Carbon Neutral Providence Technical Appendix

July 2019

Acadia Center
Advancing the Clean Energy Future

Introduction and Purpose

The objective of this project was to develop policy and program modeling scenarios that demonstrate a pathway to achieve 80-100% greenhouse gas (GHG) reduction or carbon neutrality by 2050 for the city of Providence. To best understand the changes needed to achieve deep carbon reductions, Acadia Center conducted an all-sector modeling analysis covering the residential, commercial and industrial, transportation, wastewater, solid waste and agriculture sectors. Two scenarios were modeled: (1) a Business As Usual (BAU) scenario, in which no new carbon mitigation policies or programs are introduced; and (2) a Carbon Mitigation Scenario that incorporates policies and programs to meet the 80% GHG reduction target. The Carbon Mitigation Scenario demonstrates a combination of clean energy and carbon reduction technologies that will lead to the target GHG reductions, primarily electrification of transportation and buildings paired with continued uptake of renewable, carbon-free electricity. Criteria pollutants were also modeled in each scenario to demonstrate the potential co-benefits that would be achieved through GHG reductions. This appendix describes the basis for each scenario in detail and shows the resulting emissions outputs by sector.

Methodology

Data Sources and Assumptions

One main data source for the BAU scenario is the Providence Citywide Greenhouse Gas Inventory (Providence GHG Inventory), which includes historic GHG emissions and fossil fuel consumption. The BAU model also draws on other federal and state data sources:

- Data on projected direct energy use in residential, commercial, industrial and transportation sectors comes from the U.S. Energy Information Administration (EIA) Annual Energy Outlook 2018 (AEO). The data is at the regional level for New England and includes all current laws and regulations.
- Data on electricity use in all sectors come from the 2018 ISO New England (ISO-NE) Capacity, Energy, Loads and Transmission (CELT) forecast. This report provides Rhode Island state-level data, which was modified using electric efficiency savings from Rhode Island’s annual Energy Efficiency Plans filed by National Grid to the Public Utilities Commission.
- Data on emissions in the water, wastewater, and solid waste sectors comes from the U.S. Environmental Protection Agency (EPA) State Inventory Tool (SIT), which provides state-level data.
- Data on historical fuel consumption for New England comes from the EIA State Energy Data System (EIA SEDS).
- Data on criteria pollutant emissions factors comes from the EPA, which provides data based on technology.

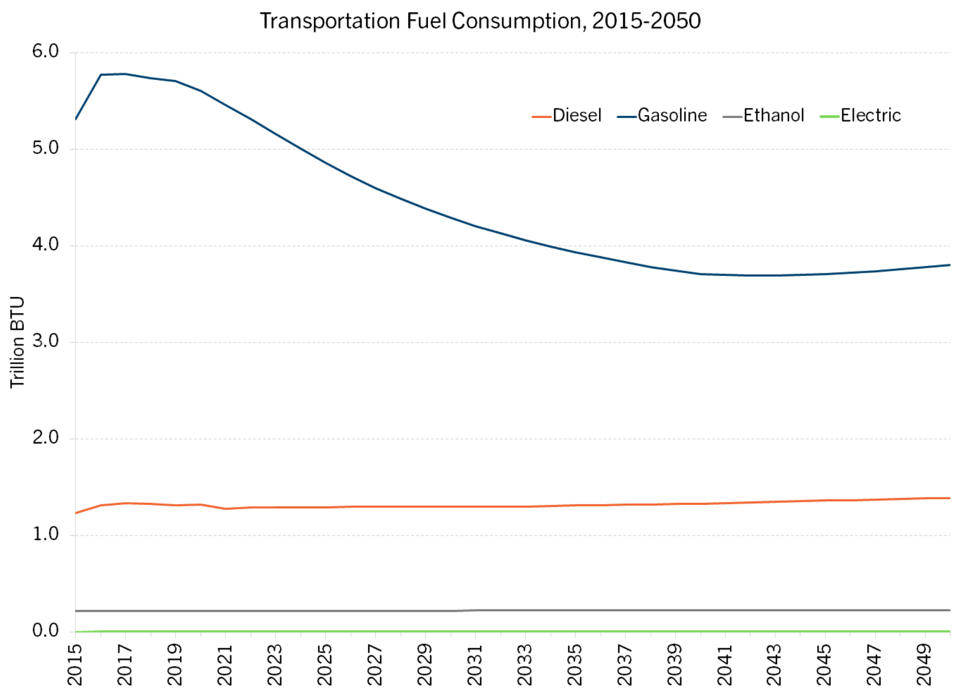
In cases where regional data was not available, nationwide projections were used and all those cases had insignificant impact on the Providence emissions projections.

Business As Usual Scenario

The BAU model forecasts carbon emissions in Providence through 2050 assuming no policy changes and taking into account existing trends. It is important to start with a BAU forecast because it helps determine in what areas policy changes are needed to lower emissions. The BAU forecast shows emissions for the following sectors: commercial and industrial,[1] residential, transportation, solid waste, industrial process and "fugitive" (leakage), water and wastewater.

Transportation Sector

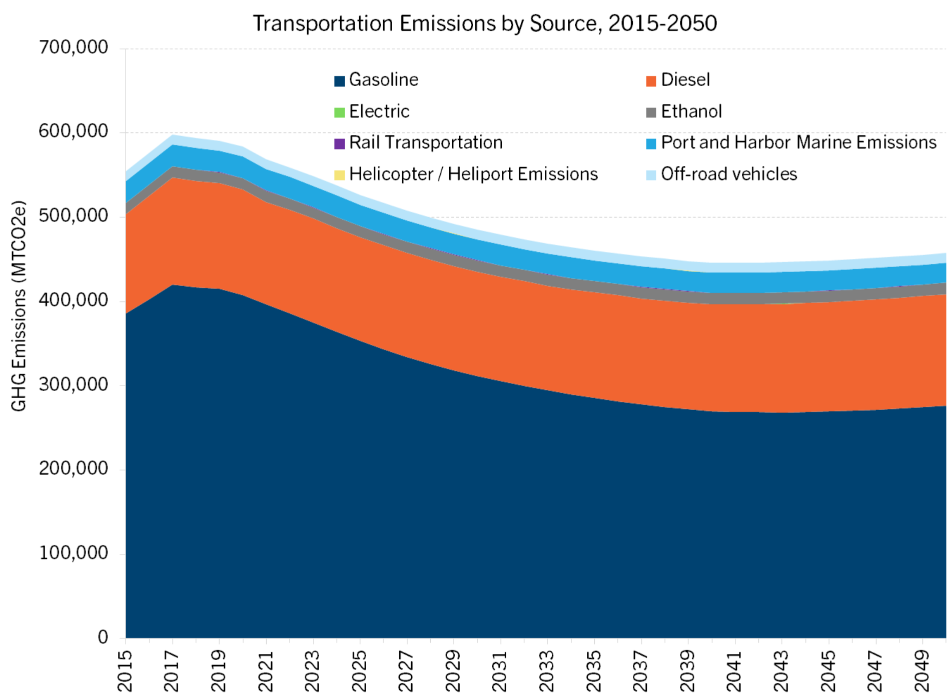
To develop transportation sector projections, direct fuel consumption projections from EIA AEO 2018 for 2016-2050 for New England were used, which include the Corporate Average Fuel Economy (CAFE) and Greenhouse Gas (GHG) Emissions standards for light-duty vehicles.[2] The New England projections were first scaled down to derive Rhode Island projections using the 2015 proportion of RI/New England consumption for each transportation fuel type. The Rhode Island projections were then scaled down to the city level using Providence/Rhode Island proportions for 2015 using data from the Providence GHG Inventory. Transportation sector emissions were calculated by multiplying the fuel consumption projections for Providence for 2016-2050 and emissions factors derived from the Providence GHG Inventory.



On-Road Transportation Fuel Emissions Factors	
Fuel	Emissions (MTCO2/MMBTU)
Diesel	0.095
Gasoline	0.073
Ethanol	0.060
Electric	0.085

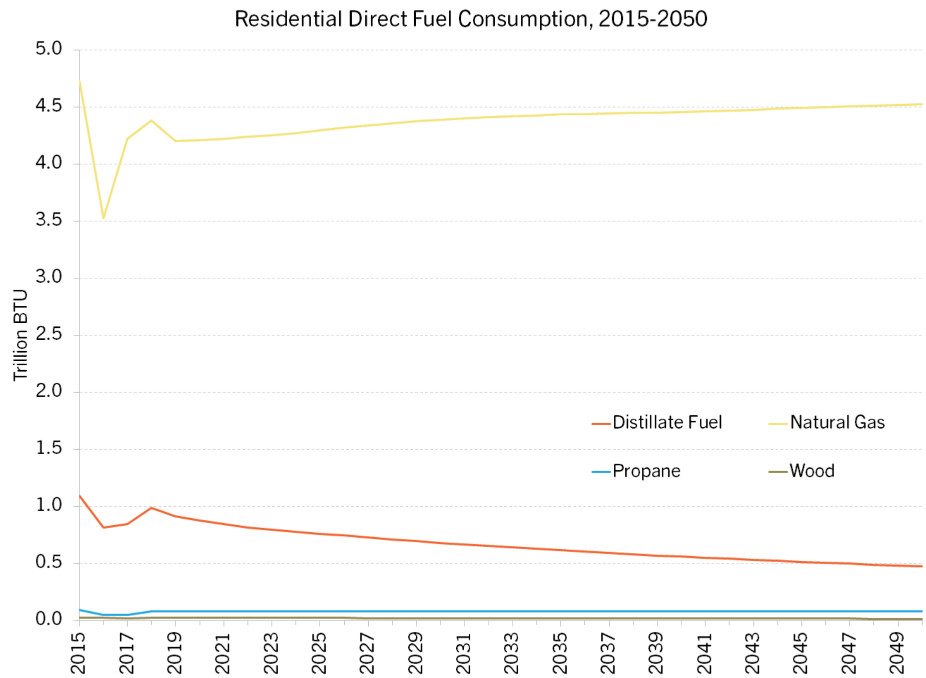
[1] Municipal buildings in Providence are included in the C&I sector.
[2] The proposed federal Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule would amend the current Corporate Average Fuel Economy (CAFE) standards, allowing for lower fuel efficiency from 2020-2026.

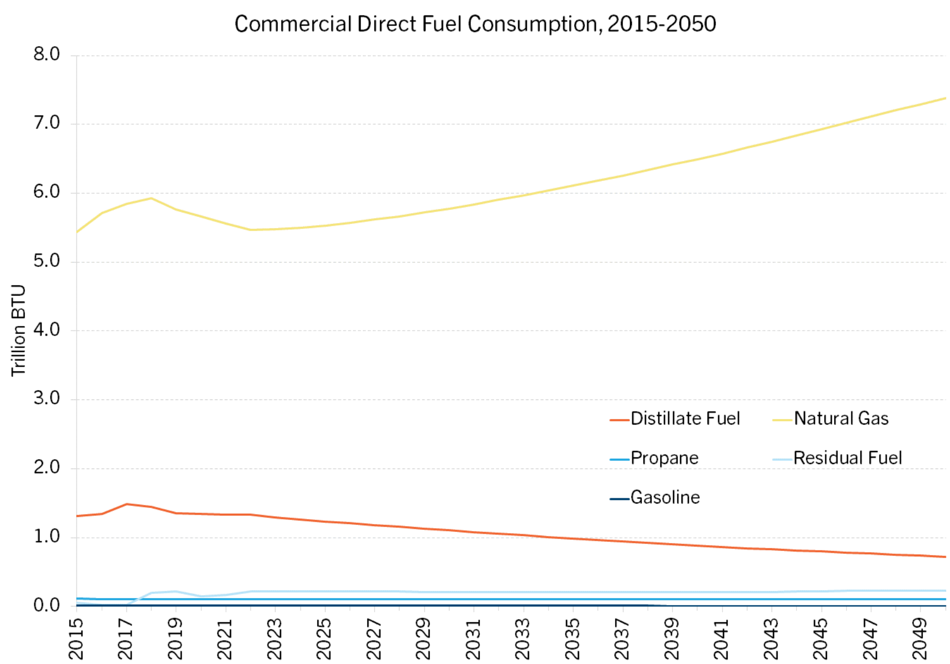
For Air, Rail and Marine vehicle projections, nationwide data was used to develop Providence-level data, as regional and state-level data was not available. For rail emissions, national EIA AEO 2018 diesel consumption data for rail use was converted to GHG emissions using an emissions factor of .074 MTCO2/MMBTU, then scaled to the Providence city level using 2015 proportions for National/Providence from EIA AEO 2018 and the Providence GHG Inventory. For Air and Marine vehicles, emissions data from the Providence GHG Inventory was projected through 2050 at the nationwide growth rate. Off-road construction vehicle emissions from the Providence GHG Inventory were assumed to stay constant through the study period.

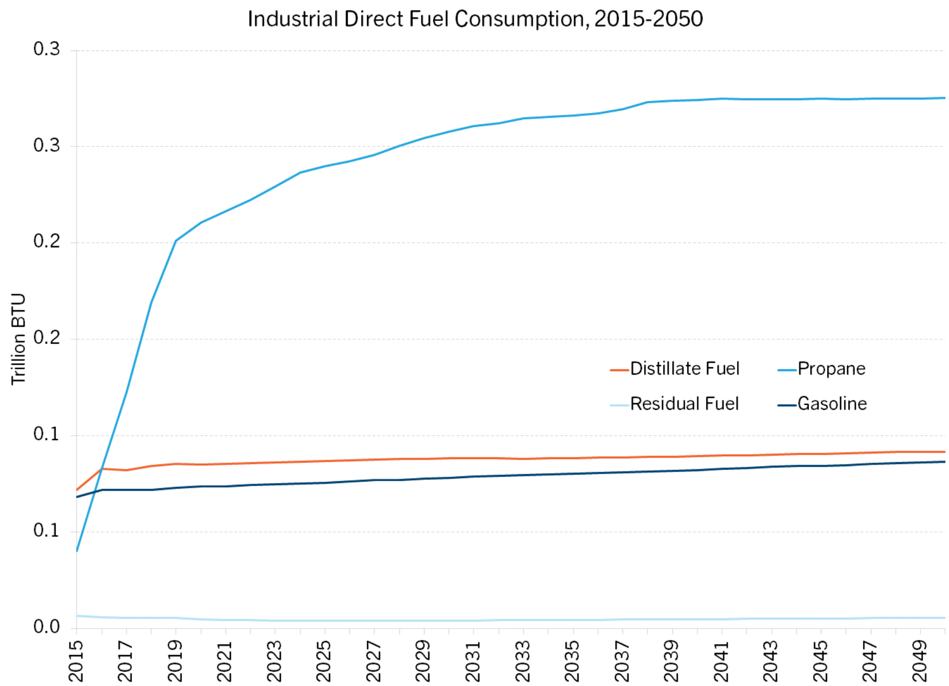


Residential, Commercial, and Industrial Sectors

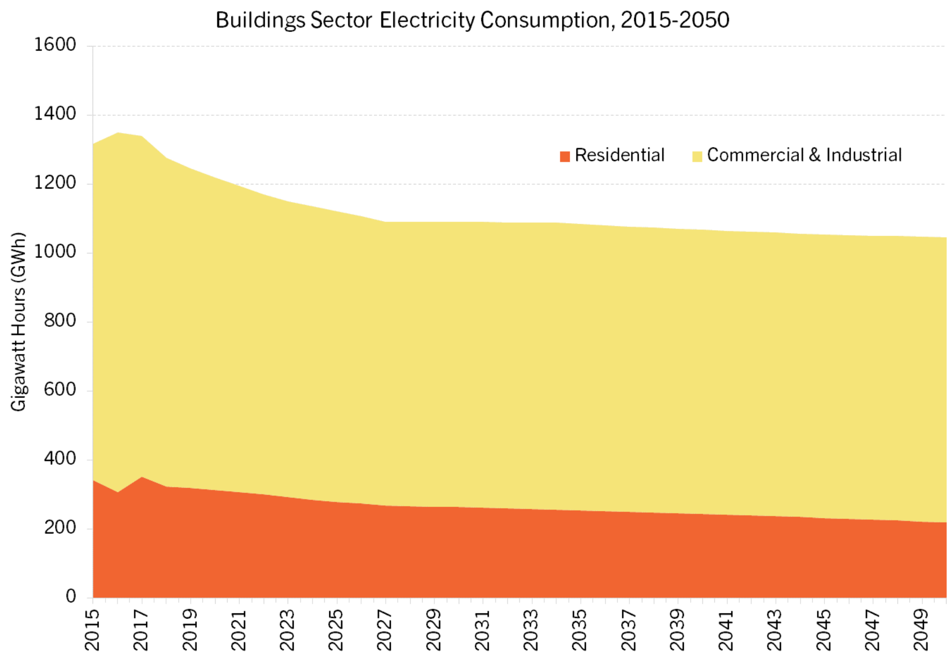
To develop projections for the residential, commercial, and industrial sectors, Rhode Island state projections were first derived for direct fuel consumption for 2016-2050 using EIA's AEO 2018 New England data and the 2015 proportion of Rhode Island/New England for each fuel type using EIA SEDS data. The majority of projections were then scaled to the Providence city level using the 2015 proportion of Providence/Rhode Island fuel consumption derived from the Providence GHG Inventory and SEDS data. In the case of residential natural gas consumption, the Providence/Rhode Island ratio was calculated for 2013-2016 and the average ratio for those years was used to project the city's gas consumption for 2016-2050.


Residential Direct Fuel Consumption, 2015-2050
Trillion BTU
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049
Distillate Fuel
Natural Gas
Propane
Wood


Commercial Direct Fuel Consumption, 2015-2050
Trillion BTU
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049
Distillate Fuel
Natural Gas
Propane
Residual Fuel
Gasoline



Electricity consumption projections for Providence were similarly done in stages. First, Rhode Island electricity consumption projections from ISO-NE's CELT 2018 forecast for 2016-2026 were extended to 2027-2050 using the same growth rates from the CELT forecast. The CELT forecast was adjusted to include electric efficiency savings impacts: data until 2020 was from National Grid's annual Energy Efficiency Plans and data from 2021-2050 was estimated using trends based on state policy. These Rhode Island residential electricity projections were scaled down to the Providence city level using the 2013-2016 average proportion of Providence/Rhode Island calculated using data from the Providence GHG Inventory and EIA SEDS. The Rhode Island commercial and industrial electricity projections were scaled to the Providence city level using the 2015 proportion of Providence/Rhode Island using data from the Providence GHG Inventory and EIA SEDS. Because Providence-specific energy efficiency savings data was not available, these proportions assumed that the city achieves the state-wide annual energy efficiency savings levels of 3% through 2019; efficiency levels are considered to drop to 2.5% for 2020-2023 and then drop again to 2% from 2024-2050 to reflect the reduction in technical potential for efficiency going forward. The assumption that Providence achieves the state-wide efficiency savings levels likely overestimates actual savings rates in the BAU scenario; however, as demonstrated in the Carbon Mitigation Scenario (see following), the city must achieve state-wide efficiency savings levels to meet the 80% GHG reduction target.

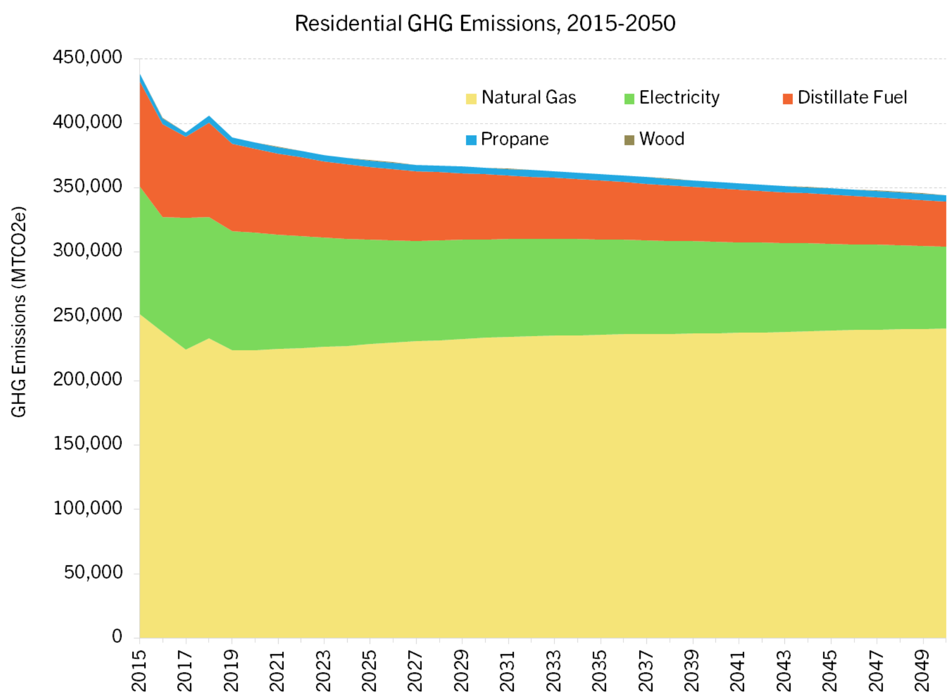


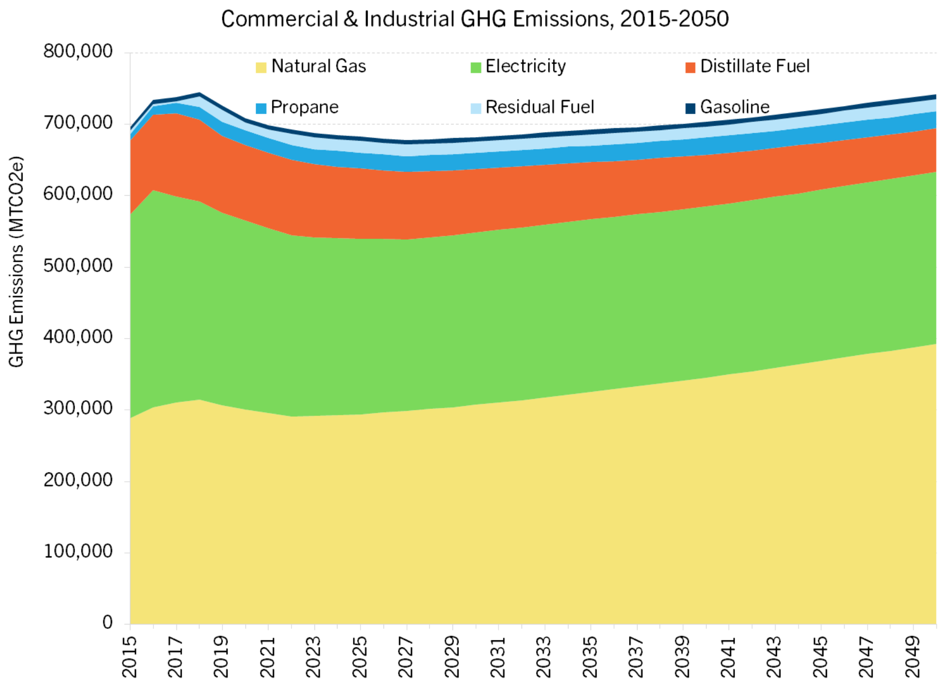
Residential, commercial, and industrial sector emissions were calculated by multiplying the derived Providence fuel and electricity consumption data from 2016-2050 by emission factors derived from the Providence GHG Inventory.

Buildings Sector Emission Factors

	Fuel	Emissions (MTCO2/MMBTU)
Residential	Natural Gas	0.053
	Electricity	0.085
	Distillate Fuel	0.074
	Propane	0.064
	Wood	0.008

Commercial & Industrial	Natural Gas	0.053
	Electricity	0.085
	Distillate Fuel	0.074
	Propane	0.063
	Residual Fuel	0.073
	Gasoline	0.071





Water, Wastewater, Solid Waste and Natural Gas Fugitive Emissions

For water, wastewater and solid waste emissions, Rhode Island emissions for 2016-2030 were evaluated using EPA's SIT model. For years 2031-2050, emissions were forecasted linearly based on historical trends. As with other sectors, the Rhode Island state projections were scaled down to derive Providence city projections using 2015 Providence/Rhode Island proportions calculated from the Providence GHG Inventory and EPA's SIT model.

Natural gas fugitive emissions were projected using the natural gas fuel consumption forecast and the distribution system leakage rate and emission factor from the Providence GHG Inventory.[3]

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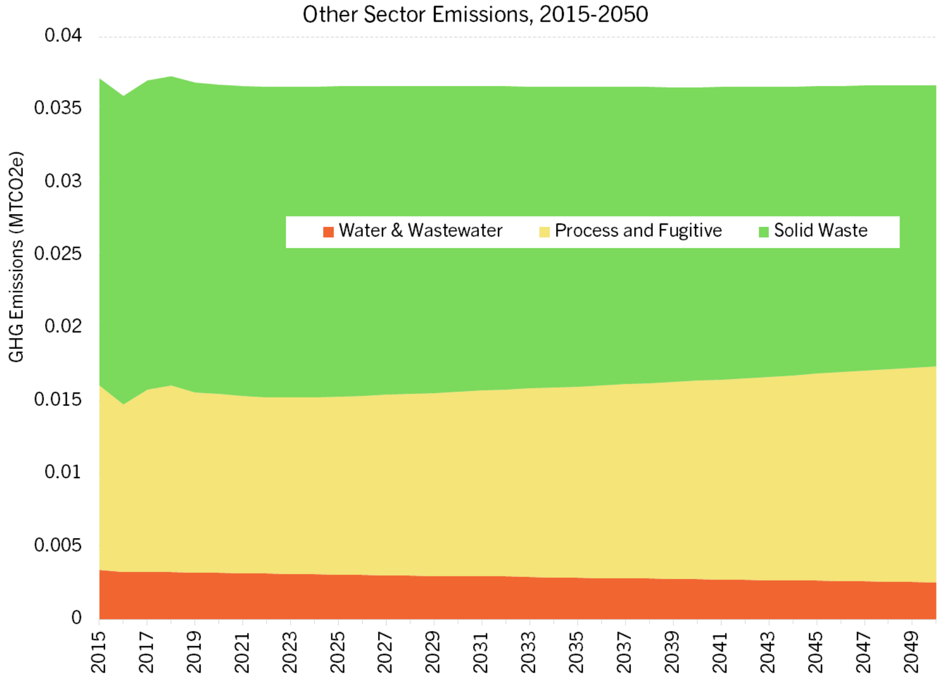
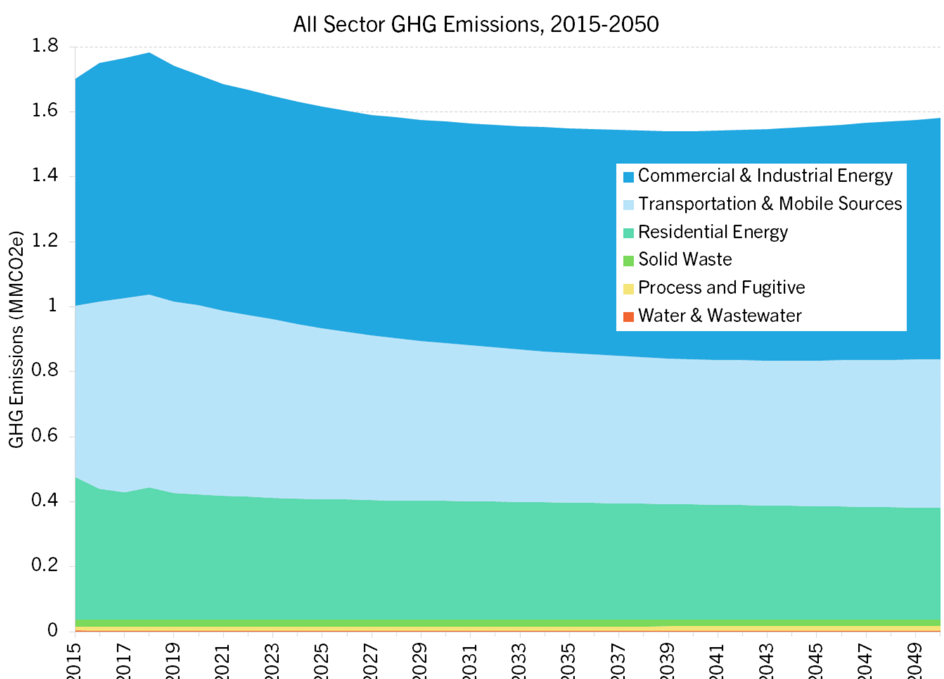
[3] The leakage rate in the Providence GHG Inventory, 0.3 MMBTU of methane leaked per MMBTU of natural gas consumed, is based on data provided by National Grid. Recent studies have shown that methane leakage rates are higher than previously reported. For example, a 2015 study in the Proceedings of the National Academy of Sciences, "Methane emissions from natural gas infrastructure and use in the urban region of Boston, Massachusetts," found that emissions from natural gas were two to three times higher than predicted by existing inventory methodologies and industry reports (PNAS, Feb. 17, 2015 112 (7) 1941-1946; available at https://doi.org/10.1073/pnas.1416261112). Rhode Island's state energy plan, Energy 2035, identified gas distribution leaks as the seventh largest source of GHG emissions in the state, as of 2012. Total leakage is projected to decline over the study period due to decreased natural gas use because of fuel-switching.



BAU Results

Emissions across all sectors for the BAU scenario were found to stay relatively flat across the study period. The two sectors contributing the most to the city's overall GHG emissions throughout the study period are buildings (residential, commerical, and industrial), at about two-thirds of the total emissions, and transportation, at one-third of total emissions.

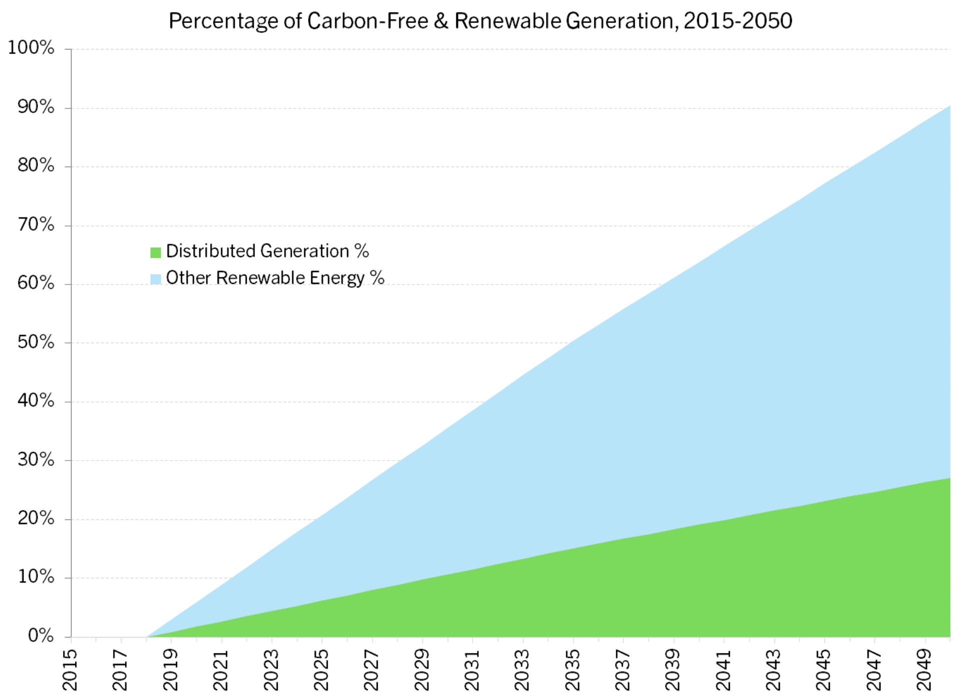


Carbon Mitigation Scenario

To develop the Carbon Mitigation Scenario, various levels of program impacts, such as energy efficiency and fuel switching, were evaluated on the BAU projections to achieve the 80% GHG reduction target by 2050. The key technology uptake rates that were part of the Carbon Mitigation Scenario are described below.

Clean Electricity

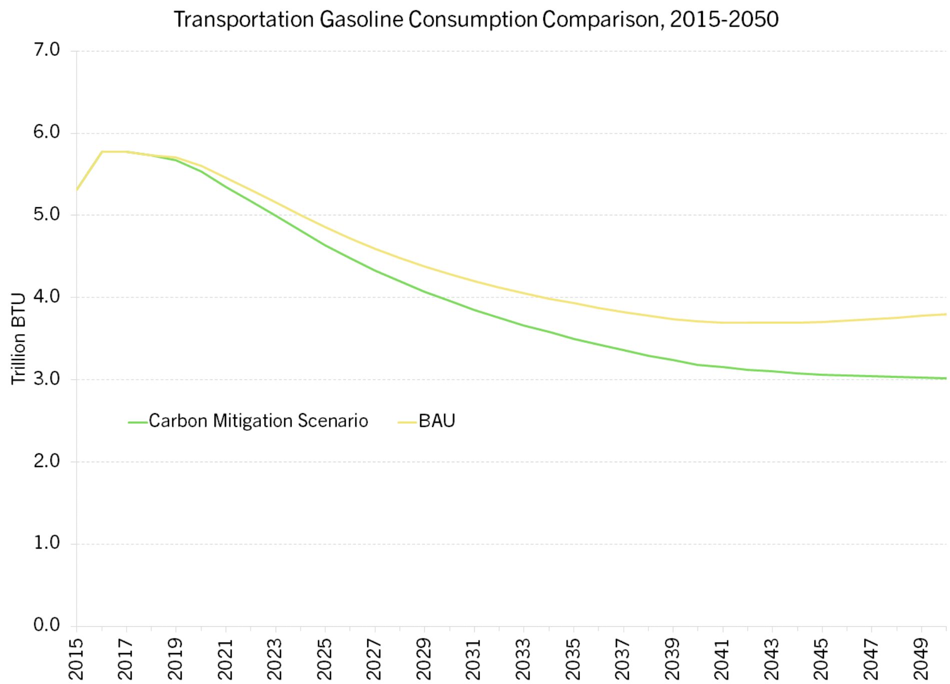
To meet the GHG reduction target, electricity generation was considered to get cleaner throughout the study period. By 2050, 90% of electricity consumed was set to be carbon-free and from renewable sources, with an interim target of about 50% carbon-free by 2035.[4] Of this renewable electricity, 30% was proposed to come from distributed resources with load management measures (storage, load shifting, etc.), and the remaining is proposed to come through procurements. This level of distributed generation is illustrative only and was selected with the goal of prioritizing local benefits and local employment. It could include both rooftop solar generation, as well as community solar or other virtual net metering installations within or outside Providence. Assuming solar capacity factors for Rhode Island remain constant over the study period at about 16%, this level of deployment would equate to about 470 MW of distributed solar by 2050, and about 185 MW by 2035. To implement carbon-free generation in the model, electricity emissions were reduced by the percentage of carbon-free generation added each year. The emissions factor for the remaining electricity consumption remained unchanged from the BAU scenario.



[4] Providence's Climate Justice Plan accelerates the 2050 clean energy target to 100%.

Transportation

By 2050, a 20% reduction in vehicle miles traveled (VMT) for light-duty vehicles is achieved due to improved mobility options, such as expanded transit options and better pedestrian and biking connections, with an interim target of about 11% by 2035 based on a linear reduction rate.[5] This reduction is implemented in the model by applying the linear reduction rate to transportation sector gasoline consumption in the BAU scenario.



In addition to reducing VMTs, the Carbon Mitigation Scenario considered that 80% of the gasoline and diesel-fueled miles driven in Providence, including light, medium, and heavy duty vehicle miles, are electrified by 2050, with an interim target of about 43% by 2035 based on a linear increase. To account for this electrification in the model, direct gasoline and diesel consumption in the transportation sector was reduced based on the linear electrification rate. The fuel consumption was then converted to a per-gallon equivalent electric consumption, and then added to the total electricity consumption for the city in the Carbon Mitigation Scenario along with the new electricity load from building electrification, as discussed below. Consumption across other transportation modes remained the same as the BAU Scenario. Low-carbon biofuels-based vehicles could also replace electric vehicles to achieve similar emission reductions without adding the additional electric load. Emissions were calculated by multiplying fuel consumption by the emission factors used in the BAU Scenario.

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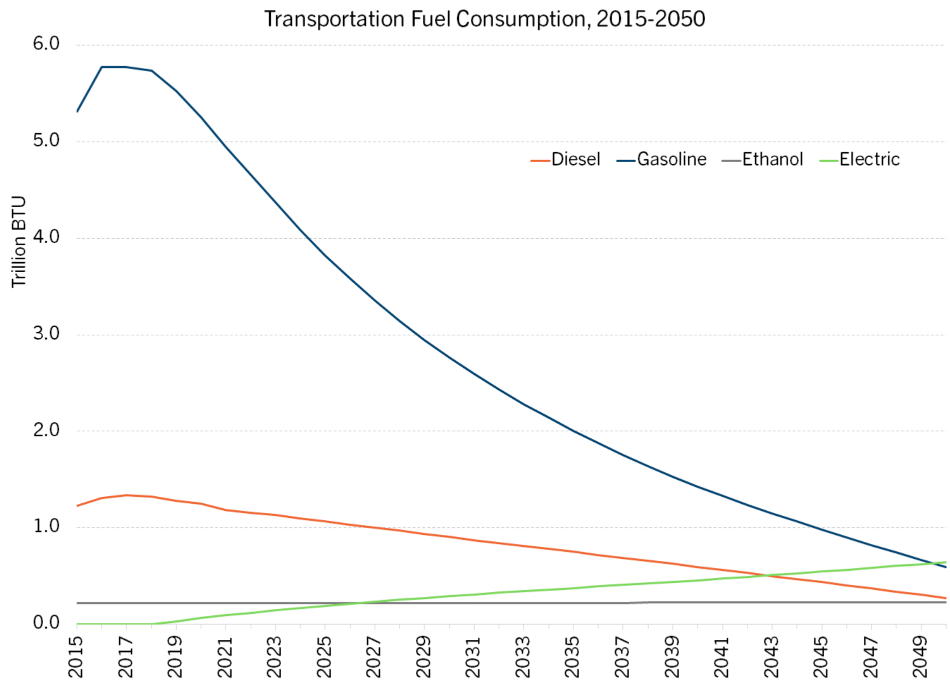
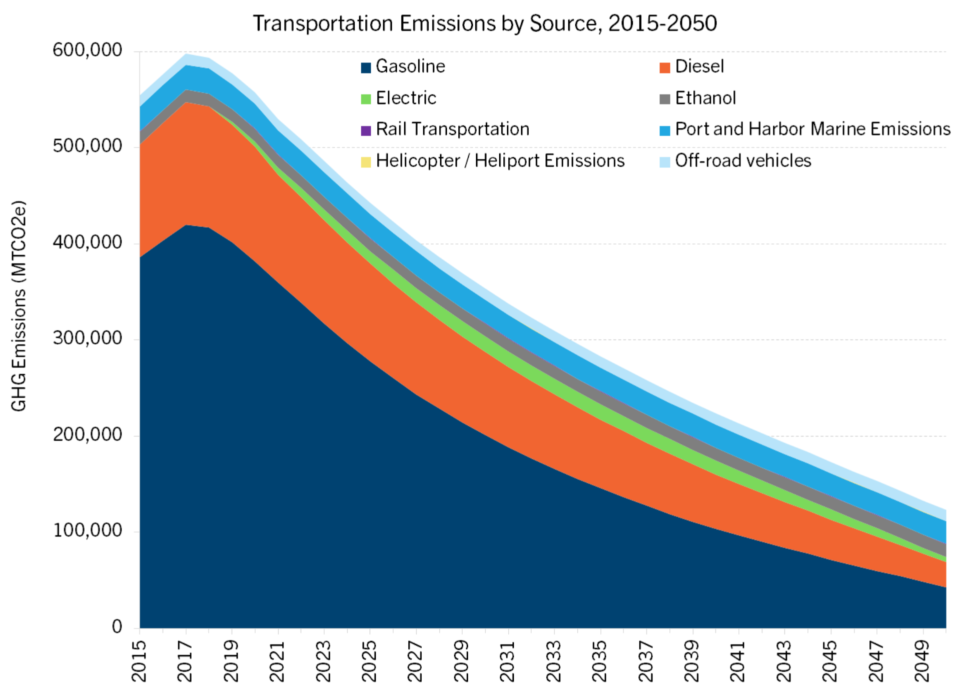
[5] VMTs are driven by a variety of factors like land use, transit, and commuting patterns that can be highly individualized to states. The Rhode Island Greenhouse Gas Emissions Reduction Plan, which calls for a 2% light-duty VMT reduction by 2035 and a 10% reduction by 2050, notes that the percent VMT reduction achievable by strategies such as infrastructure development, pricing, demand management, transit improvement and smart growth is poorly quantified.



Transportation Fuel Consumption, 2015-2050
Trillion BTU
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Diesel
Gasoline
Ethanol
Electric
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049

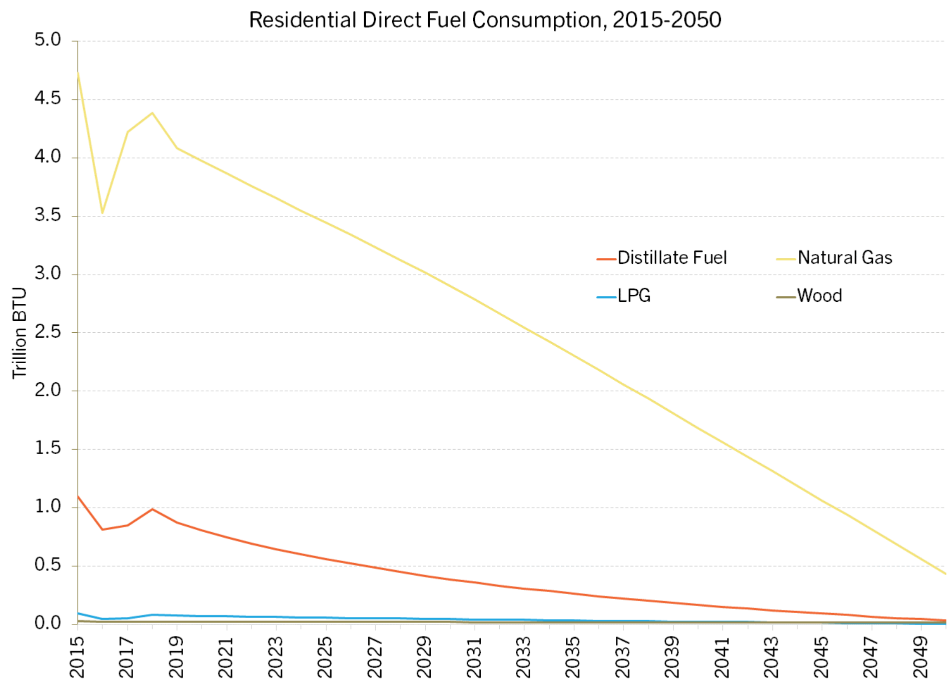


Transportation Emissions by Source, 2015-2050
GHG Emissions (MTCO2e)
600,000
500,000
400,000
300,000
200,000
100,000
0
Gasoline
Diesel
Electric
Ethanol
Rail Transportation
Port and Harbor Marine Emissions
Helicopter / Heliport Emissions
Off-road vehicles
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049

Residential, Commercial, and Industrial

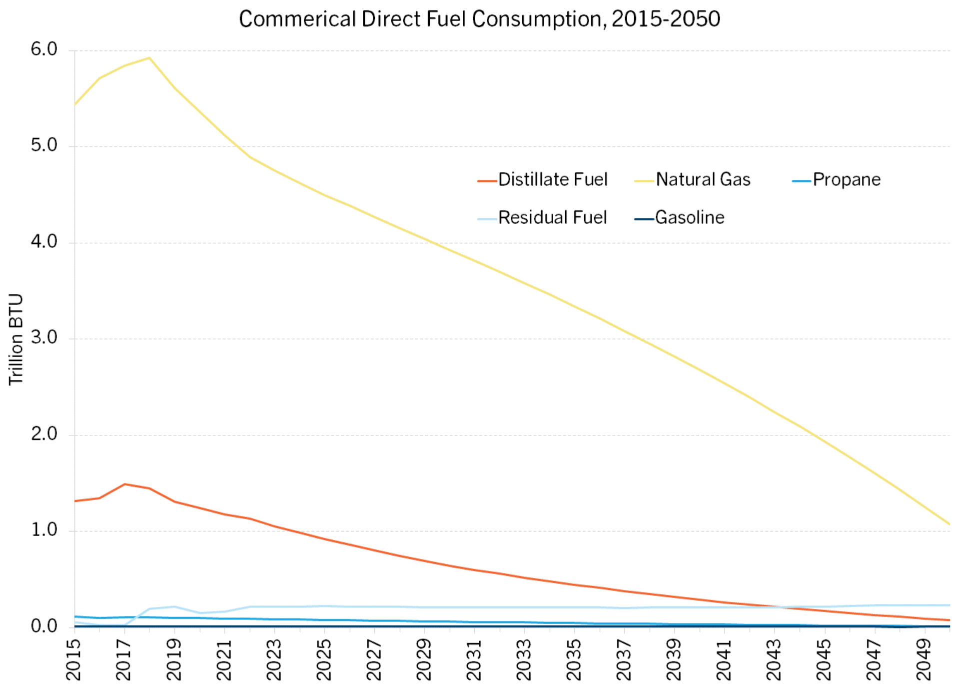
In the Carbon Mitigation Scenario, annual electric and natural gas efficiency is projected to stay at the recent levels achieved in the state of Rhode Island for all cost-effective efficiency; therefore, the electricity and gas consumption forecasts for the Carbon Mitigation Scenario are the same as the BAU Scenario. For unregulated fuels, additional efficiency of 1.2% of sales annually was applied to the BAU projection.

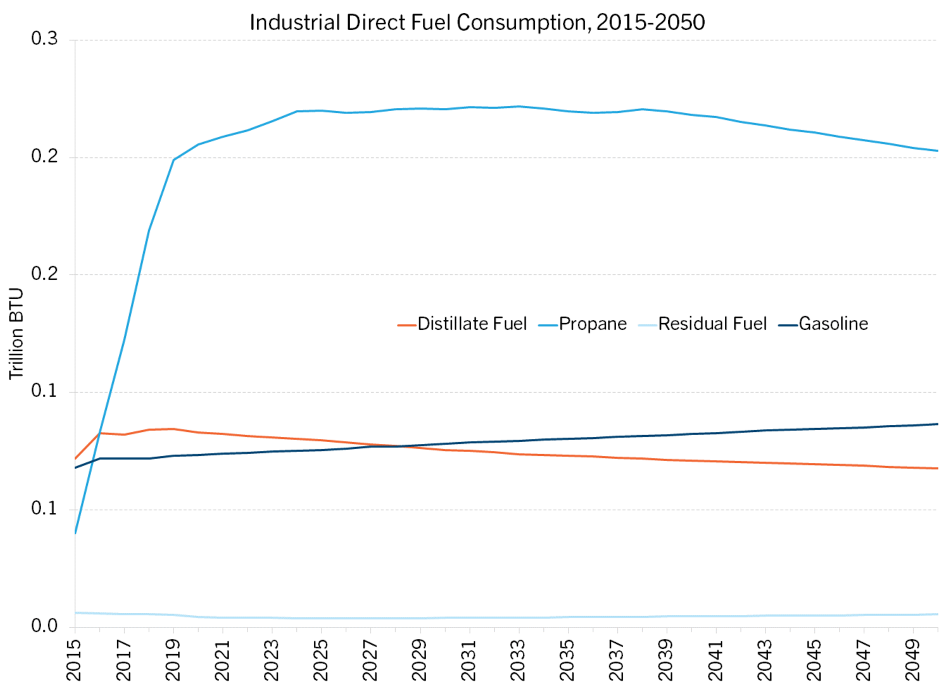
By 2050, 90% of residential natural gas, propane and heating oil fuel consumption switches to electric heat pumps with an interim target of 48% by 2035. About 85% of commercial fossil fuel consumption switches to electric heat pumps with an interim target of about 45% by 2035.[6] The new electric load from heat pumps was added to the electricity consumption projection for the Carbon Mitigation Scenario. Low-carbon biofuels could also be considered as an option to reduce some buildings emissions and would not increase electricity consumption as demonstrated in the model.[7] In total, about 1,220 GWh of new electric load will be added to the grid across the buildings and transportation sectors: about 410 GWh in the residential sector, 620 GWh in the commercial and industrial sector, and 190 GWh from transportation.



[6] Statewide, aggressive electrification of the heating sector is key to achieving the GHG reductions in the Resilient Rhode Island Act – namely, an 80% reduction from 1990 levels by 2050. The Rhode Island Greenhouse Gas Emissions Reduction Plan (December 2016) indicates that 81% of residential and 67% of commercial heating load statewide will have to be met with electric heat pumps by 2050. Available at: http://climatechange.ri.gov/documents/ec4-ghg-emissions-reduction-plan-final-draft-2016-12-29-clean.pdf.

[7] Biofuels include biogas, biodiesel, and ethanol, and can be used for transportation fuel and for space heating and industrial processes. There are GHG emissions associated with carbon-based biofuels from direct combustion as well as the energy used in, and land impacts from, producing them. A lifecycle assessment can be done to quantify net GHG reductions.


Commerical Direct Fuel Consumption, 2015-2050
Trillion BTU
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Distillate Fuel
Natural Gas
Propane
Residual Fuel
Gasoline
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049


Industrial Direct Fuel Consumption, 2015-2050
Trillion BTU
0.3
0.2
0.2
0.1
0.1
0.0
Distillate Fuel
Propane
Residual Fuel
Gasoline
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
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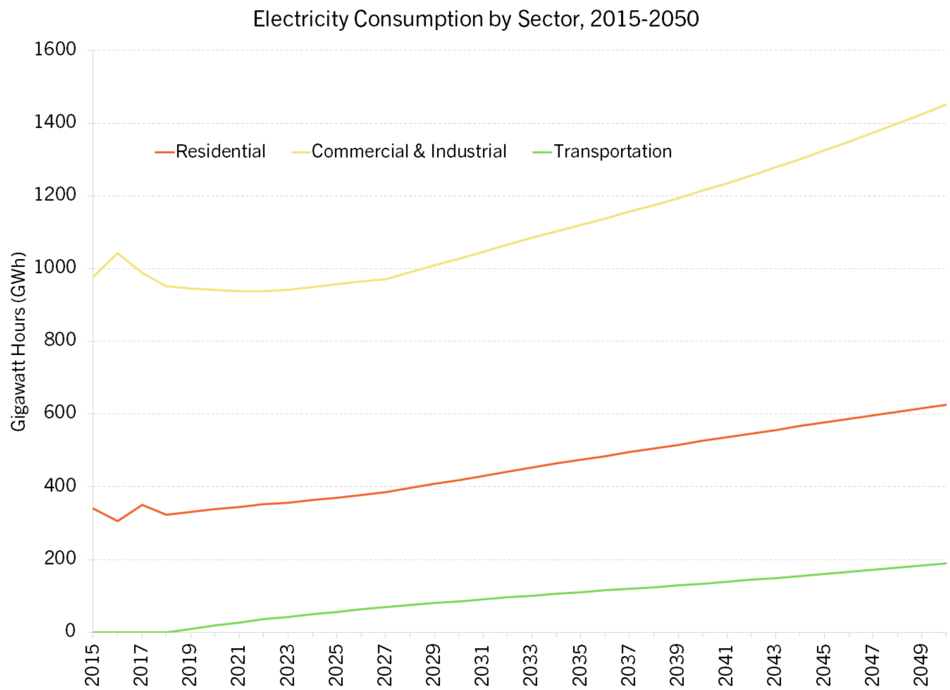
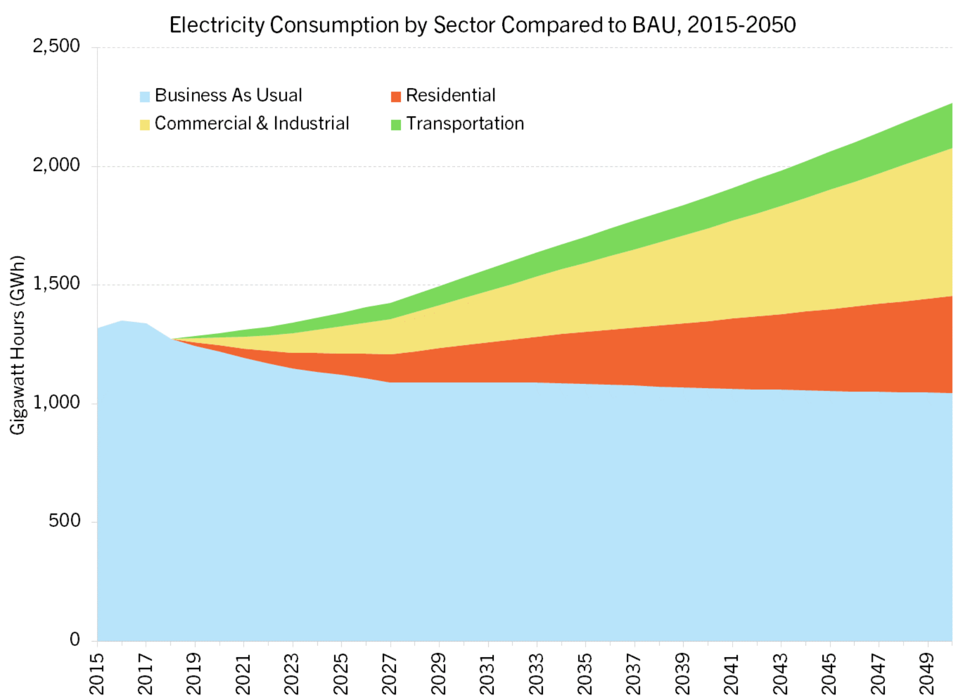
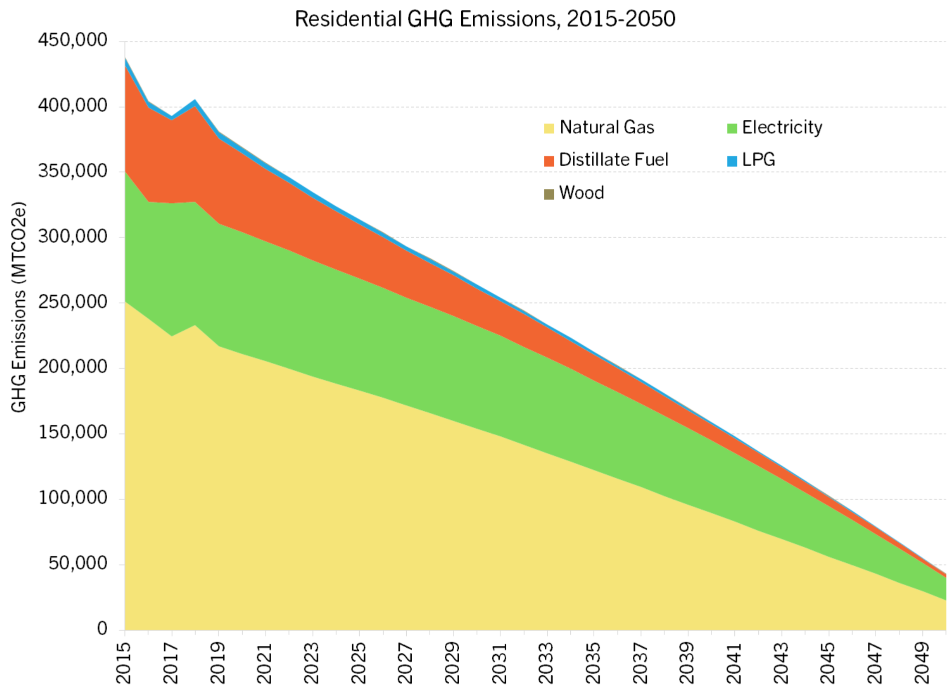
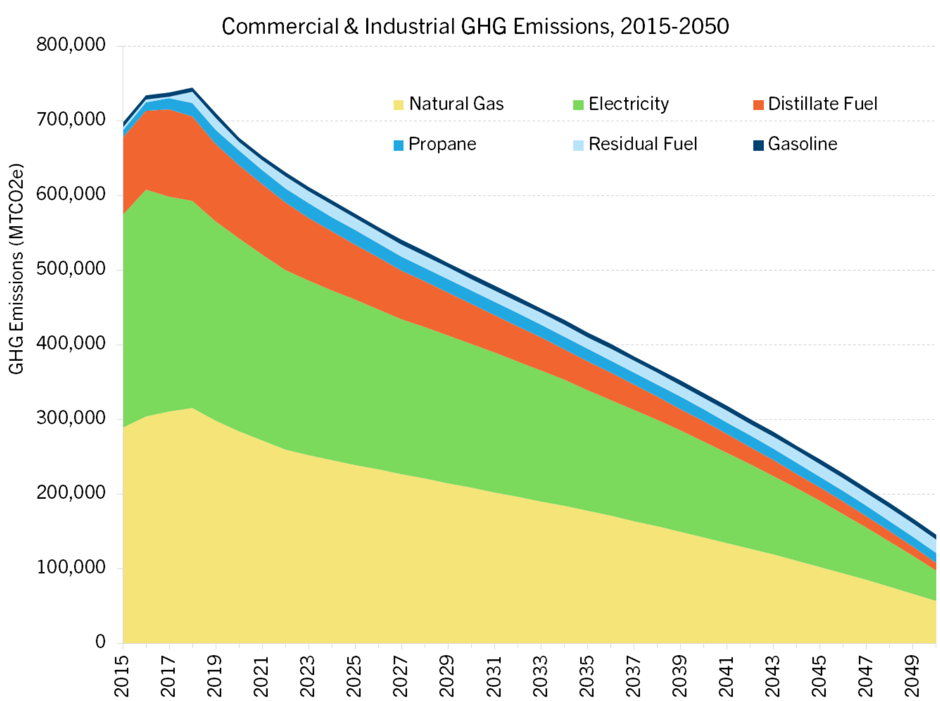
2039
2041
2043
2045
2047
2049


Electricity Consumption by Sector, 2015-2050
Residential
Commercial & Industrial
Transportation
Gigawatt Hours (GWh)
1600
1400
1200
1000
800
600
400
200
0
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049


Electricity Consumption by Sector Compared to BAU, 2015-2050
Business As Usual
Residential
Commercial & Industrial
Transportation
Gigawatt Hours (GWh)
2,500
2,000
1,500
1,000
500
0
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049



Residential GHG Emissions, 2015-2050
GHG Emissions (MTCO2e)
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Natural Gas
Electricity
Distillate Fuel
LPG
Wood
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049

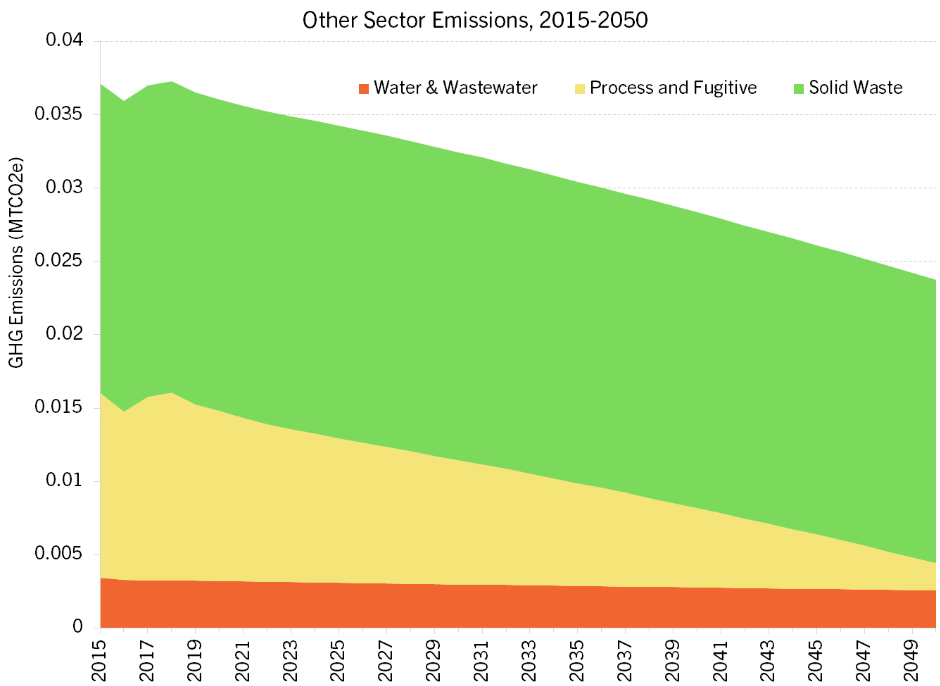


Commercial & Industrial GHG Emissions, 2015-2050
GHG Emissions (MTCO2e)
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Natural Gas
Electricity
Distillate Fuel
Propane
Residual Fuel
Gasoline
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049

Water, Wastewater, Solid Waste & Natural Gas Fugitive Emissions

Emissions reductions in the water, wastewater and solid waste sectors were not quantified as part of this study, so emissions remained unchanged from the BAU scenario.[8] These sectors make up a small portion of the city's overall emissions, so this assumption did not have a significant impact on the final emissions results.

Natural gas fugitive emissions were projected in the same way as the BAU scenario, using the natural gas fuel consumption forecast and the distribution system leakage rate and emission factor from the Providence GHG Inventory. Because overall natural gas consumption decreases between BAU and the Carbon Mitigation Scenario, fugitive gas emissions also decrease between the scenarios.



Carbon Mitigation Scenario Results

Emissions across all sectors for the Carbon Mitigation Scenario decreased by 80% across the study period. The three sectors contributing the most to the city's overall GHG emissions reductions in 2050 are clean electricity generation at 44%, fuel switching to heat pumps at 25%, and penetration of electric vehicles at 22%.

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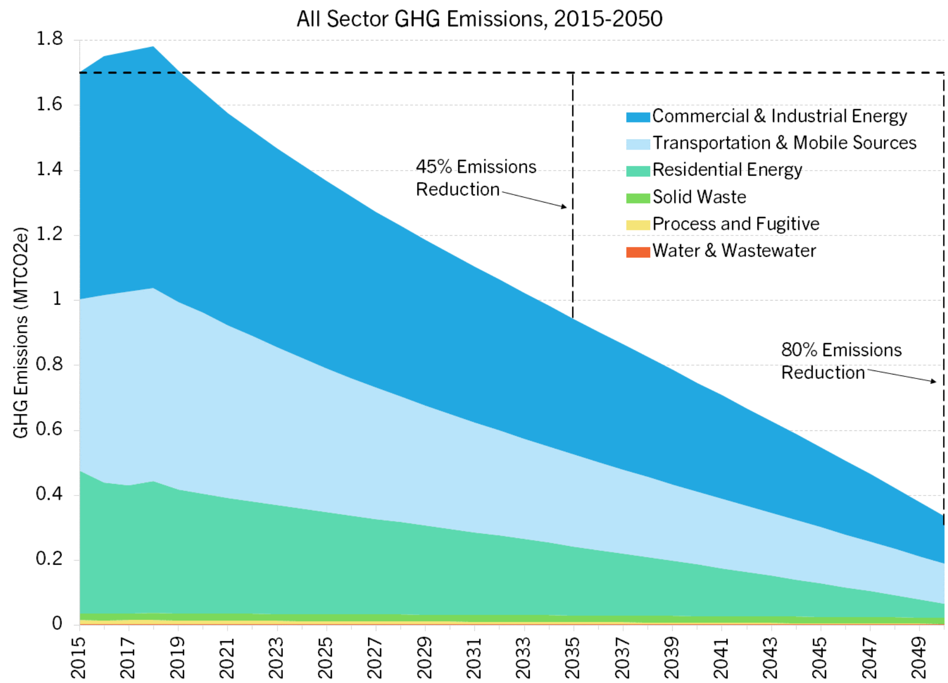
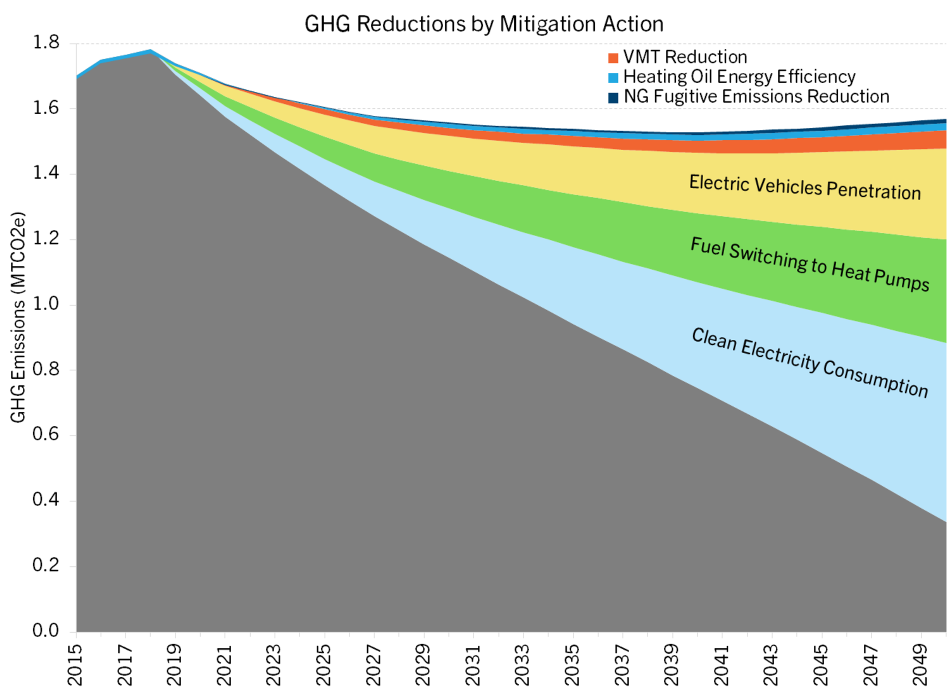
[8] Rhode Island Resource Recovery's 2015 Rhode Island Solid Waste Characterization Study found that mixed solid waste loads delivered by municipalities contain 32.1% material compostable at any scale. The City of Providence has undertaken various pilot composting initiatives in recent years to help reduce emissions in the solid waste sector.



All Sector GHG Emissions, 2015-2050
GHG Emissions (MTCO2e)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
45% Emissions Reduction
80% Emissions Reduction
Commercial & Industrial Energy
Transportation & Mobile Sources
Residential Energy
Solid Waste
Process and Fugitive
Water & Wastewater
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049

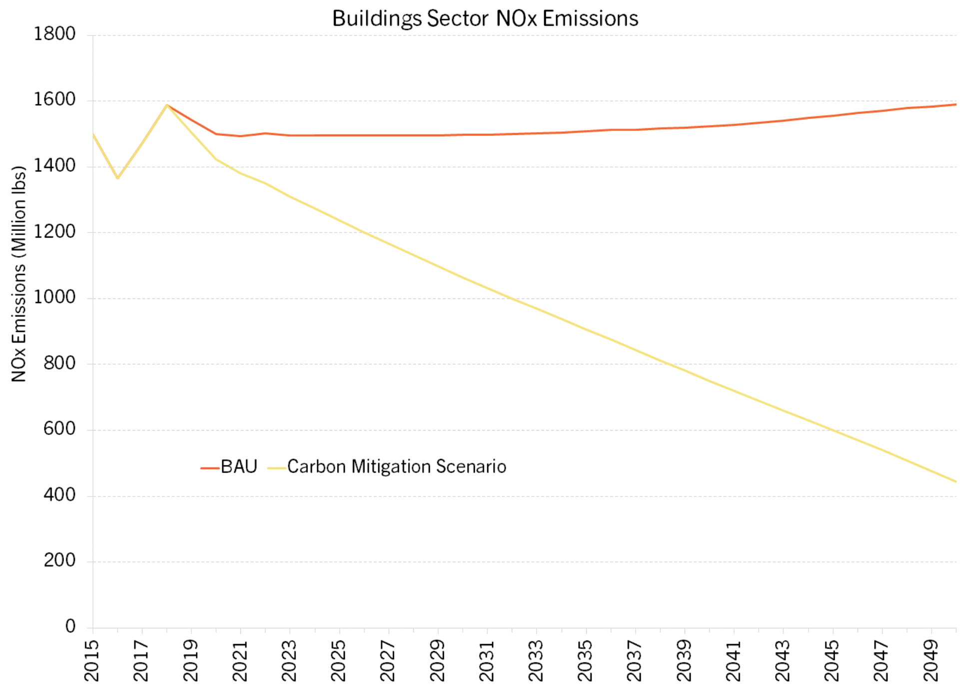


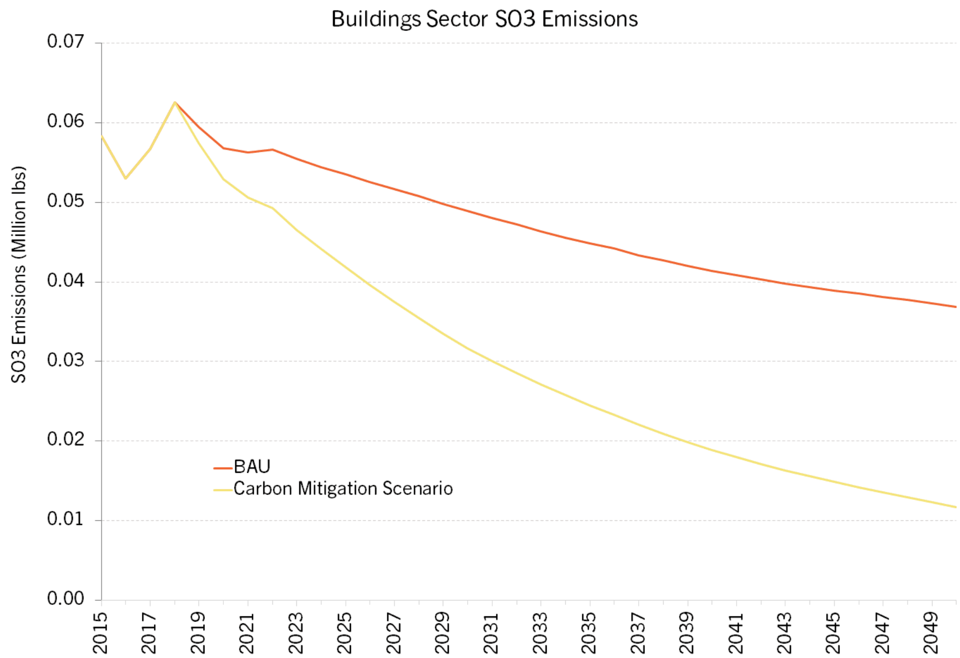
GHG Reductions by Mitigation Action
GHG Emissions (MTCO2e)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
VMT Reduction
Heating Oil Energy Efficiency
NG Fugitive Emissions Reduction
Electric Vehicles Penetration
Fuel Switching to Heat Pumps
Clean Electricity Consumption
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049

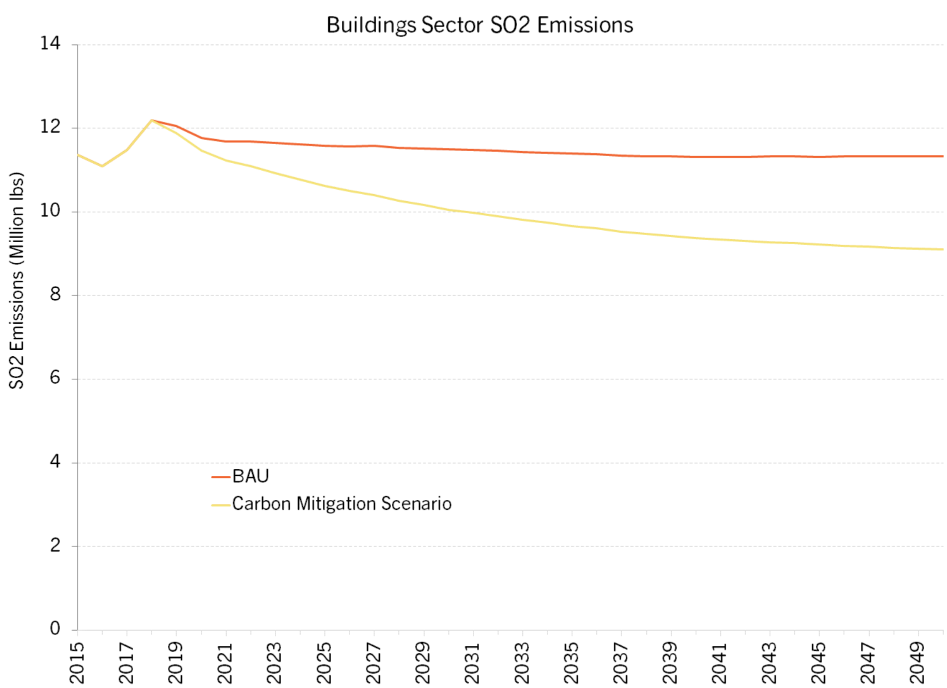
Criteria Pollutants

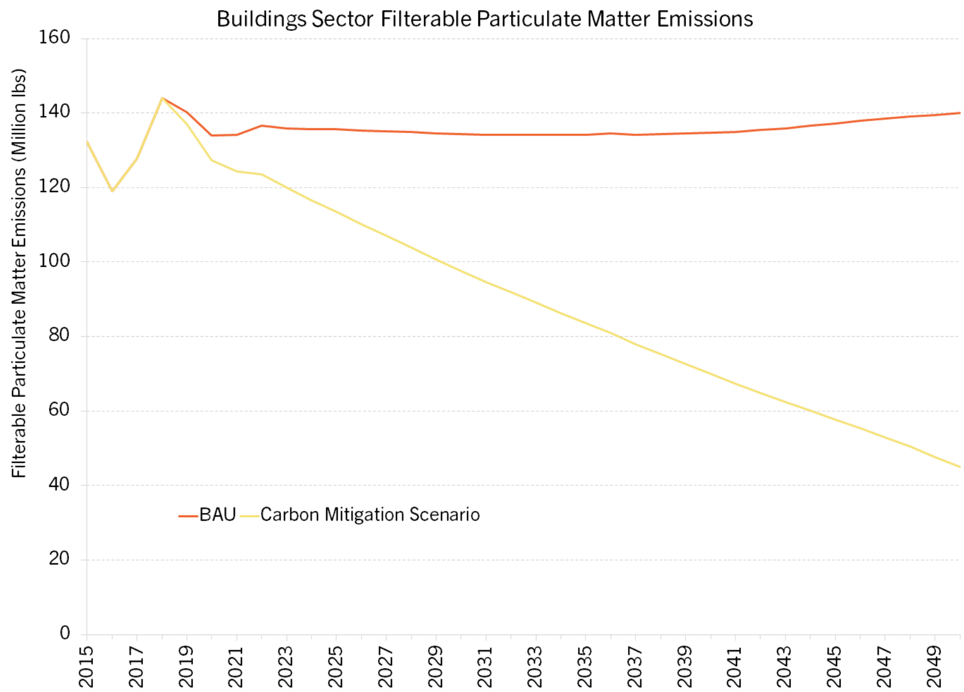
The Clean Air Act requires the U.S. EPA to set standards for six common air pollutants ("criteria pollutants") that cause health hazards. In this analysis, Acadia Center focused on criteria pollutants in the buildings sector (residential, commercial, and industrial) and the Manchester Street Power Station, and considered nitrogen oxides (NOx), sulfur oxides (SO2 and SO3), carbon monoxide, and particulate matter.

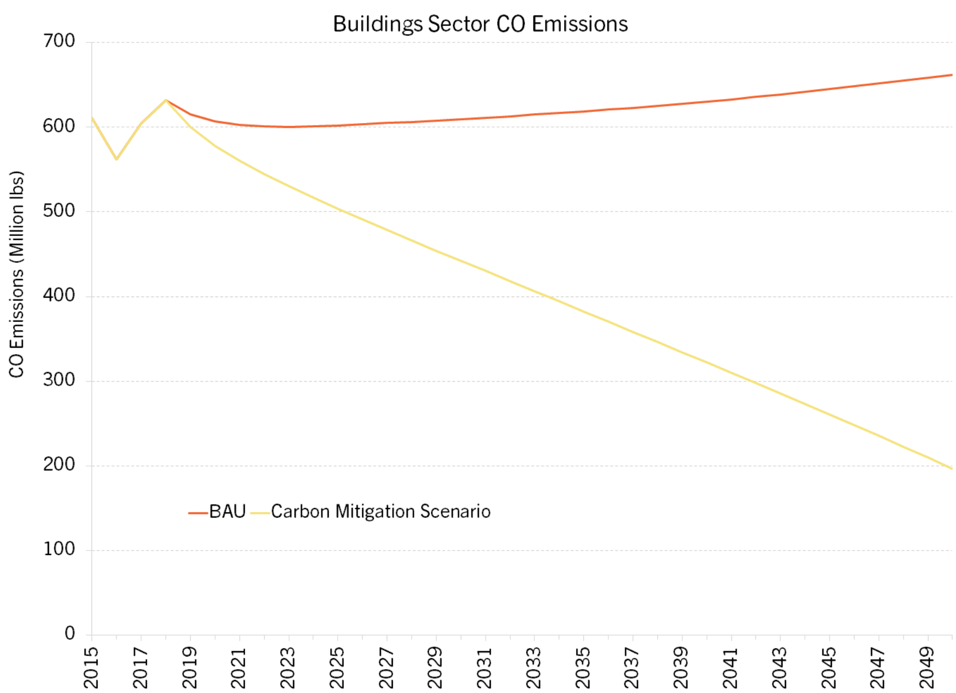
For buildings, uncontrolled combustion-based criteria pollutant emissions factors for each fuel were taken from U.S. EPA AP-42 (Compilation of Emissions Factors) documentation. These emissions factors were multiplied with the energy consumption in Providence for the BAU and Carbon Mitigation Scenarios to calculate criteria pollutants emissions from buildings during the study period.



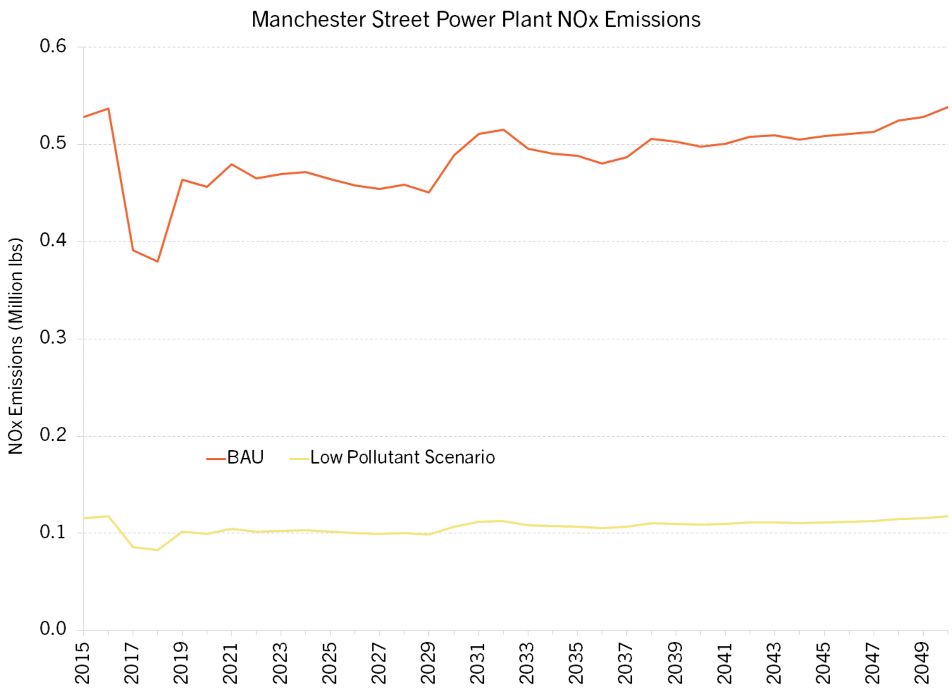

Buildings Sector SO3 Emissions
SO3 Emissions (Million lbs)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049
BAU
Carbon Mitigation Scenario

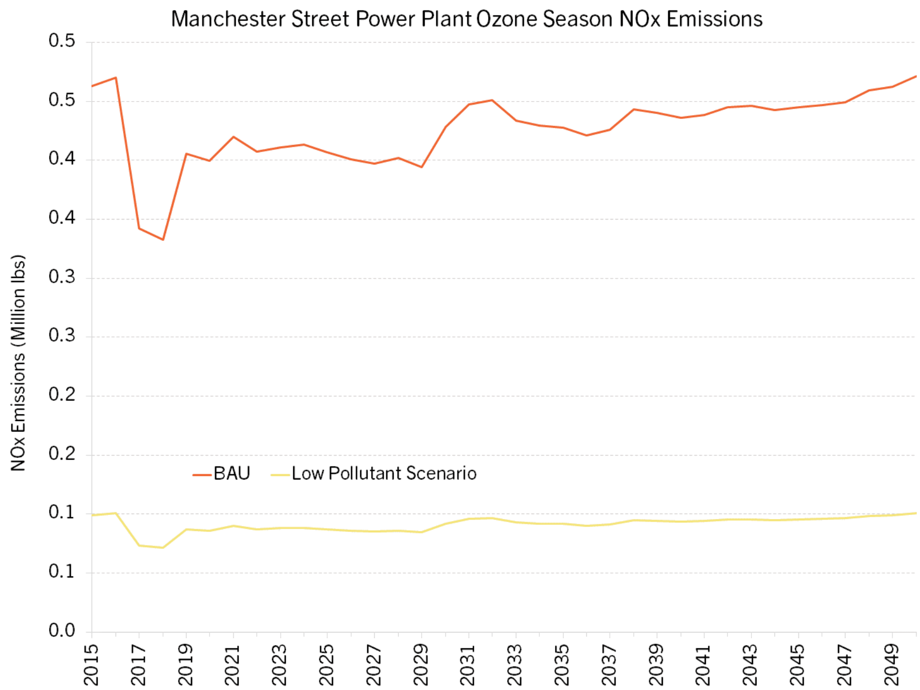

Buildings Sector SO2 Emissions
SO2 Emissions (Million lbs)
14
12
10
8
6
4
2
0
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049
BAU
Carbon Mitigation Scenario


Buildings Sector Filterable Particulate Matter Emissions
Filterable Particulate Matter Emissions (Million lbs)
160
140
120
100
80
60
40
20
0
BAU
Carbon Mitigation Scenario
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049


Buildings Sector CO Emissions
CO Emissions (Million lbs)
700
600
500
400
300
200
100
0
BAU
Carbon Mitigation Scenario
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049

Manchester Street Station and Rhode Island State Energy Center power plant NOx emissions factors were taken from U.S. EPA's Egrid (Emissions & Generation Resource Integrated Database) database. An additional Low Pollutant scenario was modeled in which the Manchester Street Station's emissions factors were reduced to the levels equal to Rhode Island State Energy Center power plant's emissions factors. These emissions factors were multiplied by Providence's consumption of natural gas and distillate fuel for electricity generation to calculate criteria pollutant emissions during the study period.




Manchester Street Power Plant Ozone Season NOx Emissions
NOx Emissions (Million lbs)
0.5
0.5
0.4
0.4
0.3
0.3
0.2
0.2
0.1
0.1
0.0
BAU
Low Pollutant Scenario
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049