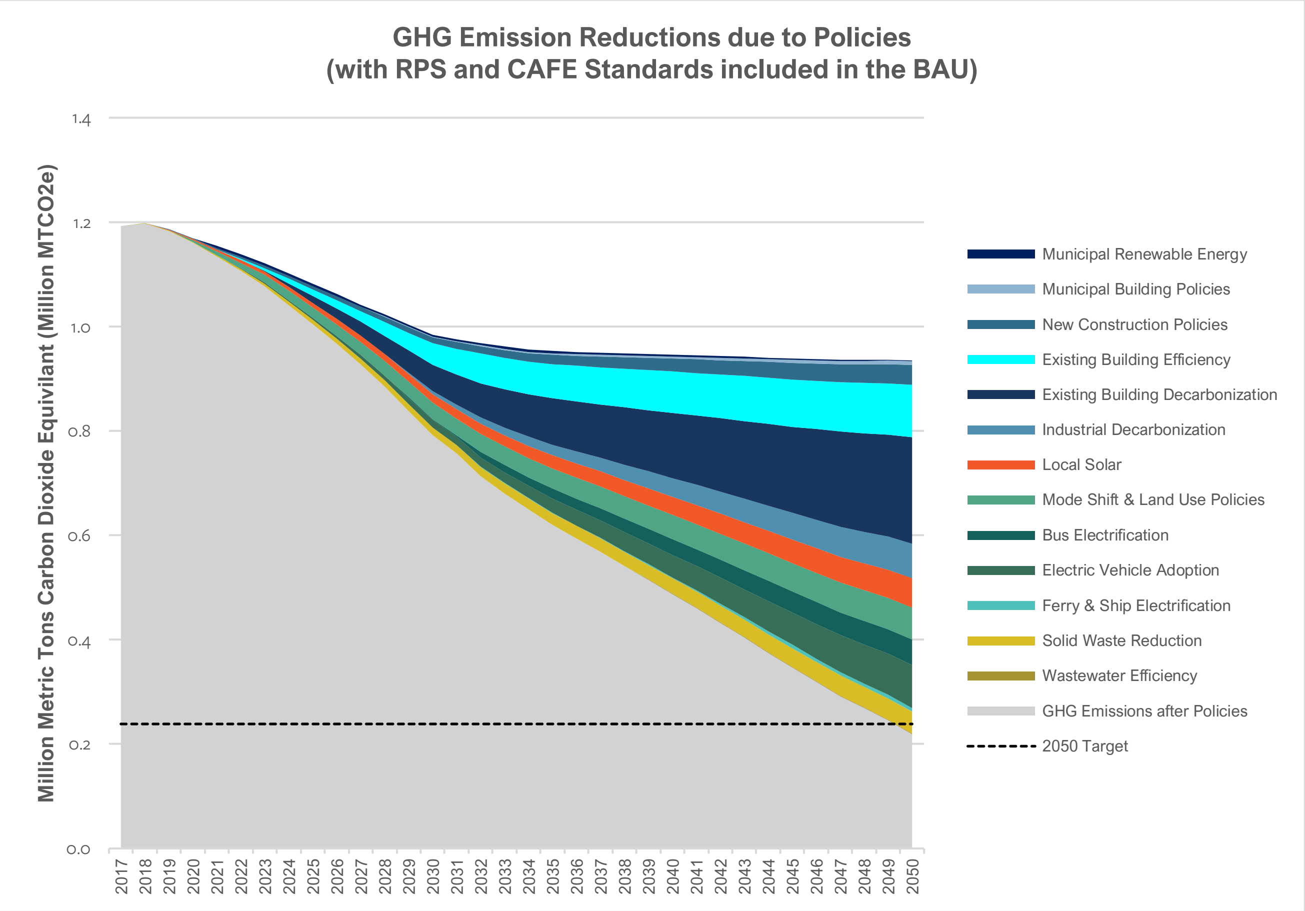

Figure 4. GHG reductions due to policies (with RPS and CAFE standards included in the BAU).

Table 23. GHG emission reductions by policy in 2030, 2040, 2050.

Absolute GHG Emissions and Reductions	GHG Reductions in Year 2030		GHG Reductions in Year 2040		GHG Reductions in Year 2050	
	MTCO$_2$e	% of reduction	MTCO$_2$e	% of reduction	MTCO$_2$e	% of reduction
Baseline (2017)	1,192,784		1,192,784		1,192,784	
BAU GHG Emissions	1,283,823		1,321,596		1,360,362	
Municipal Renewable Energy	3,567	0.7%	3,542	0.4%	1,930	0.2%
Municipal Building Policies	1,429	0.3%	4,299	0.5%	7,170	0.6%
New Construction Policies	11,797	2.4%	24,477	2.9%	38,116	3.3%
Existing Building Efficiency	41,122	8.4%	79,137	9.5%	100,336	8.8%
Existing Building Decarbonization	51,019	10.4%	125,181	15.0%	204,056	17.9%
Industrial Decarbonization	5,413	1.1%	35,779	4.3%	66,144	5.8%
Renewable Portfolio Standard	227,605	46.2%	276,951	33.2%	333,004	29.2%
Local Solar	16,598	3.4%	34,497	4.1%	56,474	4.9%
Mode Shift & Land Use Policies	30,744	6.2%	46,681	5.6%	61,089	5.4%
Bus Electrification	2,093	0.4%	29,837	3.6%	48,866	4.3%
Fuel Economy Standards	71,726	14.6%	98,559	11.8%	91,746	8.0%
Electric Vehicle Adoption	13,959	2.8%	42,853	5.1%	82,396	7.2%
Ferry & Ship Electrification	0	0.0%	1,578	0.2%	6,852	0.6%
Solid Waste Reduction	15,292	3.1%	29,292	3.5%	42,272	3.7%
Wastewater Efficiency	0	0.0%	917	0.1%	1,024	0.1%
GHG Emissions after Policies	791,459		488,017		218,887	
% Change from Baseline	-33.6%		-59.1%		-81.6%	
% Change from Default BAU	-38.4%		-63.1%		-83.9%	
% Change from a BAU that includes Renewable Portfolio Standards and Fuel Economy Standards	-23.9%		-51.7%		-75.5%	

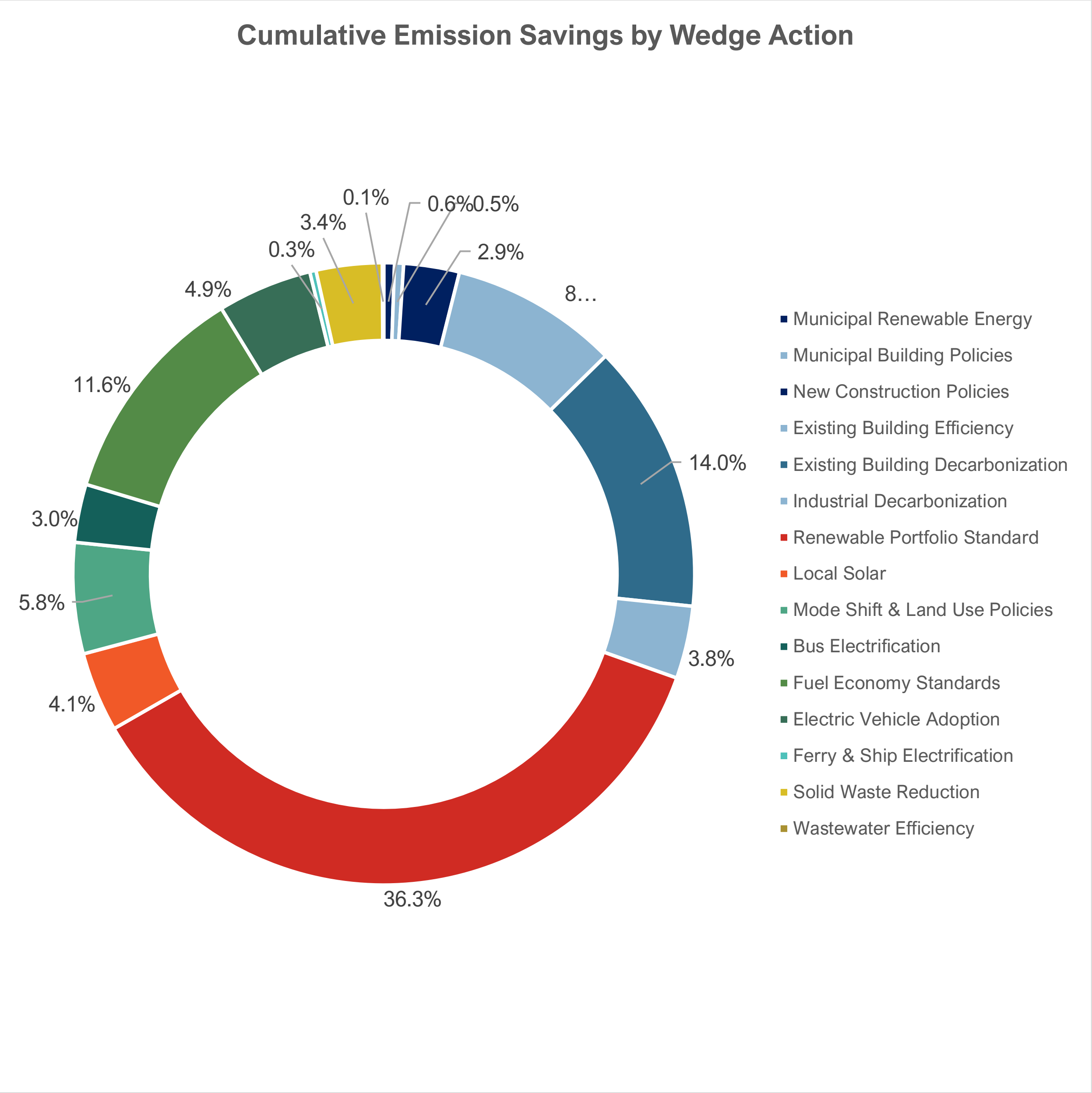

Figure 5. Cumulative emissions savings by wedge.

Table 24. Cumulative GHG emission reductions by policy.

Policy	Modeled Plan Actions	Cumulative GHG Reductions, 2020-2050	
		MTCO$_2$e	% of Reductions
Municipal Renewable Energy	BE 1.1	110,421	0.6%
Municipal Building Policies	BE 1.2, 1.3	93,748	0.5%
New Construction Policies	BE 2.1, 2.3	578,672	2.9%
Existing Building Efficiency	BE 3.1, 3.2, 3.3	1,744,458	8.7%
Existing Building Decarbonization	BE 3.4, 3.5, 5.4, 5.6	2,800,102	14.0%
Industrial Decarbonization	BE 4.1, 4.2	753,726	3.8%
Renewable Portfolio Standard	BE 5.1	7,247,418	36.3%
Local Solar	BE 2.2, 3.5, 3.6, 5.1	828,246	4.1%
Mode Shift & Land Use Policies	TLU 1 (all)	1,151,719	5.8%
Bus Electrification	TLU 2.3	604,305	3.0%
Fuel Economy Standards	N/A	2,320,100	11.6%
Electric Vehicle Adoption	TLU 2.1, 2.2, 2.4, 2.5	982,046	4.9%
Ferry & Ship Electrification	TLU 3.3, 3.4	64,965	0.3%
Solid Waste Reduction	WR 1 (all)	685,655	3.4%
Wastewater Efficiency	WR 2.3	13,998	0.1%

6.1.2 GHG Emissions by Source

Emissions reductions come from every major fuel source:

- Electricity: The Renewable Portfolio Standard, Local Solar, and Municipal Energy Purchase will reduce GHG emissions from electricity by 71% by 2030 and 100% by 2050.
- Natural Gas: Fuel Switching and Energy Efficiency in Buildings and Industry, and Energy Codes, will reduce GHG emissions from natural gas by 16% by 2030 and 70% by 2050.
- Fuel Oil: Fuel Switching and Energy Efficiency in Buildings and Industry, and Energy Codes, will reduce GHG emissions from fuel oil by 25% by 2030 and 94% by 2050.
- Gasoline: Mode Shift, Land Use Changes, Fuel Efficient Vehicles, and Vehicle Electrification will reduce unleaded gasoline use by 31% by 2030 and 74% by 2050.
- Diesel: Mode Shift, Land Use Changes, Fuel Efficient Vehicles, Electrification of Buses, Decarbonization of Municipal Vehicles, and Electric Shore Power for ferries and docked cruise vessels will reduce diesel use by 14% by 2030 and 23% by 2050.
- Solid Waste: Reduction of waste, and diversion of waste from incineration to landfills, composting, and anaerobic digestion will reduce solid waste emissions by 35% by 2030 and 89% (zero waste) by 2050.
- Wastewater: Wastewater process emissions are not affected by any plan or model actions, and so increase by 21% by 2030 and 63% by 2050.

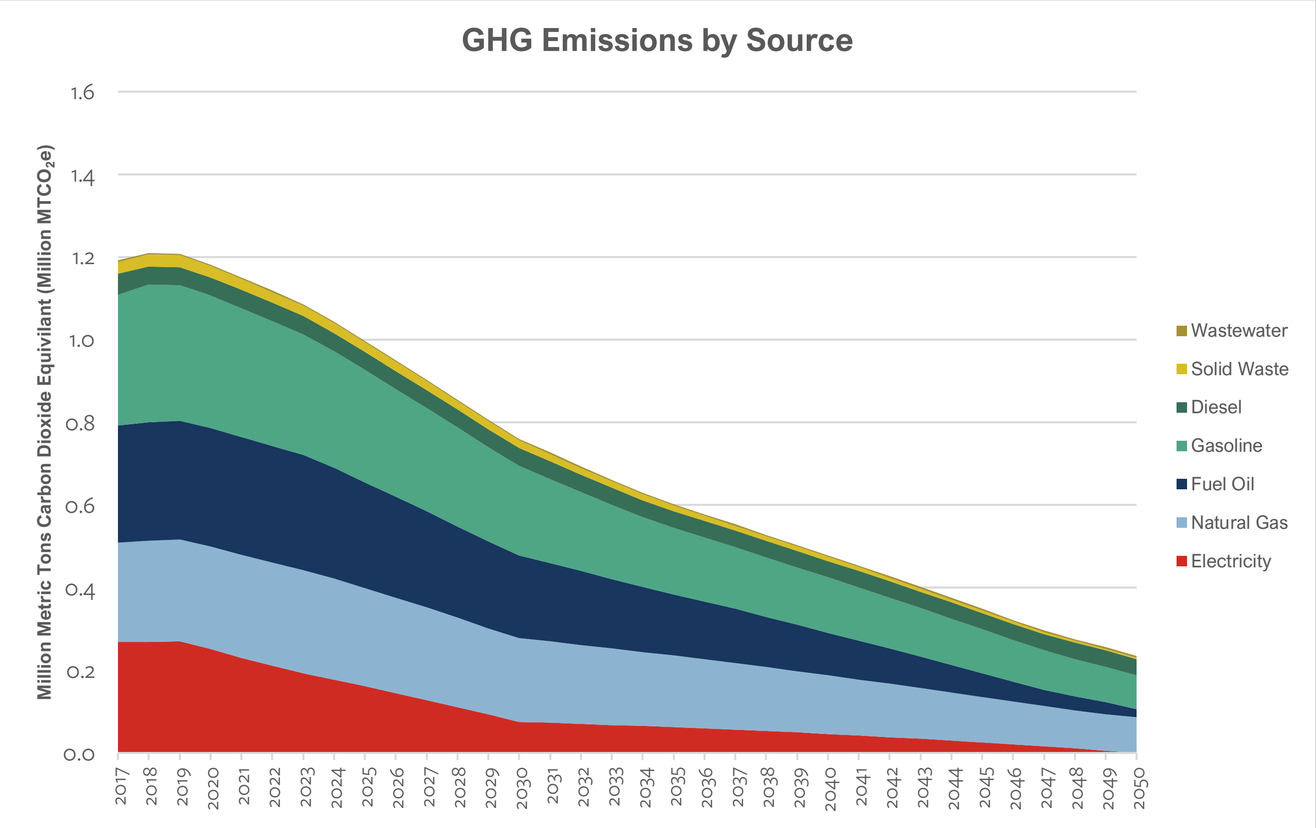

Figure 6. GHG emissions by source.

Table 25. GHG emissions by source in 2017, 2030, 2040, 2050.

Fuel	Baseline (2017)	2030		2040		2050	
	MTCO$_2$e	MTCO$_2$e	% Reduction from Baseline	MTCO$_2$e	% Reduction from Baseline	MTCO$_2$e	% Reduction from Baseline
Electricity	267,856	78,803	-71%	48,021	-82%	0	-100%
Natural Gas	241,448	203,430	-16%	134,851	-44%	66,655	-72%
Fuel Oil	283,564	212,303	-25%	107,700	-62%	17,327	-94%
Gasoline	316,208	216,925	-31%	133,955	-58%	81,691	-74%
Diesel	50,910	43,783	-14%	43,783	-14%	39,385	-23%
Solid Waste	28,211	18,316	-35%	9,711	-66%	2,990	-89%
Wastewater	3,959	4,804	21%	5,576	41%	6,471	63%
Total	1,192,784	791,459	-34%	488,017	-59%	218,887	-82%

6.1.3 Aggregated GHG Emissions Reductions

To help show the relative cumulative impact of the actions, wedges are aggregated into plan areas. The assignments were discussed in the above narrative; to review:

Table 26. Aggregated emissions groupings and associated actions.

Plan Section	Plan Sub-section	Wedge	Plan Actions	Methodology Memo Section
BE	BE 1: Municipal Buildings and Energy	Municipal Renewable Energy	BE 1.1	2.2.3
		Municipal Building Efficiency	BE 1.2, 1.3	3.2.4
	BE 2: New Construction Energy Efficiency & Decarbonization	New Construction Policies	BE 2.1, 2.3	3.2.1
	BE 3: Existing Buildings Energy Efficiency & Decarbonization	Existing Building Efficiency	BE 3.1, 3.2, 3.3	3.2.2
		Existing Building Decarbonization	BE 3.4, 3.5, 5.4, 5.6	3.2.3
	BE 4: Industrial Energy Efficiency & Decarbonization	Industrial Decarbonization	BE 4.1, 4.2	3.2.5
	BE 5: Clean and Renewable Energy	Renewable Portfolio Standard	BE 5.1	2.2.1
		Local Solar	BE 2.2, 3.5, 3.6, 5.1	2.2.2
TLU	TLU 1: Mode Shift & Land Use	Mode Shift and Land Use Policies	TLU 1 (all)	4.2.1
	TLU 2 & 3: Vehicle Electrification and Infrastructure	Bus Electrification	TLU 2.3	4.2.2
		Fuel Economy Standards	N/A	4.2.3
		Electric Vehicle Adoption	TLU 2.1, 2.2, 2.4, 2.5	4.2.4
		Ferry and Ship Electrification	TLU 3.3, 3.4	4.2.5
WR	WR 1 & 2: Waste Reduction	Solid Waste Reduction	WR 1 (all)	5.2.1
		Wastewater Efficiency	WR 2.3	5.2.2

Table 27. Cumulative emission savings by plan sector.

Name	Acronym	Cumulative GHG Reductions, 2020-2050		GHG Reductions in Year 2030		GHG Reductions in Year 2050	
		$MTCO_2e$	%	$MTCO_2e$	%	$MTCO_2e$	%
Buildings & Energy	BE	14,156,791	71%	358,550	73%	807,230	71%
Transportation & Land Use	TLU	5,123,135	26%	118,523	24%	290,948	25%
Waste Reduction	WR	699,653	4%	15,292	3%	43,297	4%
Total		19,979,579	100%	492,364	100%	1,141,475	100%

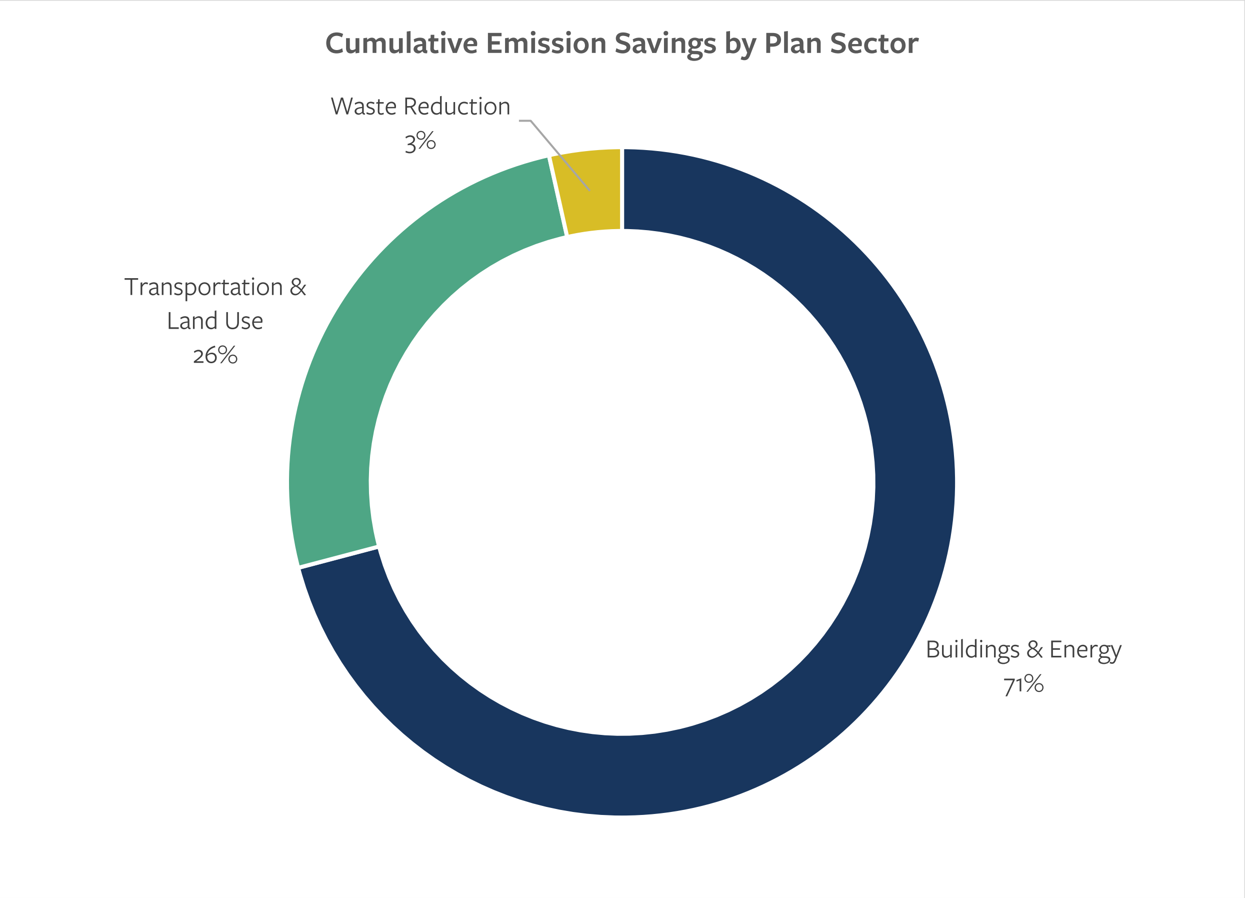

Figure 7. Cumulative emission savings by plan sector.

Table 28. Cumulative emission savings by plan sub-sector.

Name	Acronym	Cumulative GHG Reductions, 2020-2050		GHG Reductions in Year 2030		GHG Reductions in Year 2050	
		$MTCO_2e$	%	$MTCO_2e$	%	$MTCO_2e$	%
BE 1: Municipal Buildings and Energy	BE 1	204,169	1.0%	1,429	0.3%	7,170	0.6%
BE 2: New Construction Energy Efficiency & Decarbonization	BE 2	578,672	2.9%	11,797	2.4%	38,116	3.3%
BE 3: Existing Buildings Energy Efficiency & Decarbonization	BE 3	4,544,560	22.7%	92,141	18.9%	304,392	26.7%
BE 4: Industrial Energy Efficiency & Decarbonization	BE 4	753,726	3.8%	5,413	1.1%	66,144	5.8%
BE 5: Clean and Renewable Energy	BE 5	8,075,664	40.4%	244,203	50.0%	389,478	34.2%
TLU 1: Mode Shift & Land Use	TLU 1	1,151,719	5.8%	30,744	6.3%	61,089	5.4%
TLU 2 & 3: Vehicle Electrification and Infrastructure	TLU 2+3	3,971,416	19.9%	87,778	18.0%	229,860	20.2%
WR 1 & 2: Waste Reduction	WR 1+2	699,653	3.5%	15,292	3.1%	43,297	3.8%
Total		19,979,579	100.0%	488,798	100.0%	1,139,545	100.0%

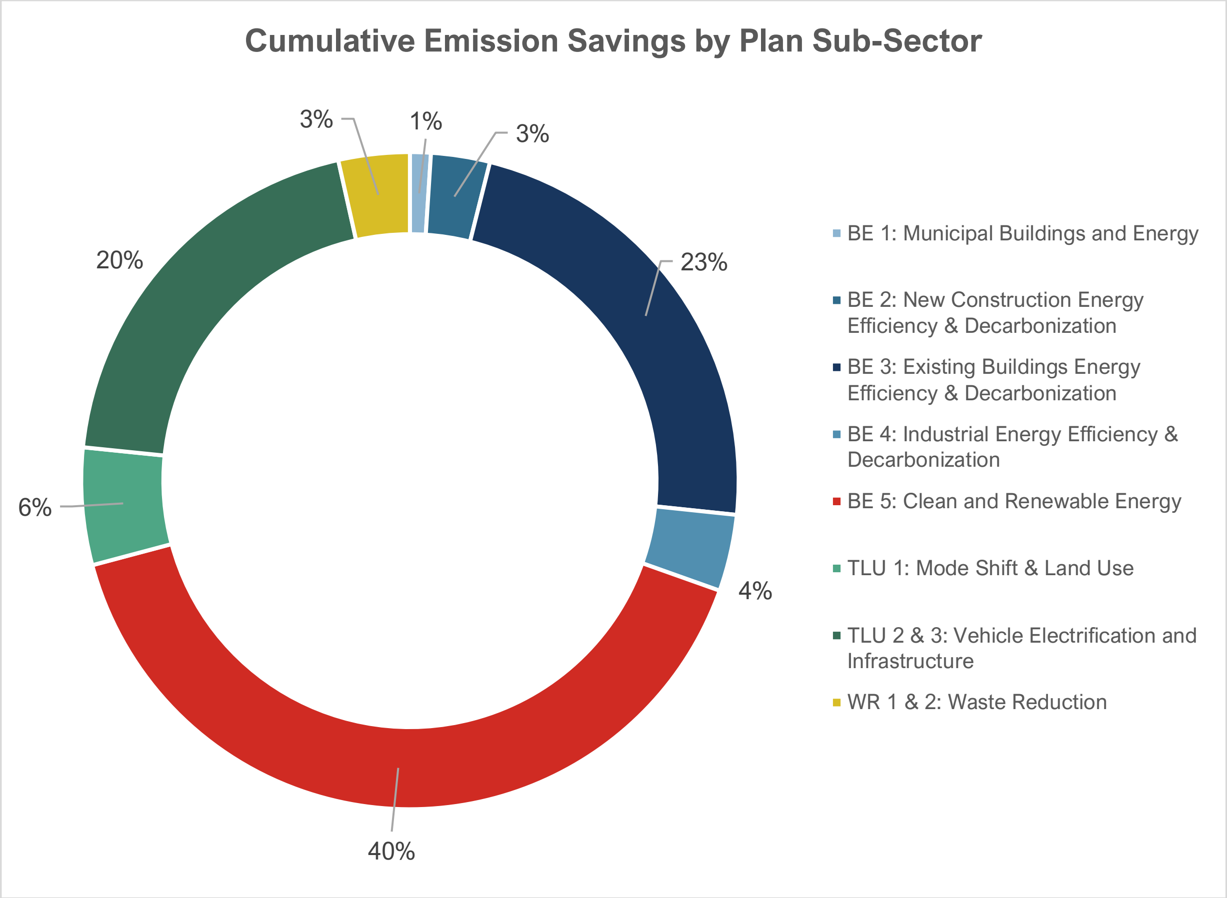

Figure 8. Cumulative emission savings by plan sub-sector.

6.2 Energy Use Results

6.2.1 Energy Use Reductions from Policies

While energy use reductions as such are not a plan goal, the prevalence of energy efficiency measures, and fuel switching to efficient electric sources, results in a total site energy savings of 45%.[25] Figure 9 shows energy use reductions from the policies. Renewable energy policies are excluded. All BE 3 actions have been combined for simplicity. These site energy savings are very relevant for considering total grid load as we electrify buildings and transportation; however, hourly and seasonal electricity loads were outside the scope of this modeling exercise.

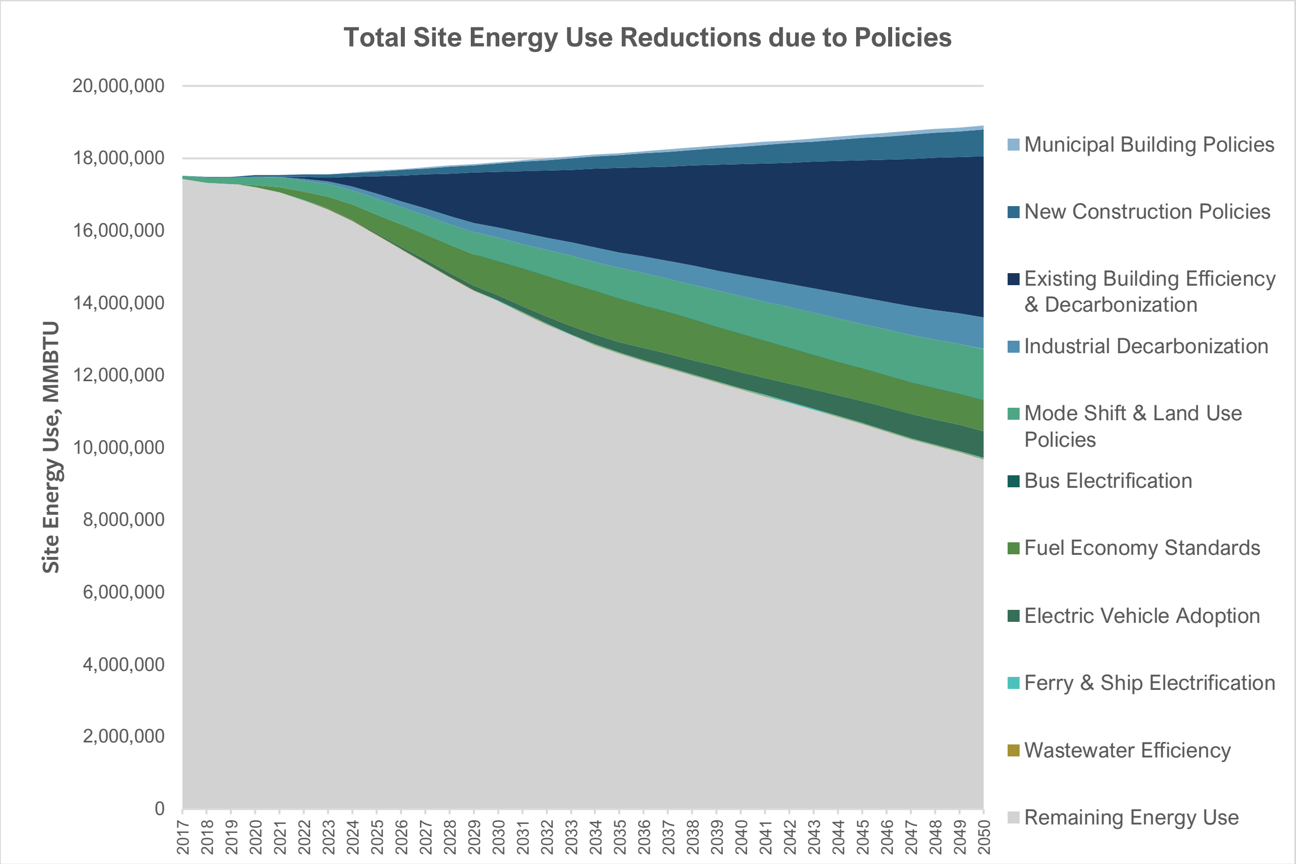

Figure 9. Total site energy use reductions due to policies.

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[25] Source energy, which accounts for losses in generation, transmission, and distribution, only decreases by 13%—at least as measured today, with an electricity source-to-site ratio of 2.8. However, most of that ratio is the result of large losses in electricity generation using fossil fuel combustion. On-site renewable energy has a source-to-site ratio of 1.0, and off-site renewable energy has an effective source-to-site ratio of 1.05 (accounting for transmission loss). Therefore, is expected that the source factor for electricity will decline dramatically as more renewable energy comes online, and the source energy savings in 2050 will be more comparable to the site energy savings.

Table 29. Site energy savings results.

Absolute GHG Emissions and Reductions	MMBTU Savings in Year 2030		MMBTU Savings in Year 2040		MMBTUs in Year 2050	
	MMBTU	% of Savings	MMBTU	% of Savings	MMBTU	% of Savings
Baseline (2017)	17,514,711		17,514,711		17,514,711	
BAU GHG Emissions	17,893,117		18,399,250		18,905,211	
Municipal Building Policies	22,104	1%	75,123	1%	109,340	1%
New Construction Policies	213,679	6%	473,473	7%	747,376	8%
Existing Building Efficiency & Decarbonization	1,376,502	40%	3,024,716	46%	4,418,252	48%
Industrial Decarbonization	102,974	3%	469,804	7%	836,634	9%
Mode Shift & Land Use Policies	646,627	19%	1,044,586	16%	1,421,867	16%
Bus Electrification	-24,817	-1%	-271,497	-4%	-392,484	-4%
Fuel Economy Standards	970,174	28%	1,333,104	20%	1,240,908	14%
Electric Vehicle Adoption	141,998	4%	445,586	7%	741,345	8%
Ferry & Ship Electrification	0	0%	21,291	0%	27,231	0%
Wastewater Efficiency	519	0%	15,046	0%	17,032	0%
Remaining Energy Use	14,443,358		11,768,018		9,737,710	
% Change from Baseline	-17.5%		-32.8%		-44.5%	
% Change from BAU	-19.3%		-36.0%		-48.5%	

6.2.2 Energy Use Reductions by Source

The energy use by fuel type also changes dramatically due to electrification:

- Electricity: Electricity use increases by 81% (1.81x)
- Natural Gas: Natural gas use decreases by 73%
- Fuel Oil: Fuel oil use decreases by 94%.
- Gasoline: Unleaded gasoline use decreases by 74%
- Diesel: Diesel fuel use for road and sea transportation decreases by 23%

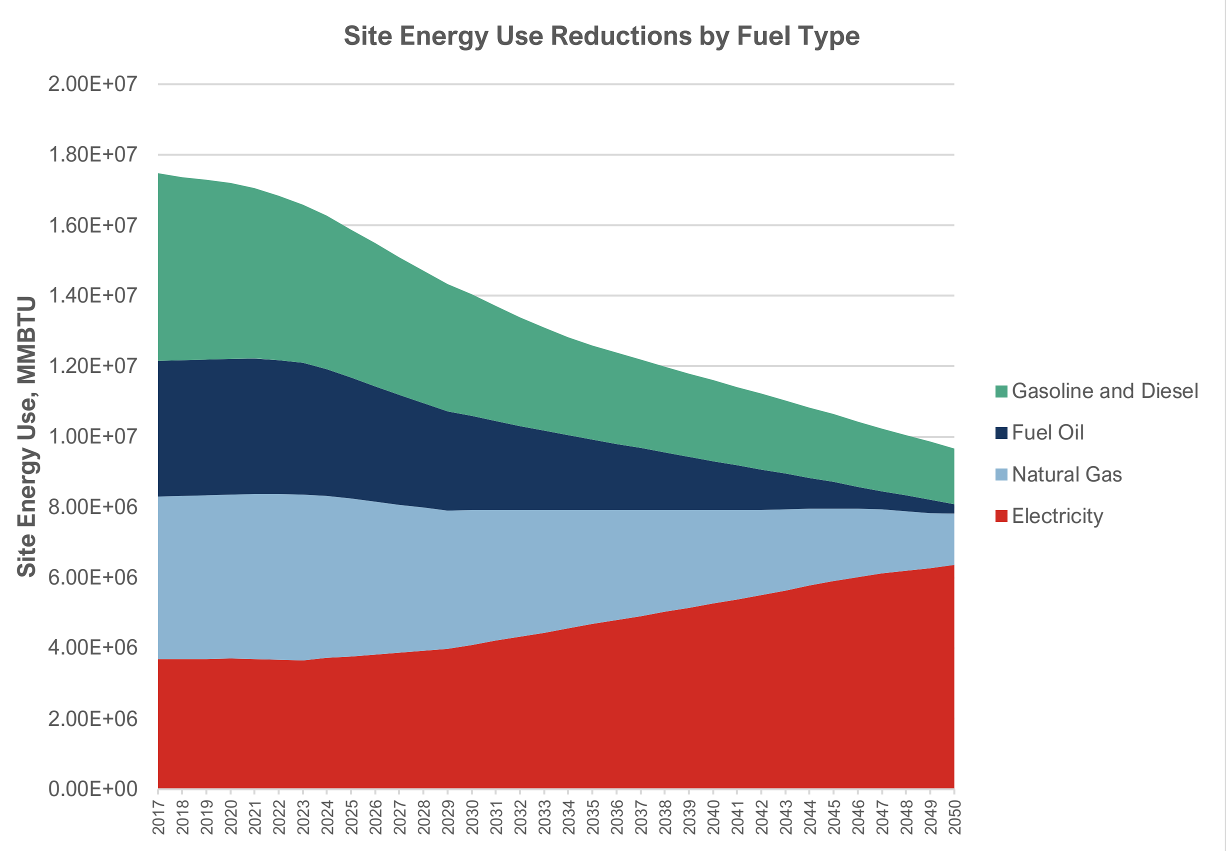

Figure 10. Site energy use by fuel type.

Table 30. Site energy use by fuel type.

	Baseline	2030		2040		2050	
	MMBTU	MMBTU	% From Baseline	MMBTU	% From Baseline	MMBTU	% From Baseline
Electricity	3,684,663	4,299,046	17%	5,477,681	49%	6,669,928	81%
Natural Gas	4,611,286	3,827,946	-17%	2,523,254	-45%	1,254,938	-73%
Fuel Oil	3,860,693	2,851,627	-26%	1,446,006	-63%	231,932	-94%
Gasoline and Diesel	5,319,825	3,464,739	-35%	2,321,077	-56%	1,580,911	-70%
Total Site Energy Use	17,476,466	14,443,358	-17%	11,768,018	-33%	9,737,710	-44%

6.2.3 Renewable Electricity

As required by the RPS, renewable electricity increases to 80% of the total by 2030 and 100% by 2050, while electricity consumption increases by 73% due to electrification of buildings and vehicles.

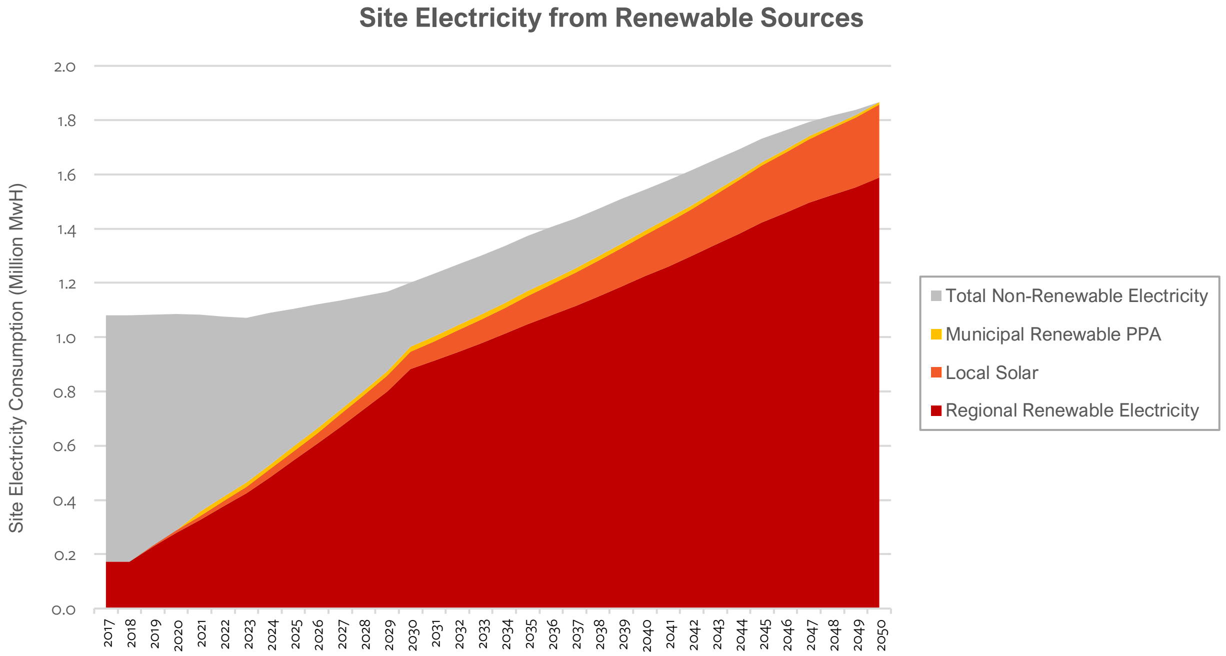

Figure 11. Site electricity from renewables.

Table 31. Site electricity from renewables.

	2017 (MWh)	2030 (MWh)	2040 (MWh)	2050 (MWh)	% of Electricity in 2050
Regional Renewable Electricity (outside the Cities)	172,786	928,057	1,271,816	1,663,150	85.1%
Local Solar Electricity	-	67,679	158,418	282,055	14.4%
Municipal Renewable Electricity Power Purchase	-	14,543	16,268	9,640	0.5%
Total Renewable Electricity	172,786	1,010,279	1,446,502	1,954,844	100%
Total Electricity Consumption	1,079,913	1,259,978	1,605,416	11,954,844	
Total Non-Renewable Electricity	907,127	249,699	158,915	0	0%
% of Electricity that is Renewable	16%	80%	90%	100%	100%