PENOBSCOT
CLIMATE ACTION

APPENDIX C
Community Energy and Emissions Modeling Technical Methodology

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1.0 Model Overview

One of the primary goals of Penobscot Climate Action is to reduce greenhouse gas (GHG) emissions in the Bangor Area Comprehensive Transportation System (BACTS) metropolitan planning area (the "region"). To analyze options toward advancing that goal, Introba (formerly Integral Group) developed a Community Energy and Emissions Planning (CEEP) model to inform and model strategies to reduce all quantified sources of GHG emissions in the region. The region includes eleven communities: Bangor, Bradley, Brewer, Hampden, Hermon, Milford, Old Town, Orono (including the University of Maine campus), Orrington, Penobscot Indian Island, and Veazie.

The CEEP model is built on and aligned with the Regional Inventory of 2019 Greenhouse Gas Emissions, which Introba completed as part of Phase 1 of the project. The CEEP model is used to estimate future energy and emissions under both a Business-as-Usual (BAU) Scenario and a Policy Scenario which quantifies the potential impact of future actions on different sectors (e.g., buildings, transportation, waste) out to 2050. The BAU Scenario includes baseline assumptions such as population growth and new development in the region, but no other policy actions. The Policy Scenario includes the same baseline assumptions as well as the relevant policy actions included in the plan's toolkits and additional strategies, any relevant federal and state-wide policies such as fuel economy standards and Maine's renewable portfolio standard, and additional assumptions outside of policy (e.g., existing building retrofit rates) that are based on best practice and are made to reflect the scale of action needed to reasonably achieve GHG reductions in certain sectors.

It is important to note that although no formal GHG emissions reduction targets were adopted as part of the Penobscot Climate Action project, the Policy Scenario does take into account targets set by the State of Maine in its "Maine Won't Wait" climate action plan.[1] These targets include a 45% reduction in GHG emissions by 2030 and an 80% reduction by 2050 from 1990 levels. In this case, targets are shown relative to the model base year, 2019, in line with the region's baseline GHG inventory.

The model is not intended to be a predictive tool and does not account for costs or externalities other than GHG emissions. The model is intended to provide communities with a high-level understanding of how they can achieve GHG reductions, and therefore, only explores policies and actions where GHG savings are quantifiable. GHG savings in some sectors are more directly quantifiable and are based on the specific requirements of applicable policies (e.g., the building sector and new construction codes) whereas GHG savings in other sectors where actions are more difficult to tie to specific savings, are based on the scale of action required to achieve significant but achievable GHG reductions. In these cases, the assessment looks to achieving specific sectoral targets based on feasible levels of market transformation. It must be noted that GHG reductions are not a given with Penobscot Climate Action; the specific design and implementation of many of the plan's recommended actions will take further analysis, including cost-effectiveness and feasibility.

This technical methodology is divided into five major sections: **Energy Supply**, **Buildings**, **Transportation**, **Waste**, and **Agriculture, Forestry and Other Land Use**. For each sector, the BAU assumptions are discussed first, and then the Policy Scenario assumptions. The GHG savings for each policy modeled are included on a final wedge chart (see section 7.0 Results). Where multiple

[1] Maine Climate Council (2020), Maine Won't Wait. maine.gov/climateplan/

policies target the same emissions source, savings are grouped under one wedge. Table 1 shows the primary source from where specific policies or model inputs are derived, the wedge on the final chart (Figure 1) where GHG savings are depicted, and the corresponding section of this report.

Table 1. Summary of Model Inputs

Policy/Input	Primary Source: PCA Section or Other	Wedge	Technical Methodology Section
Renewable Portfolio Standard	Maine Won't Wait	Renewable Portfolio Standard	2.2.1
Energy Benchmarking	PCA: Buildings and Energy	Existing Building Retrofits	3.2.1
Existing Building Decarbonization	PCA: Buildings and Energy	Existing Building Retrofits	3.2.2
Residential Building Retrofits	PCA: Toolkit 2 (Retrofit Existing Housing Stock)	Existing Building Retrofits	3.2.3
Commercial, Institutional, & Industrial Building Retrofits	PCA: Buildings and Energy	Existing Building Retrofits	3.2.4
Step Codes for New Construction, Redevelopment, and Major Renovations	PCA: Toolkit 1 (New Development Standards)	New Construction Codes	3.3.1
Electric Vehicle Adoption	PCA: Transportation Systems	ZEVs and Mode Shift	4.2.1
Mode Shift	PCA: Transportation Systems, Toolkits 3-5	ZEVs and Mode Shift	4.2.2
Fuel Economy Standards	Federal CAFE and HDPUV Standards	Fuel Economy Standards	4.2.3
Waste Diversion	PCA: Environment, Water, & Waste Systems	Waste Diversion	5.2.1
Land Use Changes	PCA: Toolkit 6 (Land Management Practices)	AFOLU Removals Based on Land Use	6.2.1

2.0 Energy Supply

The model quantifies GHG emissions from all sectors from 2019 through 2050, accounting for all energy use, energy sources, and emissions factors. The BAU Scenario assumes that the 2019 baseline emissions factors all stay constant. The modeled Policy Scenario then assesses the GHG emissions avoided through 2050 considering the implementation of the state's renewable portfolio standard.

2.1 BAU GHG Emissions Intensities

The model applies GHG emissions intensity factors (measured in tC02e/kWh) to annual energy use by fuel type (measured in kWh/year) to calculate the total annual GHG emissions by fuel type (measured in tC02e/year). These GHG emissions factors are the same as those used in the 2019 baseline GHG inventory.

The emission factor for electricity is taken from the Northeast Power Coordinating Council (NPCC) New England sub-region factor from EPA's eGrid[2] database of regional GHG intensities for 2019, which aligns with the ISO New England region. The emissions factors for natural gas, fuel oil, gasoline, and diesel are all taken from the EPA's Emission Factors List[3] for 2018. While the emissions factor for electricity may fluctuate over time, the emissions factors for fossil fuels are a function of their carbon content and are relatively constant over time. Under the model's BAU Scenario, the GHG intensities of all energy types were kept constant between 2019 and 2050.

Table 2. BAU GHG Intensity by Fuel Type

Fuel Type	Emission Factor (tC02e/kBtu)	Emission Factor (tC02e/kWh)	Modeled Trajectory
Electricity	6.51E-05	2.22E-04	BAU – constant over time Policy Scenario – declines due to RPS
Natural Gas	5.31E-05	1.81E-04	BAU & Policy Scenarios – constant over time
Fuel Oil	7.44E-05	2.54E-04	
Gasoline	7.22E-05	2.46E-04	
Diesel	7.41E-05	2.53E-04	

2.2 Avoided Energy Supply Sector Emissions Under Policy Scenario

2.2.1 Renewable Portfolio Standard

Renewable electricity currently supplies 11% of electricity in the ISO New England region.[4] Maine's new renewable energy portfolio standard (RPS) 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 determine the impact of the RPS, the Policy Scenario likewise increases the renewable portion of electricity to 80% by 2030 and to 100% by 2050. These percentages increase linearly between the target years assuming a gradual change to the electricity supply.

Table 3. Electricity Emission Factors under Maine RPS

Year	% Renewable	Emission Factor (tC02e/kWh)
2019	11%	2.22E-04
2030	80%	4.44E-05
2050	100%	2.22E-06

[2] US EPA, Emissions & Generation Resource Integrated Database (eGrid). https://www.epa.gov/egrid
[3] US EPA, GHG Emission Factors Hub. https://www.epa.gov/climateleadership/ghg-emission-factors-hub
[4] ISO New England, New England Power Grid 2022-2023 Profile. https://www.iso-ne.com/static-assets/documents/2021/03/new_england_power_grid_regional_profile.pdf

The GHG savings associated with the state's RPS show up in the **Renewable Portfolio Standard** wedge on the final chart (Figure 1). Related strategies that help support the RPS and statewide renewable energy are included in the Resilient and Renewable Energy Systems section of the plan.

3.0 Buildings

The model quantifies GHG emissions for all buildings in the region between 2019 and 2050, accounting for all energy use by buildings. The BAU Scenario assumes the energy use intensity (EUI) for each building type remains constant, while accounting for projected building growth in the region. The Policy Scenario then assesses the GHG emissions avoided through 2050 if the region were to implement a set of policy scenarios that focus on building energy efficiency and decarbonization.

3.1 BAU Building Assumptions

To address growth in the building sector, the model incorporates the region's projected population growth rate and employment rate. Net growth for residential building types is set equal to the average percent change in population among all towns in the region, using population projection data provided by BACTS. Net growth for all commercial, institutional, and industrial building types is based on the average employment growth rate among all towns in the region, using employment projection data provided by BACTS. Table 4 includes the average annual growth rate (AAGR) for each building type included in the baseline GHG inventory.

Table 4. Projected Building Floor Area

Building Type	Baseline Floor Area (Sq Ft)	AAGR (%)
Residential		
Single Family	30,351,006	-0.224%
Multifamily (2+ units)	8,078,950	-0.224%
Commercial, Institutional, and Industrial		
Government	475,200	0.448%
Education	237,600	0.448%
Commercial	27,269,404	0.448%
Healthcare	2,394,000	0.448%
Industrial	1,724,295	0.448%

The energy use intensity (EUI) for each building type can be determined by the total amount of energy a building uses per year divided by total building area. However, to allocate a specific energy consumption to the various building types in the baseline GHG inventory and in the model, Introba developed a set of preliminary EUIs based on EIA's nationwide building energy surveys. The EUIs for residential building types were developed from the 2018 Residential Energy Consumption Survey (RECS)[5] data for ASHRAE Climate Zone 6A, while the EUIs for institutional and commercial building types were developed from the 2018 Commercial Building Energy Consumption Survey (CBECS)[6] data for the New England region (Table 5).

Table 5. Energy Use Intensity Assumptions

Building Type	Total Site EUI (kBtu/sq ft)	Electricity EUI (kBtu/sq ft)	Natural Gas EUI (kBtu/sq ft)	Fuel Oil EUI (kBtu/sq ft)
Residential				
Single Family	117.0	18.2	16.09	82.7
Multifamily (2+ units)	89.0	18.2	36.4	34.4
Commercial, Institutional, and Industrial				
Government	89.1	29.5	44.1	15.5
Education	134.2	20.3	68.2	45.7
Commercial	118.4	36.2	74.2	8.0
Healthcare	240.9	51.6	146.7	42.7
Industrial	814.7	259.8	554.9	0.0

3.2 Avoided Building Sector Emissions Under Policy Scenario – Existing Buildings

3.2.1 Energy Benchmarking

The Policy Scenario includes projected effects if the region were to adopt a regional benchmarking program and "tune-up" performance standards. The program is assumed to apply to multifamily residential buildings and commercial, institutional, and industrial buildings over 20,000 square feet in size, which is a common threshold used in benchmarking programs.

Benchmarking is assumed to be implemented in the region starting in 2028 (in four years). Based on a survey of results from other cities, an 80% compliance rate is assumed and applied to the percent of floor area for each building type that is over the 20,000 square foot size threshold. Due to limited access to assessor's data for building floor area across the region, The Policy Scenario assumes that 20% of multifamily residential building floor area and 80% of commercial, institutional, and industrial building floor area is over the 20,000 square foot threshold.

Energy benchmarking is modeled as a percentage reduction in energy use across all fuel types. In this case, a 7% reduction in energy use is applied based on an IMT survey.[7] The annual penetration (i.e.,

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[5] US Energy Information Administration, 2018 RECS Survey Data. https://www.eia.gov/consumption/residential/
[6] US Energy Information Administration, 2018 CBECS Survey Data. https://www.eia.gov/consumption/commercial/
[7] Institute for Market Transformation (2015), The Benefits of Benchmarking Building Performance. https://www.imt.org/wp-content/uploads/2018/02/PCC_Benefits_of_Benchmarking.pdf

the percent of building floor area affected) is assumed to be 3% for multifamily residential buildings and 10% for commercial, institutional, and industrial buildings. It is assumed that it takes five years to reach maximum compliance and that energy savings are seen over three years from when a building first reports. For simplicity, The Policy Scenario averages energy savings over a duration of eight years. The energy use reduction due to benchmarking does not include any energy savings associated with fuel switching (see section 3.2.2 below).

The GHG savings associated with energy benchmarking show up in the **Existing Building Retrofits** wedge on the final chart (Figure 1). Related strategies that help support energy benchmarking are included in the Buildings and Energy section of the plan.

3.2.2 Existing Building Decarbonization

Given the prevalent use of natural gas and fuel oil heating in Maine, the region will not be able to achieve significant GHG reductions in line with state targets without switching most existing buildings to carbon-neutral sources of heating, such as high-efficiency, cold-climate air-source heat pumps or ground-source heat pumps. While incentives exist, there is no current policy that directly pushes for fuel switching (i.e., electrification) in the region. The Policy Scenario therefore assumes that 75% of all residential, institutional, and commercial buildings that use natural gas or fuel oil are electrified by 2050 – a rate of over 3% per year based on best practice and roughly in line with an equipment replacement lifetime of 30 years – starting in 2025.

The Policy Scenario makes the following assumptions for system efficiencies (Table 6). The fuel switch factors are the amount of additional electricity required to make up for the removed natural gas or fuel oil. For example, a natural gas fuel switch factor of 0.426 for single family homes means that for every unit of natural gas consumption removed, 0.426 units of electricity consumption will be added. In this example, a building that used to use 5,000 kBtu of electricity and 10,000 kBtu of natural gas, after fuel switching, will use 9,260 kBtu of electricity and 0 kBtu of natural gas. These factors are a function of relative efficiency assumptions and the distribution of fuel use in each building type.

Table 6. Fuel Switching Assumptions for Natural Gas (NG) and Fuel Oil (FO)

Building Type	Efficiency Factor – NG to Electricity	Efficiency Factor – FO to Electricity
Residential		
Single Family	0.426	0.484
Multifamily (2+ units)	0.460	0.362
Commercial, Institutional, and Industrial		
Government	0.497	0.413
Education	0.470	0.426
Commercial	0.421	0.362
Healthcare	0.830	0.600
Industrial	0.846	0.603

The GHG savings associated with existing building decarbonization show up in the **Existing Building Retrofits** wedge on the final chart (Figure 1). Related strategies that help support existing building decarbonization are included in the Buildings and Energy section of the plan.

3.2.3 Residential Building Retrofits

The modeled retrofits include a variety of building interventions focused on reducing energy and/or emissions apart from fuel switching, ranging from lighting upgrades to insulation, weatherization, and full envelope upgrades. Similar to existing building electrification, although incentives exist, there is no current policy that directly pushes for efficiency retrofits in the region. The retrofit rates assumed in the Policy Scenario are intended to provide a sense of the scale of action required in the existing building sector to achieve GHG reductions in line with state targets, while being realistic enough to implement through the regional adoption of a retrofit strategy.

The scale of retrofits assumed for residential buildings is equivalent to achieving 40-50% energy use reduction across 1.5% of the existing floor area each year (Table 7). Average energy use reduction increases from the near-term (2025 – 2030) to the long-term (2031 – 2050) as programs and technology are expected to improve. The Policy Scenario applies these energy reductions equally across all fuel types. In practice, retrofits are likely to be carried out through a lower average energy use reduction across a larger portion of the existing housing stock.

The GHG savings associated with residential building retrofits show up in the **Existing Building Retrofits** wedge on the final chart (Figure 1). Related strategies that help support residential building retrofits are primarily included in Toolkit 2: Retrofit Existing Housing Stock.

3.2.4 Commercial, Institutional, and Industrial Building Retrofits

The scale of retrofits assumed for commercial, institutional, and industrial buildings will range from achieving 30%-80% energy use reduction across 2%-3% of the existing floor area depending on building type (Table 7). Average energy use reduction increases from the near-term (2025 – 2030) to the long-term (2031 – 2050) as programs and technology are expected to improve. As with residential building retrofits, these rates are not based on actual policy, but intended to provide a sense of scale to support state GHG targets while also aligning with national and global best practices.

Table 7. Retrofit Assumptions

Building Type	Years	% EUI Reduction	Penetration Rate Per Year
Residential			
Single Family	2025 – 2030	40%	1.5%
Single Family	2031 – 2050	50%	1.5%
Multifamily (2+ units)	2025 – 2030	40%	1.5%
Multifamily (2+ units)	2031 – 2050	50%	1.5%
Commercial, Institutional, and Industrial			
Government	2025 – 2030	30%	3%

Table 7. Retrofit Assumptions			
Building Type	**Years**	**% EUI Reduction**	**Penetration Rate Per Year**
Government	2031 – 2050	80%	3%
Education	2025 – 2030	30%	3%
Education	2031 – 2050	80%	3%
Commercial	2025 – 2030	40%	2%
Commercial	2031 – 2050	50%	2%
Healthcare	2025 – 2030	40%	2%
Healthcare	2031 – 2050	50%	2%
Industrial	2025 – 2030	40%	2%
Industrial	2031 – 2050	50%	2%

The GHG savings associated with commercial, institutional, and industrial building retrofits show up in the **Existing Building Retrofits** wedge on the final chart (Figure 1). Related strategies that help support existing building retrofits are included in the Buildings and Energy section of the plan.

3.3 Avoided Building Sector Emissions Under Policy Scenario – New Construction

3.3.1 Step Codes for New Construction, Redevelopment, and Major Renovations

To project rates of new construction, redevelopment, and major renovations in the region, the Policy Scenario assumes net growth rates in the building sector based on population and employment projections for the region. This results in an average growth rate of -0.2% across all residential buildings, to match the projected population decline through 2050, and an average growth rate of 0.4% across commercial, institutional, and industrial building types to match employment projections through 2050. The Policy Scenario also assumes that 1% of the existing floor area for each building type will undergo redevelopment or major renovations each year, which will be subject to new construction codes. The amount of redeveloped floor area is assumed to be equal to the existing floor area it replaces.

The baseline energy code for the region is IECC 2015. EUIs for each building type by fuel source under IECC 2015 are derived from PNNL prototype building models (Table 8), except for industrial buildings where the EUI is kept consistent with that of existing industrial buildings. This is due to the lack of available energy modeling for industrial buildings and the fact that industrial EUIs are largely driven by process loads. Industrial buildings also only account for a small percentage of the overall new floor area. EUIs for fuel oil are not included below given the lack of available modeling and the small percentage of new floor space tied to fuel oil use.

Table 8. EUI Assumptions Under Baseline Energy Code (IECC 2015)			
Building Type	**EUI – Electricity (kWh/m2)**	**EUI – Natural Gas (kWh/m2)**	**EUI – Total (kWh/m2)**
Residential			
Single Family	51.2	167.5	218.8
Multifamily (2+ units)	94.8	102.5	197.3
Commercial, Institutional, and Industrial			
Government	110.8	30.1	140.9
Education	109.6	73.1	182.7
Commercial	116.3	104.6	220.9
Healthcare	228.7	160.8	389.5
Industrial	819.7	1,750.6	2,570.2

The Policy Scenario then phases in more energy efficient building codes applied to new construction, redevelopment, and major renovations in line with statewide targets. First, the Policy Scenario assumes adoption of IECC 2021 as the statewide Maine Uniform Building and Energy Code (MUBEC) in 2025, which is estimated to have a 10% EUI reduction compared to the current base code (IECC 2015). The Policy Scenario then assumes the statewide adoption of a net zero stretch code in 2035 as outlined in the Maine Won't Wait plan. The net zero stretch code is estimated to have 30% EUI reduction compared to IECC 2015 and 100% reduction in natural gas and fuel oil use. Lastly, the Policy Scenario assumes a standard lag time between permitting and building, equaling a two-year delay for single-family homes and a three-year delay for all other building types. This means that the modeled EUI improvements do not impact new floor space in the region until 2-3 years after the targeted code updates (e.g., a 10% EUI reduction is applied to single-family homes starting in 2027, two years after the MUBEC adoption of IECC 2021).

An overview of anticipated energy code updates is as follows:

1. **IECC 2015** – baseline energy code through 2025
2. **IECC 2021** – adopted in 2025, includes a 10% EUI reduction over IECC 2015
3. **Net Zero Stretch Code** – adopted in 2035, includes a 30% EUI reduction over IECC 2015 and 100% reduction in fossil fuel use

The GHG savings associated with step codes for new construction, redevelopment, and major renovations show up in the **New Construction Codes** wedge on the final chart (Figure 1). Related strategies that help support new construction codes are included in Toolkit 1: Update Zoning and New Development Standards for Low-Carbon Resilience.

4.0 Transportation

The model quantifies GHG emissions for all on-road transportation in the region between 2019 and 2050. The BAU Scenario assumes that vehicle miles traveled continues to increase at historical rates, with the current levels of vehicle fuel economy. The Policy Scenario then assesses the GHG emissions avoided through 2050 if the region were to implement a set of transportation and land use policies that encourage vehicle electrification and mode shift. The vehicle types in the model were selected to align with those used in the 2019 GHG inventory.

4.1 BAU Transportation Assumptions

Baseline transportation emissions for vehicles were based on the vehicle miles traveled (VMT), fuel efficiency, and the GHG intensities of fuel sources by vehicle type, including light duty vehicles (LDV), light duty trucks (LDT), heavy duty vehicles (HDV), and buses (Table 9). The VMT for each of these broad vehicle types is aggregated and rounded from the more granular data included in the 2019 GHG inventory.

Table 9. BAU Vehicle Assumptions

Vehicle Type	Fuel Type	Baseline VMT (miles)	BAU Fuel Efficiency (kBtu/mile)	BAU Fuel GHG Intensity (tC02e/kBtu)
LDV	Gasoline	181,088,000	3.80	7.22E-05
LDV	Electric	1,686,000	1.08	6.51E-05
LDT	Gasoline	397,967,000	7.27	7.22E-05
LDT	Diesel	10,584,000	8.02	7.41E-05
LDT	Electric	96,000	1.08	6.51E-05
HDV	Diesel	27,947,000	26.04	7.41E-05
HDV	Gasoline	11,190,000	23.58	7.22E-05
HDV	Electric	0	1.08	6.51E-05
Bus	Diesel	3,766,000	41.82	7.41E-05
Bus	Electric	0	1.08	6.51E-05

Mode share numbers are aggregated for the 11 communities in the region based on 2017-2021 American Community Survey mode split data provided by BACTS (Table 10). 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. Heavy duty vehicles are not included in the mode share numbers.

Table 10. Baseline Mode Share

Mode	Baseline Mode Share (%)
Passenger Vehicle	84.2%
Public Transit	1.1%
Walking, Biking, or Other	14.6%

4.2 Avoided Transportation Sector Emissions Under Policy Scenario

4.2.1 Electric Vehicle Adoption

The Policy Scenario assumes a 7% vehicle turnover rate, meaning that on average, a vehicle is replaced every 15 years. The Policy Scenario also assumes that the share of new vehicles sold that are zero emission vehicles (ZEV) will increase over time in line with state targets (Table 10).

The proportion of new light duty vehicles and trucks that are ZEVs will increase from 43% in 2028 to 82% in 2032, and reach 100% in 2035, based on targets in Maine's Clean Transportation Roadmap.[8] The proportion of heavy duty vehicles that are ZEVs will also increase over time, maxing out at 75% between 2035 and 2050 depending on their size, based on targets in Maine's Clean Transportation Roadmap.

Lastly, the Policy Scenario assumes a target of zero-emissions bus fleet by 2040 if the region were to adopt a regional bus electrification strategy. As buses have an average 15-year lifespan, all new bus purchases must therefore be electric starting in 2025, with the proportion increasing linearly as diesel buses are retired. This assumption goes beyond any current, smaller-scale programs such as the Community Connector's electrification plan.[9]

Table 11. ZEV Share Among New Vehicles Sold

Vehicle Type	ZEV Sales Target 1 (%)	Target Year 1	ZEV Sales Target 2 (%)	Target Year 2	ZEV Sales Target 3 (%)	Target Year 3
LDV	43%	2028	82%	2032	100%	2035
LDT	43%	2028	82%	2032	100%	2035
HDV	75%	2035	NA	NA	NA	NA
HDV – Large Diesel	75%	2050	NA	NA	NA	NA
Bus	100%	2025	NA	NA	NA	NA

The GHG savings associated with electric vehicle adoption show up in the **ZEVs and Mode Shift** wedge on the final chart (Figure 1). Related strategies that help support electric vehicle adoption are included in the Transportation Systems section of the plan.

4.2.2 Mode Shift

Land use policies and strategies to increase active and public transit are crucial to reducing GHG emissions by encouraging a shift in travel modes away from passenger vehicles. However, modeling the effects of a variety of individual policies on mode shift and VMT is extremely complex. Given this constraint, the Policy Scenario calculates GHG reductions based on the VMT changes that result from reaching a set of mode share thresholds. While there are no mode shift targets proposed as part of the plan, the Policy Scenario assumes favorable mode shift in relation to current mode share

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[8] Maine Governor's Energy Office (2021), Maine Clean Transportation Roadmap. https://www.maine.gov/future/initiatives/climate/cleantransportation
[9] Bus Electrification Transition Plan for Bangor Community Connector. (2023). https://www1.maine.gov/mdot/climate/docs/Bangor%20CC%20Electrification%20Plan%20v1.1.pdf

in the region, increasing over time to a targeted mode share of 60% for passenger vehicles in 2050, 20% for public transit, and 20% for walking and biking (or other) based on best practices (Table 12).

Table 12. Mode Share Assumptions

Mode	BAU Mode Share (%)	2050 Target Mode Share (%)
Passenger Vehicle	84.2%	60%
Public Transit	1.1%	20%
Walking, Biking, or Other	14.6%	20%

The GHG savings associated with mode shift show up in the **ZEVs and Mode Shift** wedge on the final chart (Figure 1). Related strategies that help support mode shift are included in the Transportation Systems section of the plan and various toolkits including Toolkit 3: Create a Capacity Building Strategy for Public Transit; Toolkit 4: Partnerships to Promote Active and Public Transit; and Toolkit 5: Foster Complete and Walkable Neighborhoods.

4.2.3 Fuel Economy Standards

As existing vehicles are retired and replaced with new vehicles, the average fuel efficiency of the vehicle stock and the vehicles that comprise it change. New vehicles entering the stock have a higher fuel efficiency rating due to the federal Corporate Average Fuel Economy (CAFE) Standard,[10] The GHG and energy use reduction impacts of the CAFE Standard were included in the Policy Scenario – not the BAU Scenario – to make its impact on GHG emissions explicit. However, because it is a federal regulation already in place, the CAFE Standard will achieve GHG reductions regardless of actions taken in the region.

As previously stated, the Policy Scenario assumes a vehicle turnover rate of 7%. While the overall vehicle stock is becoming more efficient over time due to the CAFE Standard, the mix of vehicles in Maine is also changing as trucks and SUVs become more popular. Therefore, the Policy Scenario assumes the overall fuel economy on Maine's roads remains unchanged through 2030 to reflect recent trends. From 2030, the Policy Scenario assumes a 2% increase in fuel economy each year for new light duty vehicles, 4% for new light duty trucks, and 10% for new heavy duty vehicles (Table 13), roughly in line with anticipated updates to the CAFE Standard. The Policy Scenario does not apply improved fuel economy standards to electric vehicles or new buses, which are assumed to switch to all electric replacements starting in 2025.

Table 13. Projected Fuel Economy Changes

Vehicle Type	Fuel Type	BAU Fuel Efficiency (kBtu/mile)	Annual Fuel Efficiency Improvement for New Vehicles (%)
LDV	Gasoline	3.80	2%
LDV	Electric	1.08	NA

[10] U.S. Department of Transportation, Corporate Average Fuel Economy Standards. https://www.transportation.gov/mission/sustainability/corporate-average-fuel-economy-cafe-standards

Table 13. Projected Fuel Economy Changes

Vehicle Type	Fuel Type	BAU Fuel Efficiency (kBtu/mile)	Annual Fuel Efficiency Improvement for New Vehicles (%)
LDT	Gasoline	7.27	4%
LDT	Diesel	8.02	4%
LDT	Electric	1.08	NA
HDV	Diesel	26.04	10%
HDV	Gasoline	23.58	10%
HDV	Electric	1.08	NA
Bus	Diesel	41.82	NA
Bus	Electric	1.08	NA

The GHG savings associated with fuel economy standards show up in the **Fuel Economy Standards** wedge on the final chart (Figure 1). This is the only wedge that cannot be linked to any of the sections in the plan or its toolkits, however, it is important to include in the model as a key strategy for reducing GHG emissions from transportation.

5.0 Waste

The model quantifies GHG emissions from all waste in the region between 2019 and 2050. The BAU Scenario assumes a proportional change in waste emissions based on population growth in the region. The Policy Scenario then assesses the GHG emissions avoided through 2050 if the region were to implement a strategy to divert waste away from landfill.

5.1 BAU Waste Assumptions

Emissions associated with waste are based on the solid waste that is disposed of in landfills and is calculated using an emissions per tonne rate (0.32 tCO2e/tonne) based on the 2019 baseline GHG inventory. The emissions per tonne rate is applied to projections of landfilled waste, factoring in overall waste reduction and diversion rates. For the purpose of this model, the emissions associated with solid waste that is recycled or composted is considered negligible (0.00 tCO2e/tonne).

As addressed in the GHG inventory, all solid waste was assumed to be landfilled due to the landscape of waste collection and disposal in the region during the inventory year of 2019. Further, no waste characterization study was available for the region, so quantities of different categories of solid waste are estimated based on the 2011 Maine Residential Waste Characterization Study. For simplicity, all waste in the region is assumed to be municipal solid waste (MSW) and the tonnage per capita (0.34 tonnes) is assumed to be constant through 2050. These generalizations do not take into account smaller scale programs, including recycling and composting programs at UMaine, which have a negligible impact on the overall waste sector in the region.

Emissions associated with wastewater treatment were excluded from the model due to the complexity and absence of any applicable policies in the plan.

5.2 Avoided Waste Sector Emissions Under Policy Scenario

5.2.1 Waste Diversion

Since there are no specific waste reduction or diversion targets included in the plan or its toolkits, the Policy Scenario applies diversion rates based on widely accepted best practices and comparable community targets. A 2050 diversion target of 80% is assumed in line with conservative definitions for zero waste targets and in line with verbal plans provided by the Municipal Review Committee (MRC), the region's primary waste management service. This means that, by 2050, 80% of the region's municipal solid waste will be diverted from landfill (i.e., recycled, composted, or other form of emissions-free disposal). Based on conversations between Introba, BACTS, MRC, and disposal facilities in the region, there is still significant uncertainty around future waste disposal practices in the region. Given this uncertainty, the Policy Scenario assumes that diversion rates increase linearly from the baseline level (0%) to the maximum diversion rate (80%) by 2050.

Table 14. Baseline and Projected Municipal Solid Waste Assumptions

Municipal Solid Waste	2019 Baseline	2050 Projected
Total (tonnes)	26,183	24,479
Per Capita (tonnes)	0.34	0.34
Landfilled (%)	100%	20%
Landfilled (tonnes)	26,183	4,896
Recycled (%)	0%	80%
Recycled (tonnes)	0	19,584

The GHG savings associated with waste diversion show up in the **Waste Diversion** wedge on the final chart (Figure 1). Related strategies that help support waste diversion are included in the Environment, Water, and Waste Systems section of the plan.

6.0 Agriculture, Forestry, and Other Land Use

The model quantifies GHG emissions for all agriculture, forestry, and other land use (AFOLU) sources in the region between 2019 and 2050. The overarching AFOLU categories incorporated in the model include emissions from livestock and land use changes – including GHG removals due to land use changes – consistent with the baseline GHG inventory. The BAU Scenario assumes that AFOLU sources and their emissions remain constant through 2050, while the Policy Scenario assesses the

GHG emissions avoided through 2050 if the region were to implement a set of improved land management practices that contribute to GHG removals (i.e., carbon sequestration).

6.1 BAU AFOLU Assumptions

The baseline GHG inventory accounts for both emissions (e.g., resulting from deforestation) and removals (e.g., resulting from reforestation) in the region. The total carbon sequestration of undisturbed forest in the region is reported in the inventory's methodology memo, but not included in the final regional emissions inventory in order to focus on the impact of emissions sources in the region, consistent with the Maine State Emissions Inventory. As such, the GHG removals associated with undisturbed forest are also excluded from the modeling assessment in order to keep the focus on changes to emissions sources in the region. Instead, the model calculates total emissions from the AFOLU sector based on emissions due to livestock, emissions due to land use changes, and removals due to land use changes. In the BAU Scenario, all sources of AFOLU emissions and removals are assumed to be constant over time.

Reporting the magnitude of carbon forest sequestration in the region, however, is valuable for informing future land use decisions, particularly around the conservation of forests. In fact, the total annual carbon sequestration of undisturbed forest in the region is equal to about 314,000 tCO2e, which balances out roughly 90% of the GHG emissions associated with the transportation sector, underscoring this importance of land use decisions.

6.2 Avoided AFOLU Sector Emissions Under Policy Scenario

6.2.1 Land Use Changes

Although the GHG removals associated with undisturbed forest are excluded from the analysis, the Policy Scenario does incorporate the GHG removals (i.e. carbon sequestration) associated with reforestation and urban canopy maintained/gained because these categories reflect active land use changes that impact GHG emissions flux. Although there are no specific targets included in the plan or its toolkits, the Policy Scenario assumes an increase in these two land use categories based on proposed improvements in land management practices and in alignment with statewide conservation goals.

The Policy Scenario therefore assumes an increase in land uses that sequester carbon if the region were to implement a land management strategy with targets for a 50% increase in urban tree canopy and reforestation by 2030, and a 100% increase by 2050. This would be equivalent to doubling the region's urban tree canopy by 2050. While not the same, these assumptions are roughly in line with existing conservation targets to increase the total acreage of conserved land from 20% to 30% (a 50% increase) by 2030 in line with Maine Won't Wait targets, and an increase from 20% to 40% (a 100% increase) by 2050 based on long-range global best practices. Table 15 demonstrates how a projected increase in land use categories that sequester carbon leads to a decrease in the total annual emissions in the AFOLU sector through 2050.

Other sources of AFOLU emissions (e.g., livestock) are assumed to remain constant through 2050 due to a lack of data and applicable strategies in the plan.

Table 15. Baseline and Projected AFOLU Emissions Assumptions			
Year/Target	**Conservation Targets (% Land)**	**Projected Increase in Land Uses that Sequester Carbon (% Increase)**	**Total Emissions (tCO2e)**
2019 State Baseline	20%	0%	46,836
2030 State Target	30%	50%	27,171
2050 Best Practice	40%	100%	18,782

The GHG savings associated with land use changes show up in the **AFOLU Removals Based on Land Use** wedge on the final chart (Figure 1). Related strategies that help support land use changes are primarily included in Toolkit 6: Adapt Land Management Practices to Support Resilience.

7.0 Results

The following section summarizes the results of the model, including the effects on GHG emissions reductions driven by the implementation of policies in the Penobscot Climate Action plan, the region's future emissions breakdown by sector, the cumulative emissions reduction impact associated with each policy "wedge," and overarching recommendations for future action.

7.1 GHG Emissions Reductions Under Policy Scenario

Based on the policies and additional assumptions modeled, GHG emissions in the region are projected to decrease by about 73% by 2050 relative to the 2019 baseline (Figure 1). While most of these savings can be attributed to the policies and other assumptions outlined in this assessment, there is some decrease in total emissions expected under the BAU Scenario, mostly due to the projected population decline in the region.

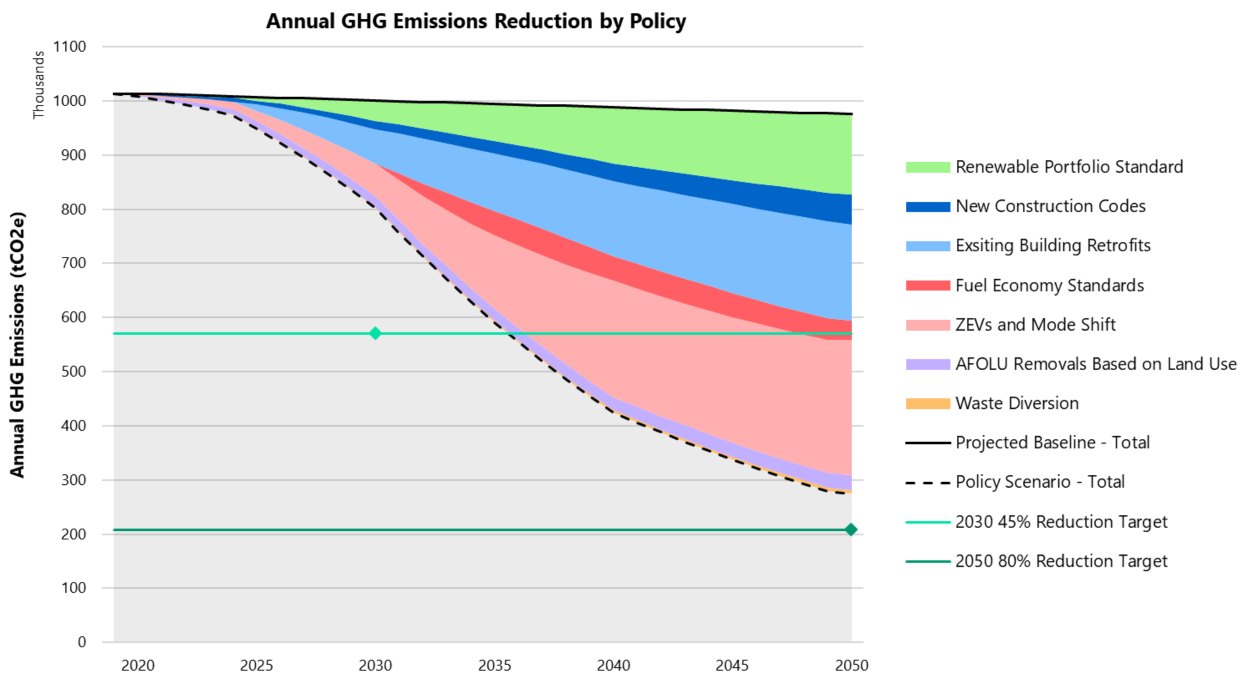

Figure 1: GHG emissions reduction in the PCA region under the Policy Scenario

Table 16 demonstrates the total emissions savings expected under the BAU and Policy Scenarios. Out of all GHG savings under the Policy Scenario, 69% can be attributed to the specific policy assumptions modeled.

Table 16. Regional emissions under BAU and Policy Scenarios

Regional Emissions	2019 (baseline)	2050 (modeled)
Total Emissions – BAU Scenario (tCO2e)	1,013,748	975,792
Total Emissions – Policy Scenario (tCO2e)	1,013,748	274,307
Total Emissions Reduction relative to baseline under Policy Scenario (tCO2e)	0	739,441
Total Emissions Reduction relative to BAU under Policy Scenario (tCO2e)	0	701,485
Total Emissions Reduction relative to baseline under Policy Scenario (%)	0%	73%
Total Emissions Reduction relative to BAU under Policy Scenario (%)	0%	69%

To help demonstrate where these GHG savings are occurring and their significance, the chart below (Figure 2) shows the total GHG emissions breakdown by sector between the 2019 baseline year and the 2050 Policy Scenario. Note that there are no emissions associated with new construction from the 2019 baseline inventory and that the new construction emissions in the 2050 Policy Scenario represent added emissions to the building sector due to future buildings that will be built between 2019 and 2050.

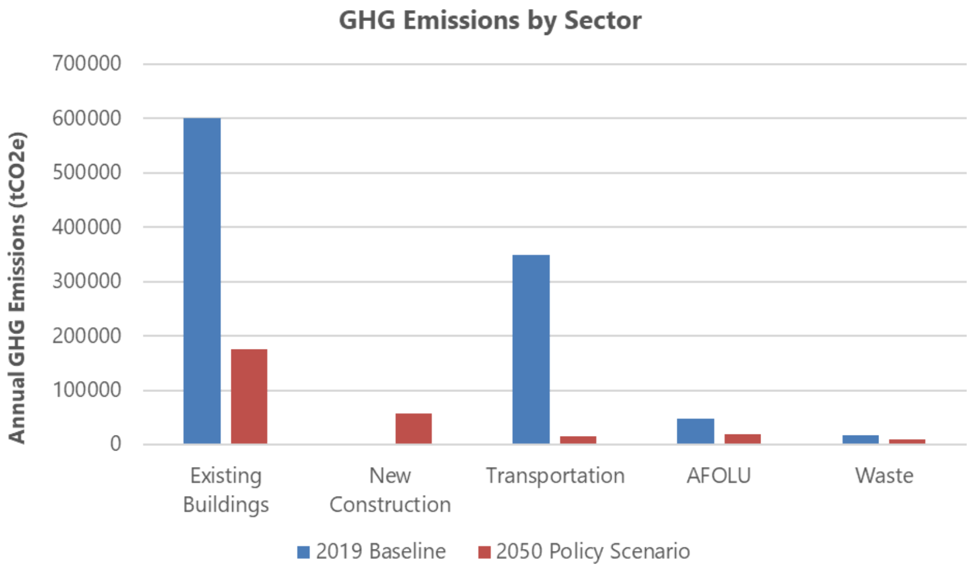

Figure 2: GHG emissions by sector between 2019 Baseline and 2050 Policy Scenario

Figure 3 is the GHG emissions breakdown (by percent of total emissions) for 2050 by sector under the modeled Policy Scenario. This shows where residual emissions are present after all modeled policies and additional assumptions are implemented, demonstrating where further action may be needed for even greater GHG savings. Note that in this figure, the total emissions from existing buildings and new construction are combined into a single building sector to better demonstrate the cumulative impact of all buildings that will exist by 2050. Under the Policy Scenario, 84% of all emissions will come from the building sector by 2050.

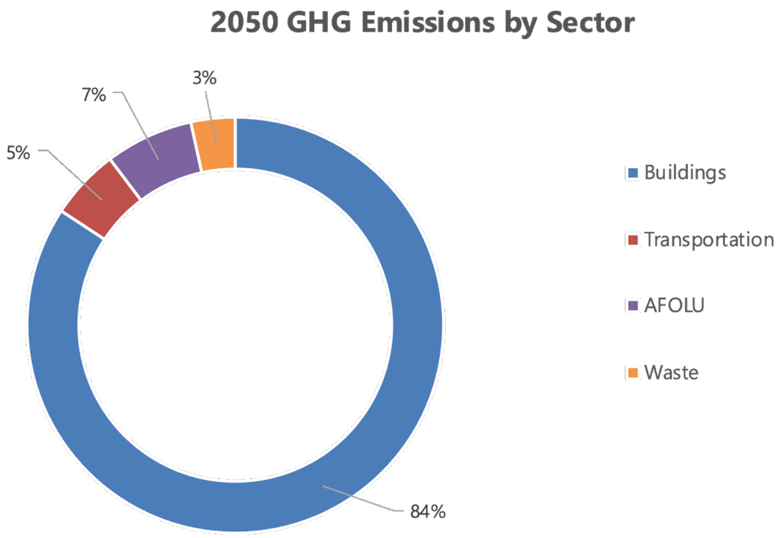

Figure 3: 2050 GHG emissions breakdown by sector under Policy Scenario

Figure 4 demonstrates the breakdown in cumulative emissions savings by policy area – or wedge corresponding to Figure 1 – among all policies and assumptions modeled in this assessment.

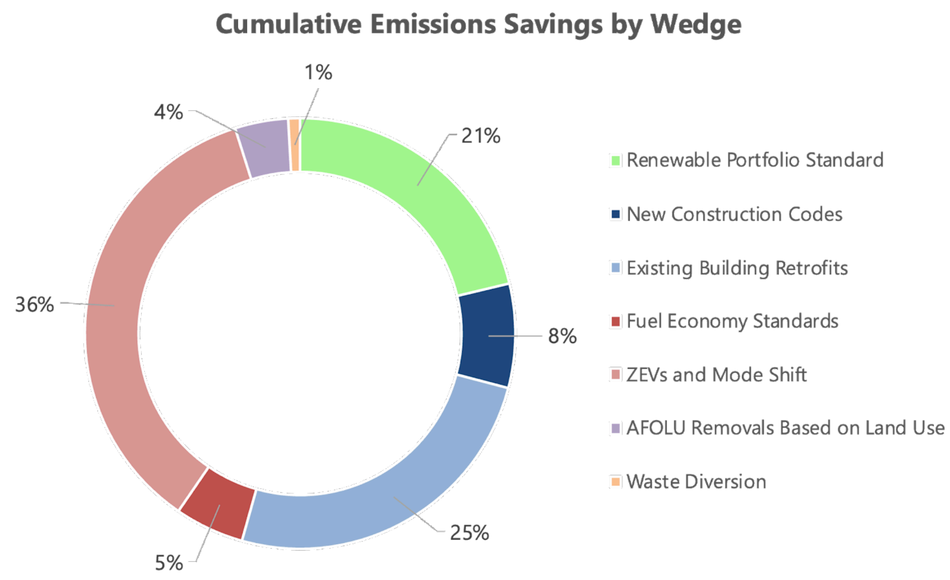

Figure 4: Cumulative emissions savings by wedge

Taking into account all GHG savings reflected in the 2050 Policy Scenario, the policy areas with the most significant potential for GHG emissions reduction include:

1. **ZEVs and Mode Shift** – 36% of all cumulative savings due to policy
2. **Existing Building Retrofits** – 25% of all cumulative savings due to policy
3. **Renewable Portfolio Standard** – 21% of all cumulative savings due to policy

Together, these three policy areas make up 82% of all cumulative savings due to policy and other assumptions in the Policy Scenario.

7.2 Recommendations for Future Action

As currently modeled, the region may fall short of GHG emissions reduction targets set in the state's Maine Won't Wait Plan, which include a 45% reduction in GHG emissions by 2030 and an 80% reduction by 2050. This can largely be attributed to the residual emissions (shown in figure 3) that result, in part, due to weaker building policies for existing buildings and new construction. Under the current policies modeled, only 75% of existing buildings fuel switch to use clean electricity by 2050, leaving 25% still on natural gas or fuel oil to meet heating needs. Additionally, all new buildings built before 2035 (i.e., when the net zero stretch code is adopted) are still assumed to use gas or oil systems, which won't be replaced before 2050. For each year that new buildings are not required to be low carbon or net zero, it will be harder to meet the state's GHG reduction targets. However, it should be noted that this is not a definitive analysis; many of the assumptions in the model are conservative and greater GHG reductions may be possible with additional state and federal support.

Nevertheless, more action is likely needed, and the GHG reductions modeled in this assessment are not a given. The region should consider greater emphasis on existing building decarbonization and new construction policies to drive GHG reductions in the building sector. This could entail more stringent benchmarking and tune up standards, and more support for existing building retrofits, that prioritize fuel switching away from natural gas and oil systems to all-electric systems. Optimistic assumptions around electrification and retrofit rates are already made under the Policy Scenario, but these assumptions are not currently backed by policy in the region (they should be and should go further). New construction policies should aim to promote all-electric buildings as soon as possible rather than wait for the 2035 net zero stretch code. It is also recommended that the region adopt formal GHG targets to ideally match those set in the Maine Won't Wait plan. Lastly, the region should plan to complete further analysis as formal GHG targets are set and specific policies are implemented. The policy assumptions laid out in this methodology are based on best practices and can be used as a guide for next steps at the regional and community level.