New York State Clean Transportation Roadmap

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NEW YORK STATE | NYSERDA

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Our Vision:

New York is a global climate leader building a healthier future with thriving communities; homes and businesses powered by clean energy; and economic opportunities accessible to all New Yorkers.

Our Mission:

Advance clean energy innovation and investments to combat climate change, improving the health, resiliency, and prosperity of New Yorkers and delivering benefits equitably to all.

New York State Clean Transportation Roadmap

Final Report

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Notice

Abstract

The New York State Clean Transportation Roadmap summarizes the current status of the State's transportation system including light-duty vehicles, medium and heavy-duty vehicles, aviation, rail, marine and non-road subsectors. The Roadmap is a comprehensive technical and policy analysis that examines several mitigation scenarios and options for reducing greenhouse gas emissions in accordance with the Climate Act. It also highlights barriers and opportunities, rates of technology adoption, and various potential impacts of decarbonization policies.

Keywords

Clean transportation, roadmap, climate act, light duty vehicles, medium and heavy-duty vehicles, aviation, rail, marine, non-road, decarbonization policies, greenhouse gas emissions, mitigation scenarios, electric vehicles, hydrogen, vehicle miles traveled, transit, smart growth, health, equity, economy, grid, utilities.

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Acronyms and Abbreviations

ACC II	Advanced Clean Cars II. Mandate requiring increasing numbers of zero-emission light-duty vehicles be sold by automakers, up to 100% by 2035.
ACT	Advanced Clean Trucks. California regulation that requires increasing numbers of medium- and heavy-duty vehicle sales be zero emissions.
BART	Bay Area Rapid Transit.
BEV	Battery electric vehicle. A vehicle powered exclusively by electricity (such as a Nissan LEAF).
Blue Hydrogen	Hydrogen energy source that uses methane and other fossil fuels in its generative process. Does not achieve the same carbon reductions as Green Hydrogen (see below).
CAPCOA	California Air Pollution Control Officers Association.
CARB	California Air Resources Board.
CLCPA	Climate Leadership and Community Protection Act.
Climate Act	Climate Leadership and Community Protection Act. Law in New York State that sets the State's greenhouse gas (GHG) emissions limit to 85% below 1990 levels by 2050.
CNG	Compressed natural gas.
CO	Carbon monoxide.
CO2e	Carbon dioxide equivalent. CO2e allows other greenhouse gas emissions to be expressed in terms of CO2 based on their relative global warming potential (GWP).
DAC	Disadvantaged Communities
DCFC	Direct-current (DC) fast charging equipment. DCFCs are sometimes called DC Level 3 (typically 208/480V AC three-phase input) and enable rapid charging of an electric vehicle.
DEC	Department of Environmental Conservation

EV	Electric vehicle. A vehicle powered, at least in part, by electricity. Unless otherwise noted, the term "EV" in this Roadmap refers to all plug-in vehicles and includes BEVs and plug-in hybrid electric vehicles (PHEVs; defined below). The term "EV" is synonymous with "plug-in electric vehicle" (PEV).
EVSP	Electric vehicle service provider. An EVSP provides the connectivity across a network of charging stations. Connecting to a central server, they manage the software, database, and communication interfaces that enable operation of the station.
FCEV	Fuel cell electric vehicle.
Green Hydrogen	Also known as Renewable Hydrogen. Production involves the process of separating water into its elements (water electrolysis) using renewably sourced electricity (wind, hydropower, solar, etc.).
GHG	Greenhouse gas. Gases that trap heat in the atmosphere, such as carbon dioxide, methane, and nitrous oxide.
HEV	Hybrid electric vehicle. A vehicle powered by an internal combustion engine in combination with an electric motor that uses energy stored in batteries. These vehicles rely on regenerative breaking rather than plugging in to off-board electricity.
HEVO	Hybrid & Electric Vehicle Optimization, a Brooklyn-based company that launched in 2011 and is developing and deploying wireless EV charging technology.
HFCEV	Hydrogen fuel cell electric vehicle.
HVIP	Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project
ICEV	Internal combustion engine vehicle. A vehicle that combusts fuel, such as gasoline or diesel, for power.
KW	Kilowatt. A unit of power.
kWh	Kilowatt-hour. A unit of energy.
LDV	Light-duty vehicle. Vehicles with a gross vehicle weight rating below 8,500 lbs, which aligns with Class 1 to Class 2a vehicles.
M1	Mitigation Case 1; Technology emphasis on electrification, VMT management and mode shift moderate.
M2	Mitigation Case 2; Technology emphasis on electrification, VMT management and mode shift aggressive.
M3	Mitigation Case 3; Technology emphasis mixed with both hydrogen and electrification, VMT management and mode shift moderate.
M4	Mitigation Case 4; Technology emphasis mixed with both hydrogen and electrification, VMT management and mode shift aggressive.
MaaS	Mobility as a Service.
MBUF	Mileage-based user fee.
MHDV	Medium- and heavy-duty vehicle. Vehicles with a gross vehicle weight rating above 8,500 lbs, which aligns with Class 2b to Class 8 vehicles.
MMT	Million metric tons.
MMTCO2e	Million metric tons of carbon dioxide-equivalent.

MTA	Metropolitan Transportation Authority.
MUD	Multi-unit dwelling. Also called “multi-family dwellings,” these are apartments, condominiums, and group quarters. The other major housing category used in this Roadmap is single-family homes.
NH3	Ammonia.
NOX	Nitrogen oxide.
NYSERDA	New York State Energy Research and Development Authority.
OMNY	Contactless fare payment system, currently being implemented for use on public transit in New York City and the surrounding area.
PHEV	Plug-in hybrid electric vehicle. A vehicle powered by electricity or an internal combustion engine.
PM10/25	Particulate matter.
RGGI	Regional Greenhouse Gas Initiative.
RUC	Road-user charge.
SJCOG	San Joaquin Council of Governments.
SO2	Sulfur dioxide.
SOV	Single-occupancy vehicle.
TCO	Total cost of ownership.
TDM	Transportation demand management.
TEDI	Transportation Electrification Distribution Impacts.
TLC	Taxi & Limousine Commission.
TNC	Transportation network company.
TOU	Time of use.
TWh	Terawatt-hour.
US DOE	United States Department of Energy.
VMT	Vehicle miles traveled.
VOC	Volatile organic compounds.
ZEV	Zero-emission vehicle.

Executive Summary

ES.1 Motivation

In 2019, New York State enacted the Climate Leadership and Community Protection Act (Climate Act), setting the State's greenhouse gas (GHG) emissions limit to 40% below 1990 levels by 2030 and 85% below 1990 levels by 2050. The nation-leading Climate Act comes at a time of rapid change in the transportation sector, which is characterized by new powertrains, fuels, and mobility options as well as the ever-present need to mitigate the inequalities currently experienced in the transportation system. Amidst this backdrop, transportation continues to be one of the largest sources of GHG emissions, at 28% of the New York State total.

This New York State Clean Transportation Roadmap (the Roadmap) summarizes the current status of the State's transportation system; explores options for reducing GHG emissions; and highlights barriers, rates of technology adoption, GHG emissions, and policy impacts. The executive summary highlights key findings in the Roadmap, which covers all subsectors within transportation, including light-duty vehicles (LDVs), medium- and heavy-duty vehicles (MHDVs), aviation, rail, marine, and non-road. Please note that the Roadmap started prior to, and at times in parallel with, the related economy-wide modeling work done to support the Climate Act. Therefore, the overall policy impacts largely align, though some numbers and figures may vary slightly due to different models and inputs used.

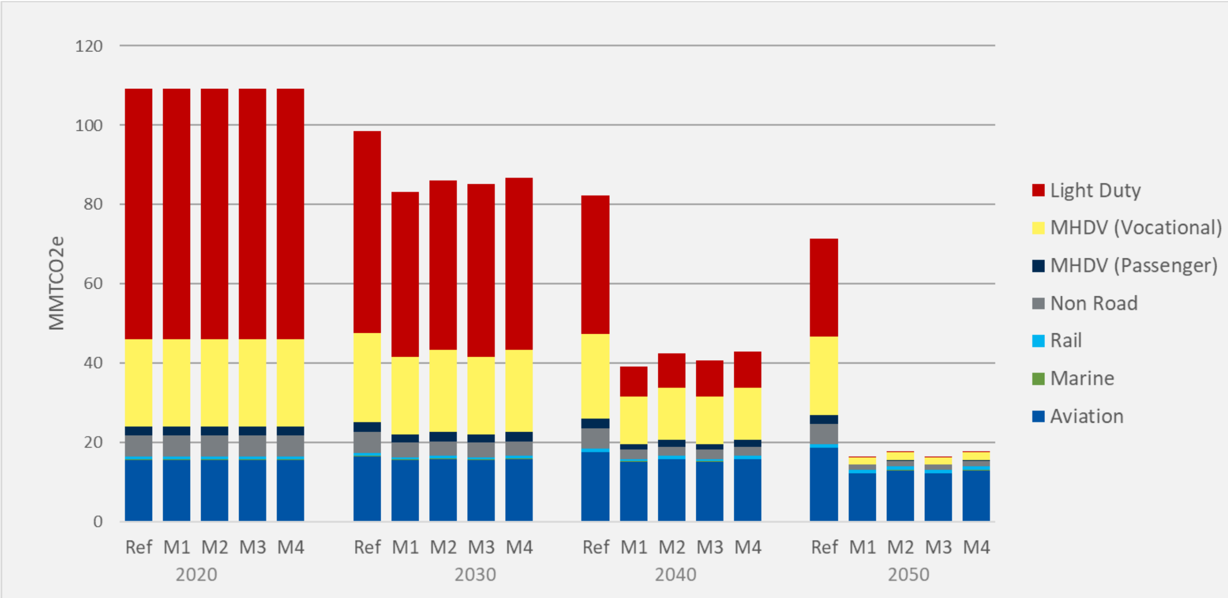
ES.2 Roadmap Organization

New York State is a leader in clean transportation and has helped modernize the movement of people and goods early in its history as demonstrated by the construction of the Erie Canal in the early 1800s and one of the first subway lines in the late 1800s. Today, the State has (1) the largest public transportation system in North America, (2) the highest share of passenger trips by public transit in the nation, (3) the greatest share of electrified passenger-miles, and (4) uses less energy per capita for transportation purposes than any state in the country. The state also provides a leadership role by promoting, implementing, and incentivizing bold new programs such as the multi-state, zero-emission vehicle standard, congestion pricing, and community-focused New York Clean Transportation Prizes.

With current policies, the State is on a trajectory for moderate transportation GHG emission reductions by 2050. New policies and strategies will be necessary to achieve the Climate Act's aggressive GHG emission reduction goals. This chapter details a reference case that describes how the transportation sector is expected to develop absent any new policies at the State and federal levels. In particular, the reference case does not include the commitments to 100 % zero-emission vehicle sales included in the law Governor Kathy Hochul signed in September 2021 (which are aligned with the Advanced Clean Cars II and Advanced Clean Truck regulations), nor does it include major federal action in 2021. The reference case reflects a moderate growth of electric vehicles (EVs),[1] which accounts for 32% of new light-duty vehicle sales in 2030 and 64% in 2050. Vehicle miles traveled increases for light-duty vehicles by 1.3% per year and for MDHVs by 1.0% per year on average. Vehicle efficiency improves according to currently enacted federal standards. While new targets or policies may be announced after the writing of this Roadmap, they will be treated as mitigation cases in the report, which will allow the models used in the Roadmap to better quantify the benefits they are expected to achieve when implemented.

Four mitigation cases help describe potential pathways for transportation decarbonization. This chapter describes four mitigation cases—labeled M1 through M4—that differ in their mix of State-led policies. The spectrum of mitigation cases helps highlight the possible range of GHG reductions and associated social, health, and economic impacts. A detailed description of policies in the reference case and mitigation cases is in Section 4.2: Structure of Mitigation Cases. Figure ES-1 shows the annual GHG emissions for the reference case and four mitigation cases each decade between 2020 and 2050. Table ES-1 expands upon this description by highlighting many of the key differences and commonalities among the mitigation cases.

Figure ES-1. GHG Emissions by Subsector across Cases and Future Years



The following bullets provide a high-level description of the four mitigation cases:

- **Mitigation Case 1 (M1) High Fuel Switch to EVs**—uses vehicle electrification, specifically battery electric vehicles, as its dominant GHG reduction strategy. M1 has less aggressive vehicle miles traveled (VMT) management and mode shift strategies compared to M2.
- **Mitigation Case 2 (M2) High VMT Management and Mode Shift with EVs**—uses more aggressive VMT management strategies than M1 and slightly less aggressive vehicle electrification policies than M1.
- **Mitigation Case 3 (M3) High Fuel Switch to EVs and FCEVs**—uses vehicle electrification and fuel cell electric vehicles (FCEVs) as its dominant GHG reduction strategy and mirrors M1 in VMT management and mode shift strategies.
- **Mitigation Case 4 (M4) High VMT Management and Mode Shift with EVs and FCEVs**—uses more aggressive VMT management strategies than M3 and slightly less aggressive vehicle electrification policies than M3.

Deep cuts to transportation GHG emissions are feasible with the right mix of policy and continued technological improvement. This chapter provides key metrics—including technology and fuel mix, VMT projections, and GHG emissions—about the four mitigation cases, M1 through M4. Through aggressive transit expansion, moderate carbon pricing, and Smart Growth policies, VMT is lower for LDVs and MHDVs by 13% to 14% below the reference case by 2050 across mitigation cases. However, VMT still increases relative to today's level by 31% to 33% across mitigation cases due primarily to population and income growth. Almost all on-road vehicles shift to electric or hydrogen power by 2050, driven by policies like the Advanced Clean Cars II and Advanced Clean Trucks regulations. Overall, mitigation cases see a reduction in transportation GHG emissions of up to 84% relative to 1990 levels.

Broader social and economic impacts of the four mitigation cases vary. This chapter describes estimated impacts on health, equity, expenditures, economic indicators, fiscal requirements, and the electric distribution system. Certain impact categories—such as health impacts—are very similar across mitigation cases since all on-road vehicles move toward either electric or hydrogen in similar fashion across all Mitigation Cases. Other impact categories, such as fiscal impacts to the State, differ widely by mitigation case.

Chapter 7 synthesizes high-level findings for decarbonizing the transportation sector in New York State. Broadly, these findings suggest there are multiple pathways for mitigating transportation sector emissions to levels consistent with achieving the 2050 Climate Act goals, although the set of viable strategies and technologies to meet these goals is narrowing. Importantly, all mitigation cases include alignment with the Advanced Clean Cars II and Advanced Clean Truck regulations, which require that sales of LDVs and MHDVs be 100% EVs or FCEVs by 2035 and 2045, respectively. These underlying policies result in similar emission trajectories and estimated impacts across mitigation cases. Opportunities for further analysis are discussed, such as modeling sensitivities and uncertainties regarding population growth, household income, and VMT forecasting, which can shift the mitigation scenarios. The technological and political feasibility of some strategies are also important factors to consider. This chapter concludes with a suggested set of follow-on research activities.

ES.3 Key Insights

Table ES-1 summarizes key metrics across scenarios in the Roadmap and highlights several findings:

- **2030 GHG Emissions.** As shown in Figure ES-1 only modest GHG reductions are projected in the aggressive policy environment of the four mitigation cases by 2030. M1 has the lowest emissions of the four mitigation cases in 2030 at 17% below 1990 levels. M4 has the highest in 2030 at 13% below 1990 levels.

- **2050 GHG Emissions.** As shown in Figure ES-1, in all mitigation cases annual and cumulative GHGs emissions are similarly lower than the reference case by 2050, reaching 82% to 85% reduction relative to 1990 levels. The reference case only reaches 29% below 1990 levels by 2050.
- **VMT Growth**. The mitigation cases reduce the LDV VMT growth rate relative to the reference case by similar magnitudes. MHDV growth rates differ by vehicle category compared to the reference case. Mitigation cases 2 and 4, which assume more aggressive VMT and mode shift strategies, increase rail VMT growth relative to the reference case.
- **EV and FCEV Growth**. By 2035, EVs and FCEVs make up 100% of new LDV sales in mitigation cases. By 2050, virtually all LDV stock is either an EV or FCEV. At the same time, EVs make up all new MHDV sales and over 90% of the MHDV stock in M1 and M2 by 2050, while M3 and M4 shift to a mix of EVs and FCEVs. Individual regions in New York State transition to EVs and FCEVs at different rates based on underlying characteristics of the region.
- **Health Burden**. The cumulative burden on public health from criteria pollutants emitted directly by on-road transportation sources is similar across mitigation cases and its value is about 30% lower than the public health burden found in the reference case cumulatively from 2020 to 2050. The similarities between mitigation cases are driven by the pace of electrification and use of hydrogen in on-road vehicles across cases. Large differences exist between counties for a given case, signifying that the public health benefits of lowering VMT or electrifying vehicles are not uniform across the State.
- **Mode Share.** The share of walk, bike, and transit trips increases dramatically in mitigation cases relative to today and to the reference case, particularly in the aggressive VMT and mode shift cases (M2 and M4). Upper income households (greater than $85,000 per year) and regions with high non-white populations have the largest percentage point shift in mode share. This outcome is driven by urbanized regions seeing the greatest shifts away from vehicle travel and increased mobility-oriented development across New York State. As described in section 4.2, the primary drivers for these mode shifts are expanded transit service, incentive to commute via nonpersonal automobile, and greater mixed-use development.
- **Household Spending on Transportation**. Annual spending on transportation *per household* (including personal vehicles, transit, and active transportation) increases slightly by 2050 across the reference case and all mitigation cases but results vary by income level. For example, low-income households earning less than $35,000 per year spend *less* on transportation per household in M2 and M4 cases in 2050 compared to today and to the reference case. Middle-income households ($35,000 to $85,000 per year) spend 5% *more* on transportation per household in M2 and M4 in 2050 compared to today. Competing forces shape this spending—as real household incomes rise, VMT per household and vehicle-related costs also rise. However, households shift trips toward transit and active transportation (biking, walking, e-bikes, and e-scooters), which lowers travel costs. Additionally, the cost of vehicle travel per mile declines relative to today because of expected cost savings from electrification. Overall, spending on transportation changes by 4% or less in the mitigation cases relative to today or to the reference case across all income groups.

- **Total Expenditures**. Similarly, the cumulative cost of on-road vehicle ownership to households and fleets (including upfront costs, fuel, and maintenance) from 2020 to 2050 is lower in all mitigation cases than the reference case because of expected cost reductions in EVs and FCEVs and lower VMT in these cases. As discussed in section 6.3, aggregate upfront vehicle costs are lowest in the aggressive VMT and mode shift cases (M2 and M4) because of fewer vehicles and fewer miles traveled. The cost of fuel and maintenance is lowest in the high-electrification cases (M1 and M2). Overall, on-road, vehicle-related expenditures are lowest in M1, $80 billion less than the highest cost case (M3).
- **State Fiscal Impacts**. As discussed in section 6.5, the cumulative state fiscal impact (relative to the reference case) between 2020 and 2050 varies widely between the moderate and the aggressive VMT and mode shift cases, with the moderate VMT and mode shift cases (M1 and M3) costing about a third less than the aggressive VMT and mode shift cases (M2 and M4).
- **Distribution System Impacts**. A parallel study—the Transportation Electrification Distribution Impacts (TEDI) study—used inputs from this Roadmap to understand cost impacts of high-transportation electrification on the electricity distribution system. In close coordination with New York State utilities, the study used a detailed cost model and incorporated increased loads from all sectors (e.g., buildings). By 2050, the substantial growth in EVs will contribute 141, 331, and 152 terawatt-hours (TWhs) in load to the grid in the reference case, M1, and M4, respectively (M2 and M3 were not included). In the highest cost scenario with unmanaged charging in M1, the cost of expanding the distribution system in 2050 is less than one cent per kilowatt hour (kWh) of transportation load. When these costs are applied per EV rather than per kWh, costs are $171 per EV per year when including LDVs and MHDVs. Managed charging lowers these costs by about 50%.

In summary, the mitigation cases reach similar levels of GHG emissions and health outcomes, driven primarily by new policies including requiring that all new LDVs and MHDVs sold in the State be zero emission by 2035 and 2045, respectively. Household spending on transportation increases slightly across mitigation cases but results vary by income group, with low-income households decreasing transportation spending relative to the reference case. Estimated State government spending varies widely across mitigation cases, with the moderate VMT and mode shift cases (M1 and M3) costing about a third less than the aggressive VMT and mode shift cases (M2 and M4).

Table ES-1. Summary of Key Metrics across Scenarios

Section(s)	Column1	Ref	M1	M2	M3	M4
	Demand Growth					
3.4, 5.2	LDV VMT Growth Rate, 2020-2050 (% growth in miles/year)	1.3%	0.8%	0.7%	0.8%	0.7%
3.4, 5.2	MHDV VMT Growth Rate, 2020-2050 (% growth in miles/year)	1.0%	1.1%	1.2%	1.1%	1.2%
3.4, 5.2	Rail VMT Growth Rate, 2020-2050 (% growth in miles/year)	2.2%	2.2%	3.5%	2.2%	3.5%
3.4, 5.2	Aviation Passenger Miles Growth Rate, 2020-2050 (% growth in mi/yr)	1.6%	1.6%	1.6%	1.6%	1.6%
3.4, 5.2	Marine Energy Growth Rate, 2020-2050 (% growth in GJ/year)	0.0%	0.0%	0.0%	0.0%	0.0%
3.4, 5.2	Non-Road Energy Growth Rate, 2020-2050 (% growth in GJ/year)	0.0%	-3.4%	-3.4%	-3.0%	-3.0%
	Zero-Emission Vehicle Growth					
5.1	LDV EV Sales Share, 2030 (%)	19.1%	68.8%	62.1%	56.8%	56.7%
5.1	LDV FCEV Sales Share, 2030 (%)	0.0%	0.0%	0.0%	1.7%	1.7%
5.1	LDV EV Sales Share, 2050 (%)	43.4%	100.0%	100.0%	53.6%	53.5%
5.1	LDV FCEV Sales Share, 2050 (%)	0.0%	0.0%	0.0%	46.4%	46.5
5.1	LDV EV Stock Share, 2030 (%)	6.4%	19.8%	17.6%	15.8%	15.8%
5.1	LDV FCEV Stock Share, 2030 (%)	0.0%	0.0%	0.0%	0.6%	0.6%
5.1	LDV EV Stock Share, 2050 (%)	38.1%	99.8%	99.6%	62.0%	62.0%
5.1	LDV FCEV Stock Share, 2050 (%)	0.0%	0.0%	0.0%	37.6%	37.7%
5.1	MHDV EV Sales Share, 2030 (%)	7.7%	38.1%	38.0%	18.6%	18.5%
5.1	MHDV FCEV Sales Share, 2030 (%)	0.0%	0.0%	0.0%	19.5%	19.5%
5.1	MHDV EV Sales Share, 2050 (%)	28.1%	100.0%	100.0%	47.0%	47.1%
5.1	MHDV FCEV Sales Share, 2050 (%)	0.0%	0.0%	0.0%	53.0%	52.9%
5.1	MHDV EV Stock Share, 2030 (%)	2.3%	9.8%	9.8%	4.8%	4.8%
5.1	MHDV FCEV Stock Share, 2030 (%)	0.0%	0.0%	0.0%	5.0%	5.0%
5.1	MHDV EV Stock Share, 2050 (%)	22.0%	94.1%	94.7%	44.7%	45.1%
5.1	MHDV FCEV Stock Share, 2050 (%)	0.0%	0.0%	0.0%	49.4%	49.6%

Table ES-1. Continued

Section(s)	Column1	Ref	M1	M2	M3	M4
	GHG Emissions					
5.3	Annual GHG Emissions, 2030 ($MMTCO_2e$)	98.5	83.1	86.0	85.2	86.7
5.3	Annual GHG Emissions, 2050 ($MMTCO_2e$)	71.5	16.4	17.6	16.5	17.6
5.3	Cumulative GHG Emissions, 2020-2030 ($MMTCO_2e$)	1,154.0	1,090.1	1,101.8	1,096.3	1,104.1
5.3	Cumulative GHG Emissions, 2020-2050 ($MMTCO_2e$)	2,806.1	1,917.8	1,987.3	1,953.9	1,999.3
6.1	Cumulative Criteria Pollutant Burden, 2020-2050 ($2020 Billions)	$13.4	$9.6	$9.7	$9.7	$9.7
	Social, Health, and Economic Impacts					
6.2	Change in Annual Cost of Transportation per Household between Today and 2050, (% Change in 2050 Relative to Today in Constant $)	2%	3%	1%	3%	1%
6.3	Cumulative Vehicle Expenditures, 2020-2050 ($2020 Trillions)	$2.82	$2.59	$2.52	$2.54	$2.51
6.3	Cumulative Fuel & Maintenance Expenditures, 2020-2050 ($2020 Trillions)	$1.30	$1.13	$1.14	$1.21	$1.21
6.4	Economic impacts (Jobs)	TBD	TBD	TBD	TBD	TBD
6.4	Economic Impacts (Gross State Product)	TBD	TBD	TBD	TBD	TBD
6.5	Cumulative Gross State Fiscal Costs Relative to Reference Case, 2020-2050 ($2020 Billions)	N/A	$41.3	$60.7	$39.0	$60.2
6.6	Peak Electricity Demand from Unmanaged Transportation, 2030 (MWh)	1,175.7	3,030.7	N/A	N/A	2,568.6
6.6	Peak Electricity Demand from Managed Transportation, 2030 (MWh)	1,193.0	1,980.4	N/A	N/A	2,678.7[a]
6.6	Peak Electricity Demand from Unmanaged Transportation, 2050 (MWh)	8,861.0	26,893.5	N/A	N/A	12,630.0
6.6	Peak Electricity Demand from Managed Transportation, 2050 (MWh)	8,180.9	15,092.6	N/A	N/A	10,287.7
6.6	Average Rate Increase from Unmanaged Transportation Electrification, 2050 ($/kWh)	$0.003	$0.009	N/A	N/A	$0.002
6.6	Average Rate Increase from Managed Transportation Electrification, 2050 ($/kWh)	$0.002	$0.005	N/A	N/A	$0.001

[a] By design, M4 has a higher magnitude system peak for transportation electrification load in the managed case than the unmanaged case in 2030. The peak for the managed case occurs around 8:00PM while the peak for the managed case occurs around midnight.

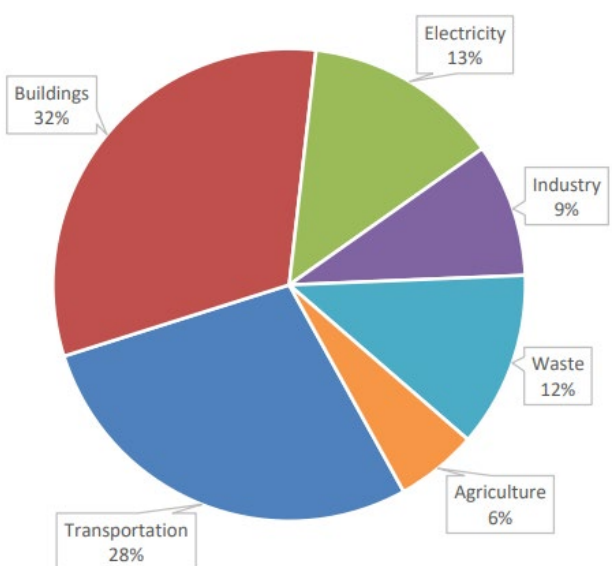
1 Introduction

New York State enacted the Climate Leadership and Community Protection Act (Climate Act) in 2019, which set greenhouse gas (GHG) emission reduction targets at 40% of 1990 levels by 2030 and 85% of 1990 levels by 2050.[2] To achieve these ambitious targets, New York State will need to reduce GHG emissions across its economy. The New York State Energy Research and Development Authority (NYSERDA) commissioned this Clean Transportation Roadmap to examine the transportation sector in the state and identify actions to achieve deep GHG reductions in accordance with the Climate Act. This Roadmap summarizes the path ahead, highlighting tradeoffs and enumerating the costs and benefits of various GHG emission mitigation strategies.

1.1 Transportation Emissions in New York State

At 28% of statewide GHG emissions, the transportation sector accounts for a large portion of the State's total emissions by sector (Figure 1). Emissions from transportation peaked in 2005 and have been falling for past 15 years but are still higher than 1990 levels. Even as emissions from fossil fuel combustion have decreased across all sectors, the rate of decline has been slower in the transportation sector. Aviation is the fastest growing transportation subsector, as demand for air travel has grown faster than have improvements in aircraft design and operations.

Figure 1. Breakdown of 2019 GHG Emissions in New York State, by Sector



1.2 Strategies for Meeting Climate Goals

Analysis completed in support of the Climate Act's Climate Action Council process suggests that to reach the GHG goals stated in the Climate Act requires New York State to reduce annual GHG emissions to no more than 20 $MMTCO_2e$ per year in 2050.[3] This information, along with the State's current GHG emissions and the rate of replacement of vehicles, provides a set of constraints for the analysis below.

The analysis explores transportation emission reductions through three core strategies:

- **Fuel switching** shifts away from use of emissions-intensive fuels toward low- or zero-emission sources to reduce pollution from a given activity. A shift already underway, also highlighted in the reference case, is from gasoline to electricity for light-duty vehicles (LDVs). Furthermore, in some instances fuel-switching can enable more value to be leveraged from a given amount of energy. Electric drive systems are many times more effective at converting energy to power at the wheels than are gasoline engines, resulting in higher energy efficiency.[4]
- **VMT management** involves reducing trip distances, the need to travel, and discretionary vehicle trips, all of which lower total energy demand and thereby reduce emitting activities.
- **Mode shift**, driven by increased mobility-oriented development, focuses on transitioning trips that would normally be taken in a personal automobile to other modes of travel, such as public transit, biking, walking, and micro e-mobility.

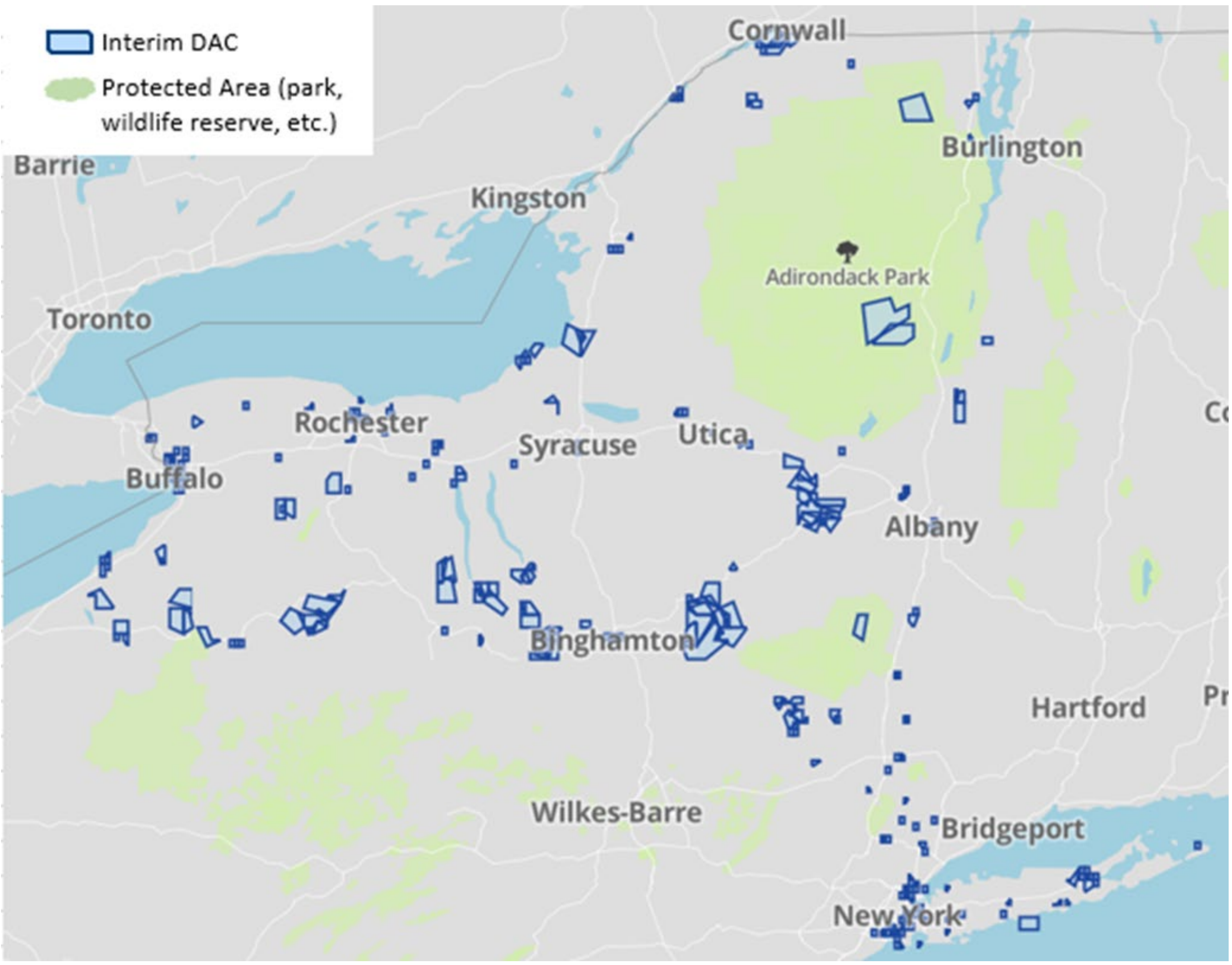
Policies can straddle multiple strategies and affect changes on different geographic levels and time scales. How to prioritize these policies also depends on technological readiness, consumer acceptance, cost, capacity for behavior change, and the magnitude of potential reductions they can generate. New York State is looking to identify one or more suites of policies that will enable it to meet its decarbonization goals while maximizing other key beneficial impacts.

1.3 Social Equity and Co-Benefits

New York State's transportation system delivers access and mobility, connecting people to jobs, schools, healthy food choices, recreation, health care, and other services and destinations that are vital to securing economic opportunities and providing well-being. However, the benefits conveyed, and costs levied by the system differ between households. This is due, in large part, to inequities embedded in historical transportation and land-use decisions and patterns of racial and economic disparities.

The Climate Act aims to address some of these inequities by directing the benefits of spending on clean energy and energy efficiency programs toward affected communities. Figure 2 shows the census block groups designated as disadvantaged communities under interim criteria New York State is using while a final definition is developed. Communities designated as disadvantaged communities under the final definition will be priority recipients of these benefits.

Figure 2. Interim Disadvantaged Communities (DAC) Map



2 Goals and Current Status

This section summarizes the current state of the transportation sector in New York State and describes the reference case—an internally consistent projection of the transportation sector to 2050 under a continuation of current trends and policies. The current clean transportation activities described in the next section are already in place and treated as such in the reference case. New targets or policies have been announced after the writing of this Roadmap, and for purposes of this report they are treated as part of the mitigation cases, which allows the modeling analysis to better quantify the benefits that these additional policies and programs are expected to achieve when implemented. Therefore, the modeling completed for this report do not exactly match the modeling presented in other analyses done for the Climate Act.

2.1 Current Clean Transportation Activities in New York State

New York State has a long history of innovative clean transportation programs, starting as far back as October 1904, when operations began on the electric New York City subway line (known as the Interborough Rapid Transit) from City Hall to 145th Street. In more recent times, the State's emission reduction efforts focus on transit, VMT management, vehicle efficiency, and fuel swapping. Each year, New York State and local governments invest more than $9.5 billion in clean transportation initiatives.[5]

A defining feature of the State's transportation sector emissions is the importance of public transportation. New York State has the highest share of transit commuters of any state in the country, accounting for 39% of all public transit commuters in the nation.[6] Capital spending on the subway, transit buses, commuter rail, and ferries exceeded $6 billion in 2019, far above the next highest state (California) at $4.6 billion.[7] Moreover, New York State has lower VMT and uses less energy per capita for transportation purposes than any other state largely because of its compact land use and transit availability in the New York City metro area.

Innovative VMT management programs complement the State's transit programs. For example, the New York State Department of Transportation's Active Transportation and Demand Management Program is a statewide program that works to reduce public VMT and, in turn, lower emissions. The goal is to encourage people, through outreach and support to employers and community organizations, to avoid single-occupancy vehicle (SOV) travel and to use alternatives, such as transit, carpool, vanpool, ridesharing, bicycling, walking, and telecommuting. New York State also plans to implement the nation's first cordon/congestion pricing program in the New York City Central Business District. This program will reduce traffic congestion by tolling incoming traffic to the Manhattan Central Business District, defined as 60th Street and below. Proceeds from congestion pricing, per statute, are dedicated to renewing and modernizing public transportation services provided by the Metropolitan Transportation Authority.

New York State follows the country's strictest vehicle emission standards. In 1990, New York State adopted California's Low Emission Vehicle program, requiring all new light-duty passenger vehicles sold in New York State to meet California light-duty passenger vehicle emissions standards, which are more stringent than federal standards. In 2021, Governor Hochul signed legislation to continue following California in phasing out the sale of internal combustion engine vehicles (ICEVs) by 2035 for light-duty vehicles and by 2045 for medium- and heavy-duty vehicles. The law also establishes a goal to transition to 100% sales of zero-emission, off-road vehicles and equipment by 2035. Because this legislation was signed in 2021, it was not included in the reference case described below in section 3.2.

In 2013, New York State initiated two major actions in transportation electrification programs. First, the State signed the light-duty, zero-emission vehicle (ZEV) memorandum of understanding, which formed the Multi-State ZEV Task Force, a coalition of states working together to advance the deployment of ZEVs through policy research and marketing campaigns. Second, the State launched Charge NY, a series of initiatives that, over time, grew to include the Drive Clean Rebate program, offering up to $2,000 for EV purchases or leases; the New York State Truck Voucher Incentive Program, offering incentives of up to $385,000 for the purchase or lease of electric trucks and buses; the Charge Ready NY program, offering $4,000 per Level 2 charging port; the Department of Environmental Conservation (DEC) Municipal vehicle and infrastructure rebate programs; and public awareness and educational campaigns.

There are numerous additional statewide programs underway today:

- To advance light-duty EV adoption, the State launched the Clean Fleets NY program in 2015, which supports deployments of EVs in State government fleets. In 2018, the New York Power Authority launched Evolve NY program, which complements Charge NY 2.0 with an additional $250 million investment in EV charging infrastructure, services, and consumer awareness efforts.
- New York State actively participates in the Federal Highway Administration's Alternative Fuels Corridor designation program. As of June 2021, New York State has 19 corridors designated as corridor-ready or pending for electric, hydrogen, propane, liquid natural gas, and/or compressed natural gas vehicle technologies.[8]

- Through the New York Truck Voucher Incentive Program, New York State aims to a ccelerate the deployment of all-electric and alternative fuel trucks and buses in medium- and heavy-duty vehicle (MHDV) classes throughout New York State. NYSERDA administers the program, which currently offers $58.3 million in funding and uses funds from the Volkswagen settlement overseen by the New York State Department of Environmental Conservation and the Congestion Mitigation and Air Quality Improvement program overseen by the New York State Department of Transportation. New York State also directed Volkswagen funds ($9.8 million) to the New York City Clean Trucks Program, which replaces Class 4-8 diesel trucks in New York City industrial business zones that are within defined environmental justice areas.
- New York State has employed numerous VMT management strategies to incentivize shifts in transportation modes and travel behavior patterns. In 2019, New York City initiated a pilot program to encourage freight companies to use cargo bicycles to reduce vehicle congestion and mitigate GHG emissions. Furthermore, the NYS Rail Plan of 2009 established 20-year and near-term goals to improve freight and intercity passenger rail service to shift the movement of goods from large internal combustion engine trucks to alternative modes.

In July 2020, New York State announced two sweeping new programs. First, New York State was one of 15 states to sign a MHDV ZEV memorandum of understanding, with the goal of having 30% of MHDV sales be ZEVs by 2030 and 100% by 2050. Second, New York State announced a $701 million Make-Ready program by investor-owned utilities, which pays up to 100% of the infrastructure costs necessary to make sites ready for charging electric light-duty vehicles (LDVs).

Finally, the five largest non-MTA New York transit systems in Buffalo, Rochester, Albany, Westchester County, and Suffolk County have committed to converting 25% of their transit bus fleets to zero emission by 2025 and 100% by 2035. In addition, the MTA, which has also committed to converting its entire bus fleet, the nation's largest, to all-electric by 2040 and will purchase only zero-emission buses for its fleet after 2029. The MTA will also partner with the United States Department of Energy to analyze the potential for using traction power substations for bus charging. Smaller transit systems such as those in Tompkins County and Ulster County are also taking a proactive approach toward transit bus electrification.

Case Study: V2G School Buses

In an innovative pilot project funded by NYERSDA and Con Edison, five electric school buses in White Plains now provide electricity to Con Edison's customers. Each White Plains bus is able to dispatch 13.2 kilowatts of electricity to the grid through Nuvve's bidirectional chargers, for a total capacity of 66 kilowatts.[9,10]

Bidirectional vehicle-to-grid (V2G) is an emerging technology that enables EVs to transmit stored electricity from their batteries to the electrical grid through a bidirectional charger. V2G-enabled vehicles can help utilities maintain reliability as electricity generation from intermittent renewable sources, like solar and wind, increases. School buses are particularly well-suited for V2G because they have significant non-operational time. For instance, they can plug in during summer months when electricity demand is high, and they are on the road less frequently. The White Plains pilot is providing a maximum of only 66 kilowatts, but, if electrified, the 8,000 school buses in Con Edison's service territory could provide battery storage capacity in the tens or hundreds of megawatts.

During the school year, National Express, which owns and operates the White Plains School District's buses, will be able to generate additional proceeds outside of normal operating hours by charging overnight, when electricity rates are lower, then selling the stored electricity back to Con Edison during peak periods of the day when electricity rates are higher. By tapping into public and utility funding, National Express reduced its upfront costs to make the transition to electric school buses more affordable. With nearly 10% of the nation's school buses, New York is poised to lead the way on this innovative technology that can benefit local communities, schools, and utilities alike.[11]

In addition to State-level initiatives, many local jurisdictions and organizations—including counties, cities, utilities, ports, and others—are aggressively pursuing climate action and transportation emission reduction activities. For example, New York City is a member of the C40 Cities Climate Leadership Group that implemented a 2050 carbon neutrality goal,[12] and it has already purchased more than 2,000 EVs for its fleet.[13]

All New York State residents can also take advantage of available federal programs aimed at increasing vehicle electrification (such as the federal EV tax credit) and at lowering transportation emissions (such as the Diesel Emission Reduction Act [DERA] and Voluntary Airport Low Emissions [VALE] program).

2.1.1 Key Trends among New York State Transportation Policies and Programs

2.1.1.1 Private-Sector Leadership

New York State is home to several EV-related companies that operate locally and provide innovative products and solutions to the EV market. These businesses range from small technology startups to large multinational corporations. A notable example is BAE Systems' electric systems plant in Endicott, NY, where the company develops drive trains for electric buses that have been used throughout the world.[14] New York State is also home to Hybrid & Electric Vehicle Optimization (HEVO), a Brooklyn-based company that launched in 2011 and is developing and deploying wireless EV charging technology.[15] One of the newest EV-related companies in New York State is Revel Transit, a dockless electric moped-sharing startup. Initially launched in 2018, the company now offers 1,000 scooters in Brooklyn and Queens and 400 scooters in Washington, D.C.[16] Product demonstrations in New York State are underway or under development from other transportation electrification companies such as AMPLY Power, the Lion Electric Co., and Proterra.

New York State's business community is also well-positioned to support the deployment of fuel cell electric vehicles (FCEVs) and hydrogen fueling infrastructure. Plug Power, a leading supplier of hydrogen and fuel cell solutions headquartered in Latham, has deployed over 40,000 fuel cell systems for e-mobility and has installed over 100 hydrogen fueling stations worldwide.[17] Plug Power is the world's largest supplier and user of liquid hydrogen and includes, among its product offerings, electrolyzers, which can be integrated with electricity from renewables to produce green hydrogen for FCEVs.

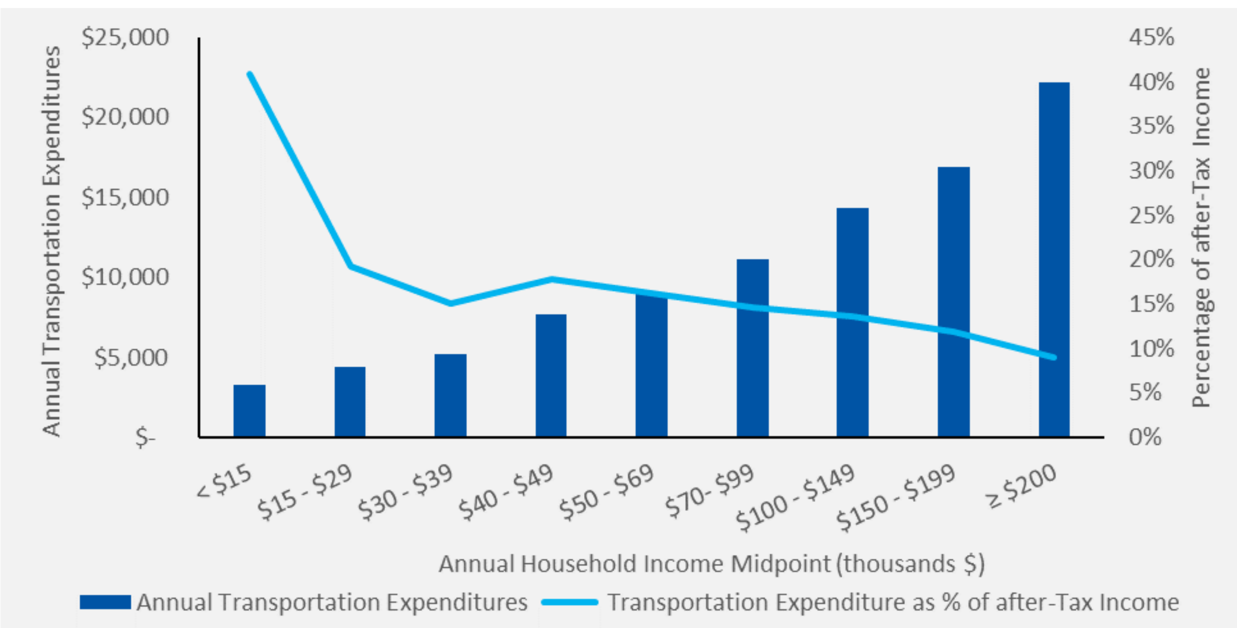
HYZON Motors, headquartered in Rochester, is a global supplier of hydrogen fuel cell commercial vehicles, including heavy-duty trucks, buses, and coaches.[18] Standard Hydrogen Corporation, based in Albany, New York, is building hydrogen stations in the State that will produce hydrogen using electrolyzers to provide EV charging and hydrogen refueling as well as grid balancing, renewable power integration, and other services for utility customers.[19] Ecolectro Inc., in Ithaca, develops and manufactures alkaline exchange polymers for hydrogen electrolyzers and fuel cells.[20] Several fuel cell and hydrogen system component suppliers and testing companies also reside in the State.[21]

New York State is also a thriving location for startups in clean transportation. For example, Circuit is an electric micro-transit solution that helps fill the first- and last-mile gap in trips; ClearRoad is a cloud-based platform that facilitates dynamic congestion pricing; Brooklyness is a subscription-based, e-scooter and e-bike micro-mobility provider; and Numina is a computer-vision technology that helps cities analyze and manage their curbs and streetscapes.

2.1.1.2 Disproportionate Burdens of Transportation Costs and Criteria Pollutants

Transportation-related costs are a significant portion of household spending across all income brackets. In absolute terms, lower-income households spend less on transportation than their higher-income neighbors, but in relative terms, low- to moderate-income households spend a much larger percentage of after-tax income on transportation-related expenditures, as much as 40% of total expenses in certain low-income groups (Figure 3).[22] Likewise, rural and suburban residents in the State drive an average of 36% more miles annually in personal vehicles than their urban-dwelling counterparts,[23] which suggest policies that impact the cost of driving have a differential impact. To the extent feasible within the modeling framework of the project, this Clean Transportation Roadmap aims to prioritize these considerations by investigating the equity impacts of policies in the State.

Figure 3. Annual Transportation Expenditures versus Percentage of After-Tax Household Income for Northeastern Region

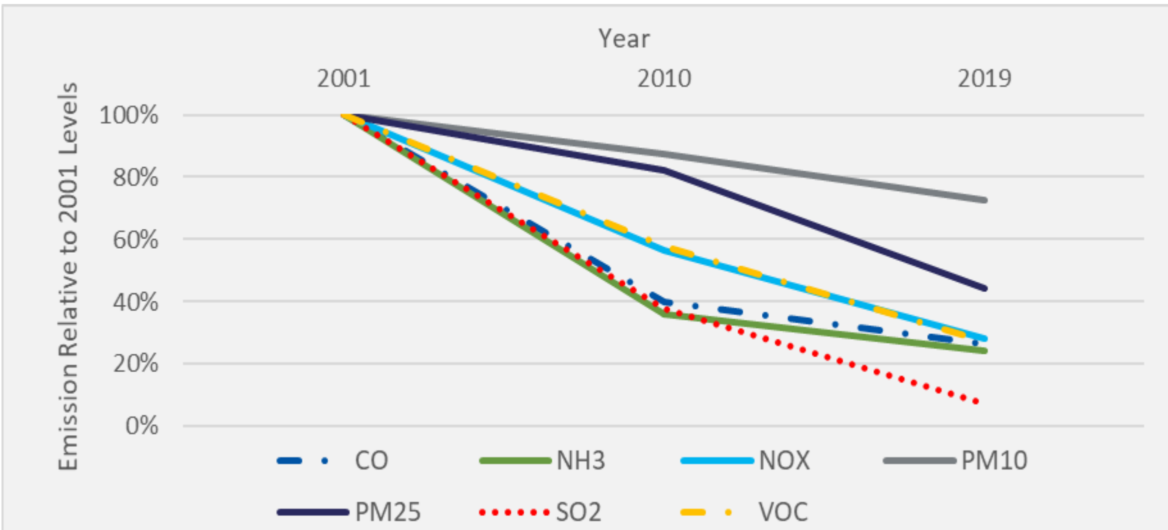


Not only is the transportation sector responsible for the largest share of GHG emissions in the State, but it is also a major emitter of criteria air pollutants (Table 1). At the same time, across all major criteria pollutants, the magnitude of transportation-related emissions has declined substantially over the last 20 years (Figure 4).

Table 1. Transportation Contribution to Statewide Criteria Air Pollutant Emissions (% of Total)

Carbon Monoxide (CO)	Nitrogen Oxide (NOX)	Volatile Organic Compounds (VOC)	Particulate Matter (PM2.5)	Sulfur Dioxide (SO2)	Particulate Matter (PM10)	Ammonia (NH3)
85.9%	64.7%	36.2%	13.1%	8.7%	8.2%	7.5%

Figure 4. Trends in Criteria Air Pollutant Emissions from On-Road Transportation in New York State



Transportation-related climate and air pollution emissions also occur disproportionately across communities. State-level trends overall have declined over time; however, these trends obscure the fact that air pollutants and their associated negative health effects are localized. In general, transportation-related sources of criteria air pollutants are more dispersed than stationary sources like factories or refineries, but these sources can still be heavily concentrated in certain areas.

The substantial geographic variation in exposure to these pollutants is interwoven with issues of income inequality, political influence, and histories of racial discrimination and redlining. It is critical to account for this uneven burden of air pollution across communities when assessing the social equity and public health effects of clean transportation policies. In September 2021, Governor Hochul announced that the State will conduct hyperlocal air quality assessments in historically overburdened communities in order to drive tailored strategies to reducing air pollution and GHG emissions.

2.1.2 Key Barriers to Decarbonization

Despite policy leadership, State and local investments, as well as an active and entrepreneurial private sector, the transportation sector still faces substantial barriers to decarbonization—particularly when shifting to new fuels and powertrains. Table 2 presents, based on a combination of literature and expert interviews, key barriers to fuel and powertrain related decarbonization strategies, by vehicle segment. These barriers have been identified and structured through a combination of literature reviews and consultations with industry experts.

Table 2. Key Barriers by Segment

Subsector or Segment	Relevance of Barrier to Each Subsector or Segment		
	Light Duty Vehicles	Medium/Heavy Duty Vehicles	Non Road Vehicles
Electrification Barriers			
Initial purchase price	Medium	High	High
Electrical infrastructure impacts	Medium	High	High
Reduction in payloads	N/A	Medium	Medium
Cost depreciation	Medium	Medium	Unknown
Insufficient model availability	Medium	High	High
Vehicle range anxiety	High	Medium	High
Residential charging access and infrastructure	Medium	N/A	N/A
Public perception and awareness	High	Medium	Medium
Lack of interoperability of equipment	Medium	Medium	Unknown
Cold weather	Low	Medium	Unknown
Stock turnover	Low	Medium	High
Long charge times	Medium	Medium	High
Battery recycling challenges	Unknown	Unknown	Unknown
Hydrogen Fuel Cell Adoption Barriers			
Fuel availability	High	High	High
FCEV cost	High	High	High
Fuel cost	Medium	Medium	Medium
Public perception and awareness	Medium	Medium	Medium
Tunnel and bridge restrictions	High	Medium	Low
Hydrogen station permitting process	Medium	Medium	Medium
Biofuel Adoption Barriers			
Fuel availability	High	High	High
Fuel cost	Medium	Medium	Medium
Public perception and awareness	Medium	Medium	Medium

Other broader barriers exist that limit the ability to manage VMT, increase system efficiency, and shift modes, but these are not described in this table. These barriers include the relatively long lifetime of urban infrastructure, the multi-jurisdiction of transportation infrastructure ownership, the enduring patterns of land use and land development, and the imprint of historic policy decisions on the current transportation landscape. These issues are often exacerbated by perverse incentives embedded into policies and systems for the allocation of funding.

One example is the lingering effect of federal development of the Interstate Highway System. In reviewing literature on its consequences on transit, the Federal Transit Administration determined that the federal funding formula "biased transportation investments in favor of urban freeways" and "facilitated the suburbanization of households and jobs," thereby impeding transit's ability to compete with the automobile.[24]

2.2 Characteristics of the Reference Case

This section addresses a central question: how will the transportation sector develop over the coming decades absent additional policies? The project team created reference case assumptions, defined as the continuation of current trends in technology costs, vehicle availability, consumer behavior, and policies already enacted. Table 3 summarizes the high-level factors assumed in the reference case.

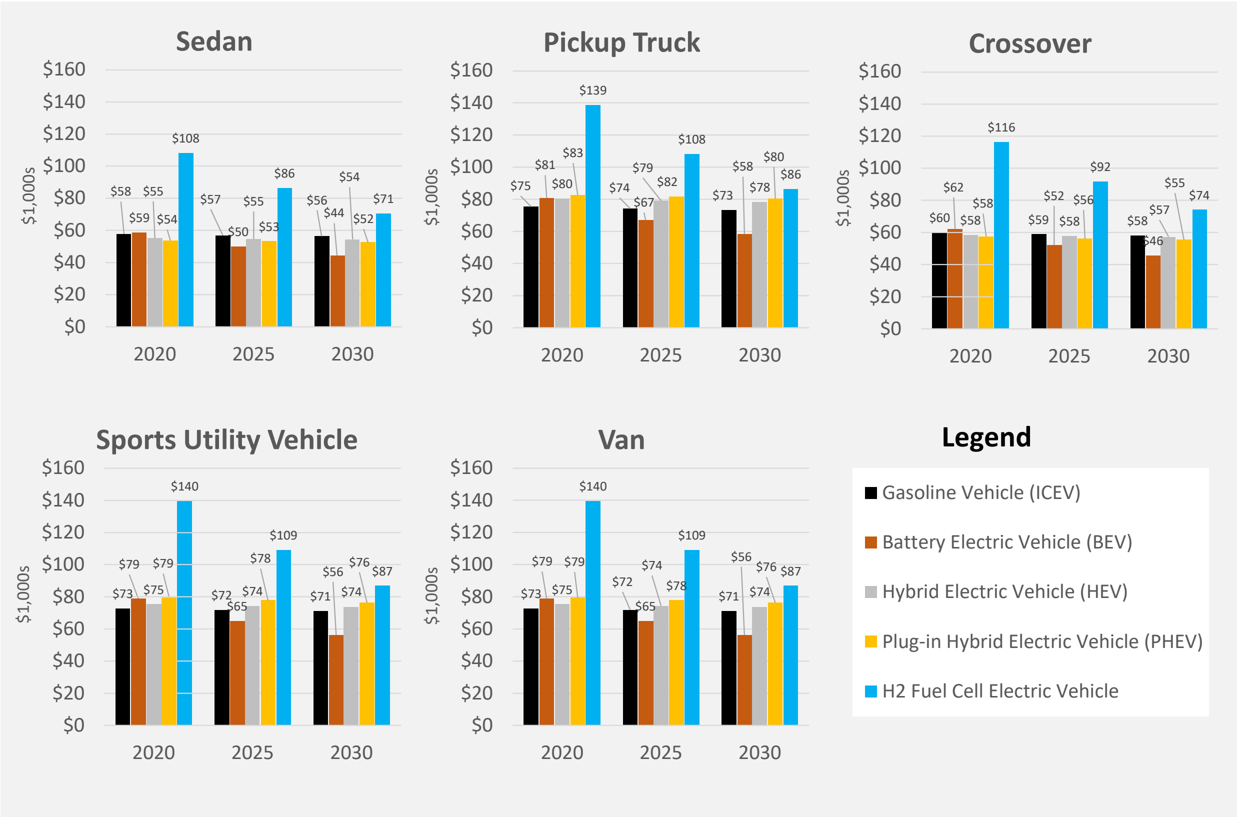
Table 3. Reference Case Characteristics

Factor	Scenario Descriptors
Socioeconomic and Lifestyle	
Urbanization/Deurbanization	• New York State does not change its level of urbanization
Economic Activity	• The global economy grows at a rate consistent with historical trends
Equity	• Equity continues to be a central social issue
Consumer, Corporate, and Institutional Behavior	• E-commerce continues to grow at a rate consistent with historical trends (as people have become accustomed to the convenience of home delivery)
Population	• Population grows according to Cornell University population growth projections
Policy and Institutions	
Federal Action	• California's Clean Air Act waiver is maintained
	• National fuel economy standards for LDVs and MHDVs return to Obama-era standards
	• The federal EV tax credit continues in its current form and is phased out as automakers reach their 200,000 vehicle limit
State Action	• New York State's vehicle and charging incentives continue at their current levels
	• The Advanced Clean Cars rules are not expanded after 2025
	• No new transportation electrification policies are introduced beyond those that already exist
Technological Change	
Mobility Options	• Shared autonomous vehicles do not gain traction
	• Micro-mobility (such as e-scooters) grows slowly over time
	• EV model availability is aligned with current automaker investments
Energy Supply and Delivery	• EV battery costs decline consistent with historical trends
	• Fuel prices stay at approximately the same levels

2.3 Market Trends in Vehicle Total Cost of Ownership

Trends in vehicle ownership and operating costs help inform the types of regulatory policy and incentives needed to transition toward EVs and FCEVs. The total cost of ownership (TCO) of vehicles includes the cost of the vehicle, fuel, maintenance, end-of-life disposal, and other vehicle-specific costs like battery replacement or home chargers.[25] Light-duty EVs are nearing cost parity with comparable ICEVs on a TCO basis, although the exact year of parity depends on the vehicle segment. Battery electric vehicles (BEVs) are expected to reach TCO parity within the next five years, while plug-in hybrid electric vehicles (PHEVs) will reach parity nearer to 2030.[26] Figure 5 shows the projected TCO of light-duty vehicles.

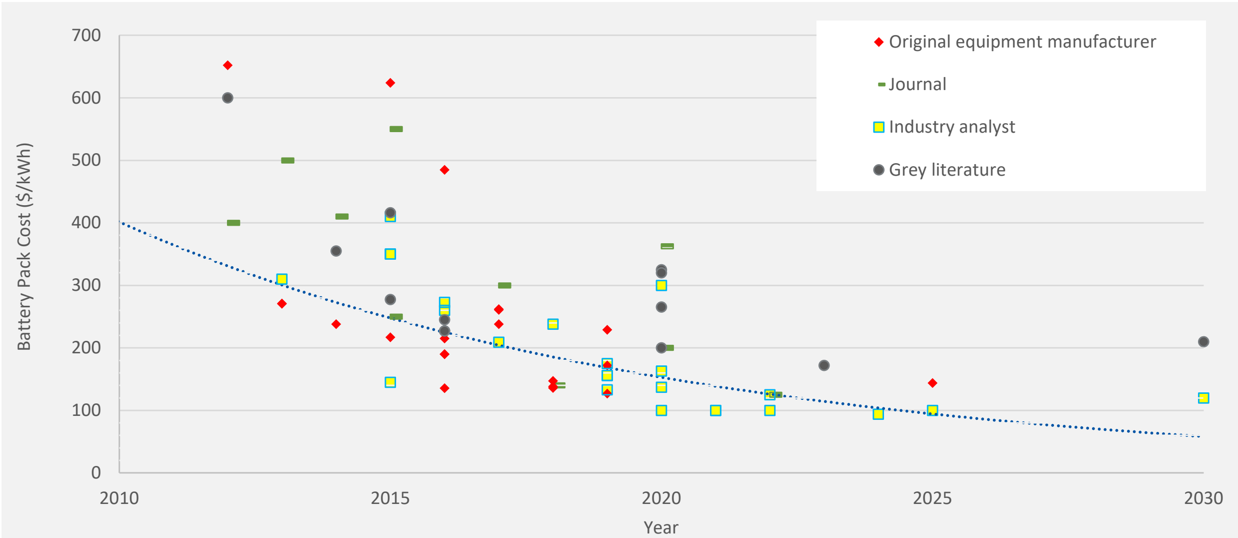
Figure 5. Projected Lifetime Total Cost of Ownership of Light-Duty ICEVs, BEVs, HEVs, PHEVs, and FCEVs ($ thousands)



Costs of EVs declined rapidly in recent years due to falling battery pack costs. Figure 6 shows a market scan of 74 cost estimates of battery packs from original equipment manufacturers, journal articles, industry analysis, and grey literature based on Kapoor et al.[27] Values from 2020 onward are projected costs while values prior to 2020 are observed costs. The cost decreases are driven by increased production volumes of the batteries and through innovation in the battery supply chain.

Light-duty FCEVs are farther from cost parity than light-duty EVs. The upfront cost of light-duty FCEVs available on the market today (three models in limited markets) is roughly twice comparable to fully electric or hybrid vehicles, due in large part to small production volumes and the need for platinum as a fuel cell catalyst.[28] Additionally, hydrogen fuel currently costs more than gasoline or diesel on a dollars-per-mile basis.[29] The higher purchase price and fuel costs means a higher TCO for FCEVs than for ICEVs and EVs in all LDV categories in future years, but future technological breakthroughs could change this. Absent a significant investment in hydrogen fueling infrastructure under the reference case, no significant adoption of FCEVs is projected in the State's LDV market.

Figure 6. Battery Pack Costs from 74 Independent Estimates



As with electric LDVs, the costs of electric MHDVs are declining yet remain more expensive than comparable diesel and gasoline vehicles on a TCO basis for most vehicles. Key challenges are battery costs (MHDVs require much larger batteries than LDVs) and installation costs of charging infrastructure (many MHDVs require charging speeds above 50 kilowatts). Additionally, TCO of MHDV is highly dependent on electricity costs and the associated demand charges; these vary widely throughout New York State, with upstate regions far cheaper than downstate. Note that certain vehicle categories, such as parcel delivery trucks, can have similar TCO as conventional counterparts even today because they have high daily miles, fixed routes, slow charging speed required, and the ability to charge overnight.

The upfront cost for medium- and heavy-duty FCEVs is also higher than available alternatives, and these models are in limited supply. Deloitte reports that FCEV buses in the U.S. cost approximately $1,000,000, compared to $700,000 for electric buses and $470,000 for ICEV buses. The fuel cell system and the hydrogen tanks account for most of the FCEV bus incremental costs.

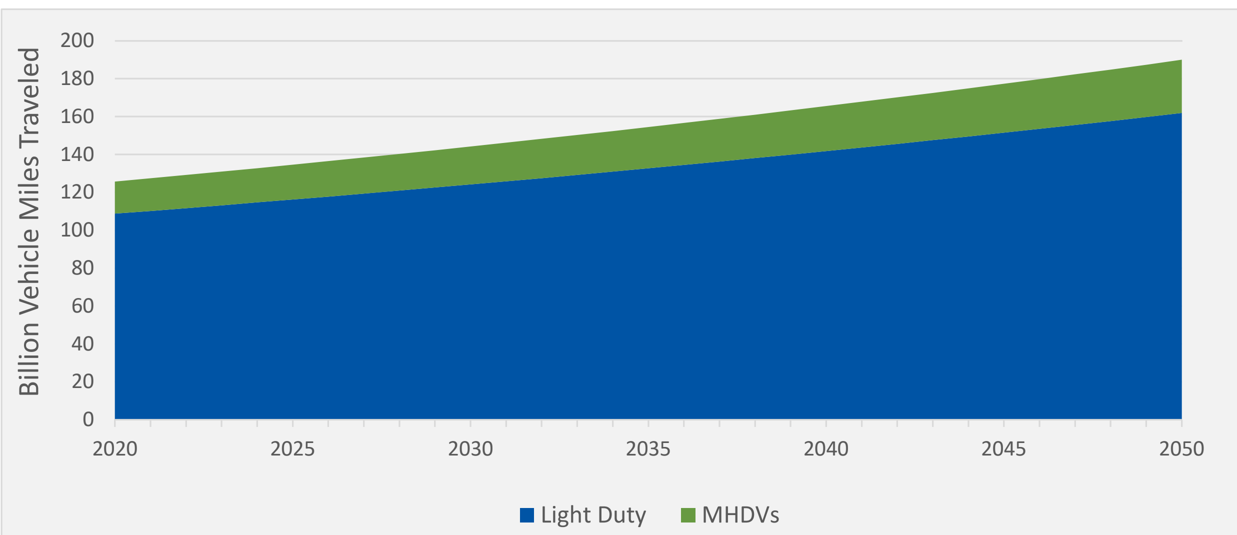
Many fleet operators are constrained in their capital budgets, which means they often acquire the vehicle that has the lowest upfront cost. Furthermore, these vehicles are not anticipated to be suitable for the full array of use cases in the MHDV subsector, especially for those with high daily mileage requirements, heavy payloads that necessitate a more energy dense fuel than battery electricity, or minimal downtime for charging. As a result, large numbers of electric MHDVs are not expected in the near term without public-sector incentives for both the vehicle and charging cost.

Currently, EV penetrations are low, so the incremental cost to the electric transmission and distribution system to serve vehicle loads is minimal from a system perspective but can be significant on a site-by-site basis. As more EVs are adopted, however, EV charging that coincides with the system peak as well as that exceeds the capacities of the local distribution system or building-level services will necessitate investments to expand and enhance infrastructure to accommodate this demand. Typically, these additional system investments are reflected in electricity rates or charges to the end users responsible for the needed system upgrades. Potential distribution system impacts are discussed in section 6.6.

2.4 Reference Case Vehicle Miles Traveled Projections

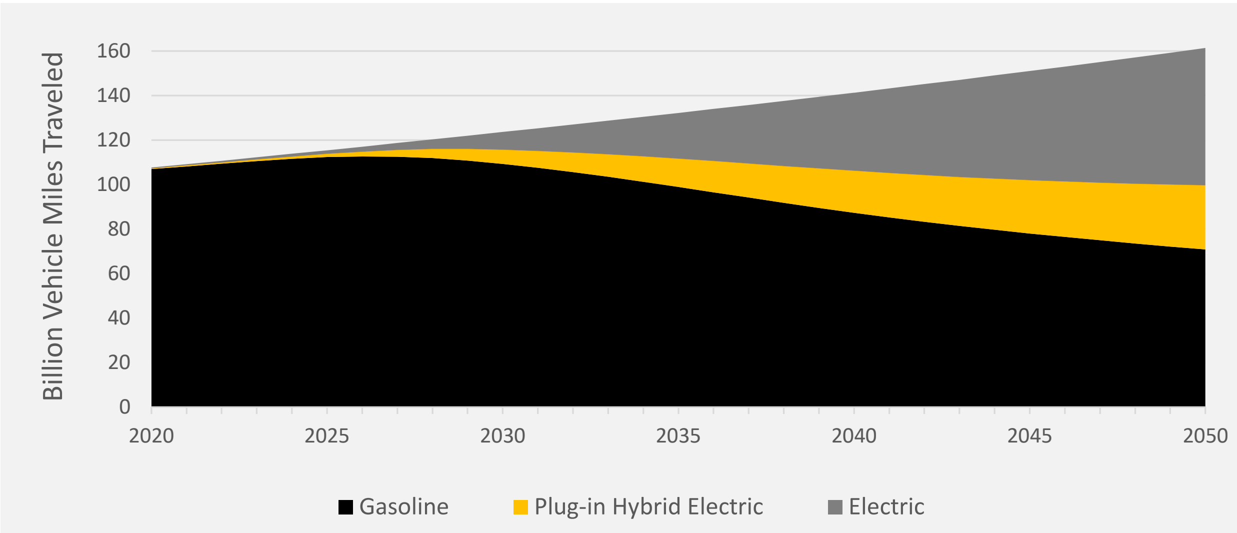
Overall, on-road vehicle miles are projected to increase by an average of 1.29% per year, as illustrated in Figure 7. LDV VMT, which is projected to grow at an average rate of 1.33 per year through 2050, accounts for most of this growth because LDVs are responsible for the vast majority of on-road miles. This growing trend is proportional to projected shifts in population and income. The average population across all counties is projected to grow annually by 0.24% from 2018 to 2050, while the per-capita income across all households is projected to grow annually by 1.4% over those same years.

Figure 7. On-Road Vehicle Miles Traveled Projections (Reference Case)



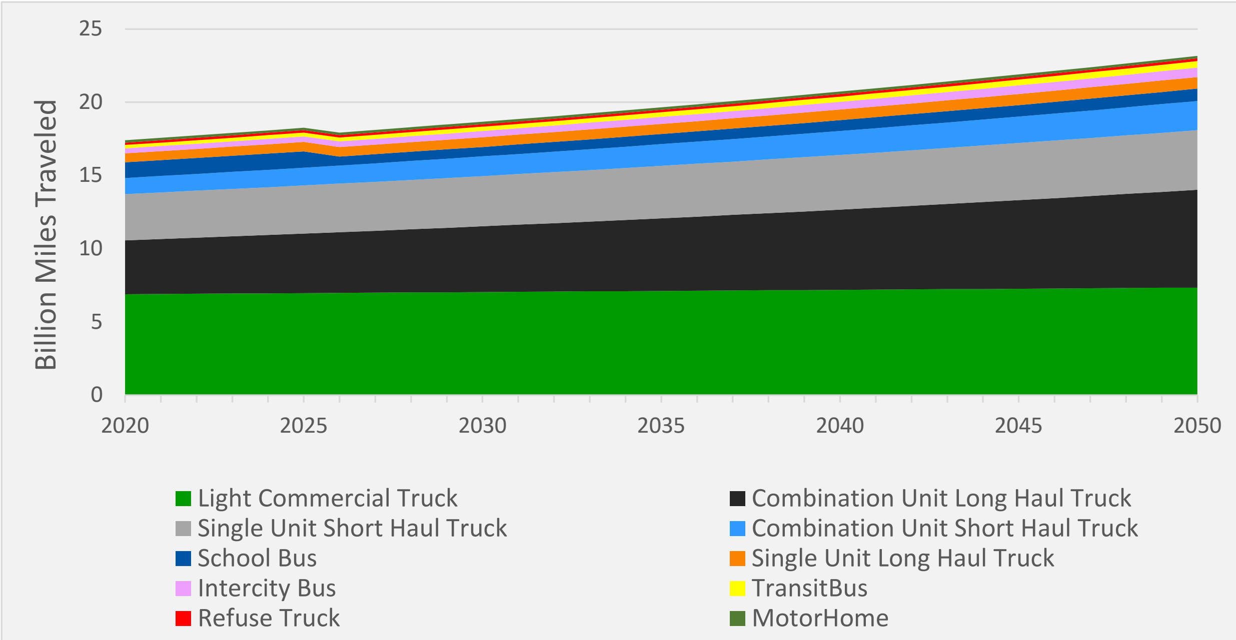
With no additional policy actions, there is no significant shift in the share of transportation modes projected for the reference case. An increase in EV sales share simply means that these vehicles comprise a growing proportion of the total vehicle stock and, consequently, are responsible for an increasing share of VMT over the coming decades (Figure 8). The reference case does not include large quantities of hydrogen FCEVs, biodiesel-powered vehicles, and HEVs.

Figure 8. Total Miles Traveled Annually by Light-Duty Vehicles (Reference Case)



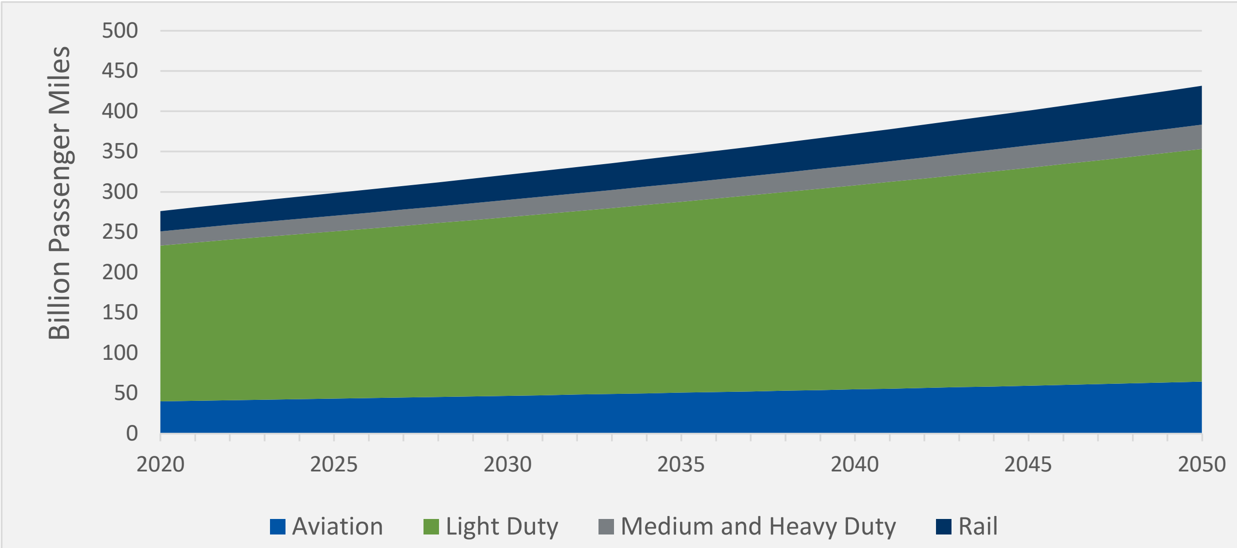
Likewise, in the reference case, MHDV VMT is projected to grow by 1.1% per year through 2050. This growing trend is driven by a combination of increasing population, increasing real income, and an increasing demand for freight. Notably, the commercial light truck and heavy-duty truck subsectors are anticipated to experience the highest growth in annual VMT, whereas refuse trucks, motor homes, and single-unit, long-haul trucks are expected to exhibit more moderate growth (as shown in Figure 9.)

Figure 9. Total Miles Traveled Annually by Medium- to Heavy-Duty Vehicles (Reference Case)



Aviation and rail are also likely to expand in the future. Under the reference case, in which no new policies are introduced, total passenger miles will be 47% higher in 2050 than they were in 2020.[30] The principal cause for this growth is the increase in LDV miles, though aviation passenger miles—which grow by an assumed 1.6% per year—also make a sizable contribution. Under the reference case, transit ridership (indicated by the Medium and Heavy-Duty category in Figure 10) and rail ridership increased by an assumed 0.91% each year from 2020 levels.

Figure 10. Total Passenger Miles Traveled Annually across All Modes (Reference Case)



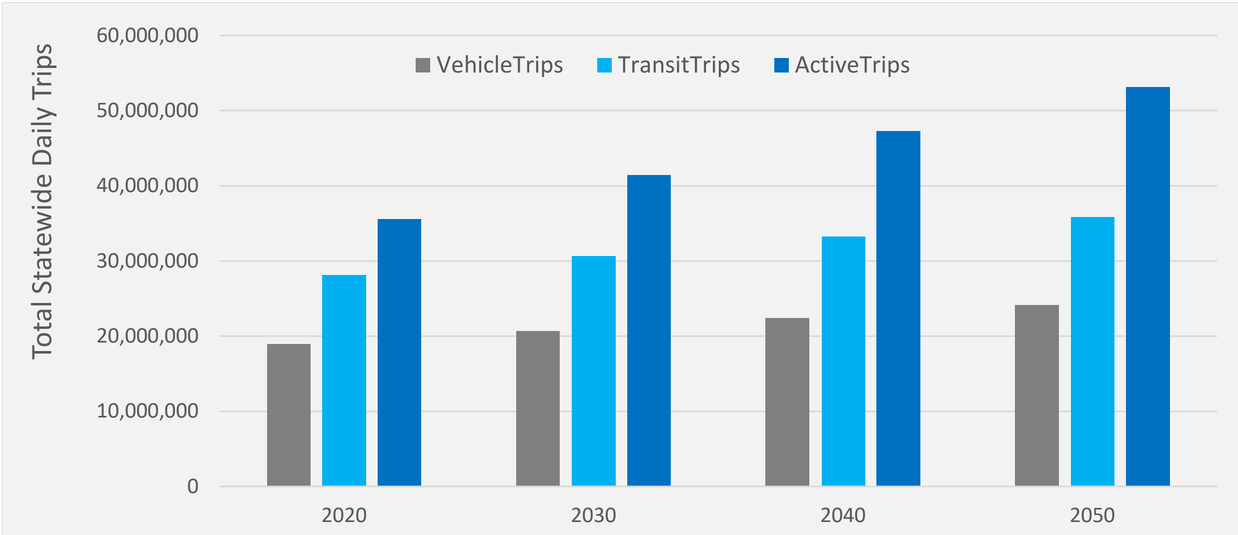
2.5 Reference Case Mode Share Projections

As shown in Figure 11, the share of total trips shifts toward walk and bike trips (active trips) and away from transit and vehicle trips in the reference case (note that the figure does not include aviation, rail, or ferry passenger trips). A trip is defined as a journey between an origin and destination with a singular purpose. Thus, an increase in multimodal travel increases the total number of trips. In the reference case, the share of active trips increases by 4% by 2050, while the shares of trips by vehicles and transit declines by 2% each.

Mode share is driven primarily by future household income levels and the relative costs of the various modes. The modeling in this Roadmap assumes income levels in urban areas grow faster than incomes in rural areas, resulting in a shift toward active trips (which are more common in urban areas).

Furthermore, the total number of daily trips statewide increases by 27% between 2020 and 2050, driven in large part by the increase in active trips.

Figure 11. Total Daily Active, Transit, and Vehicle Trips (Reference Case)



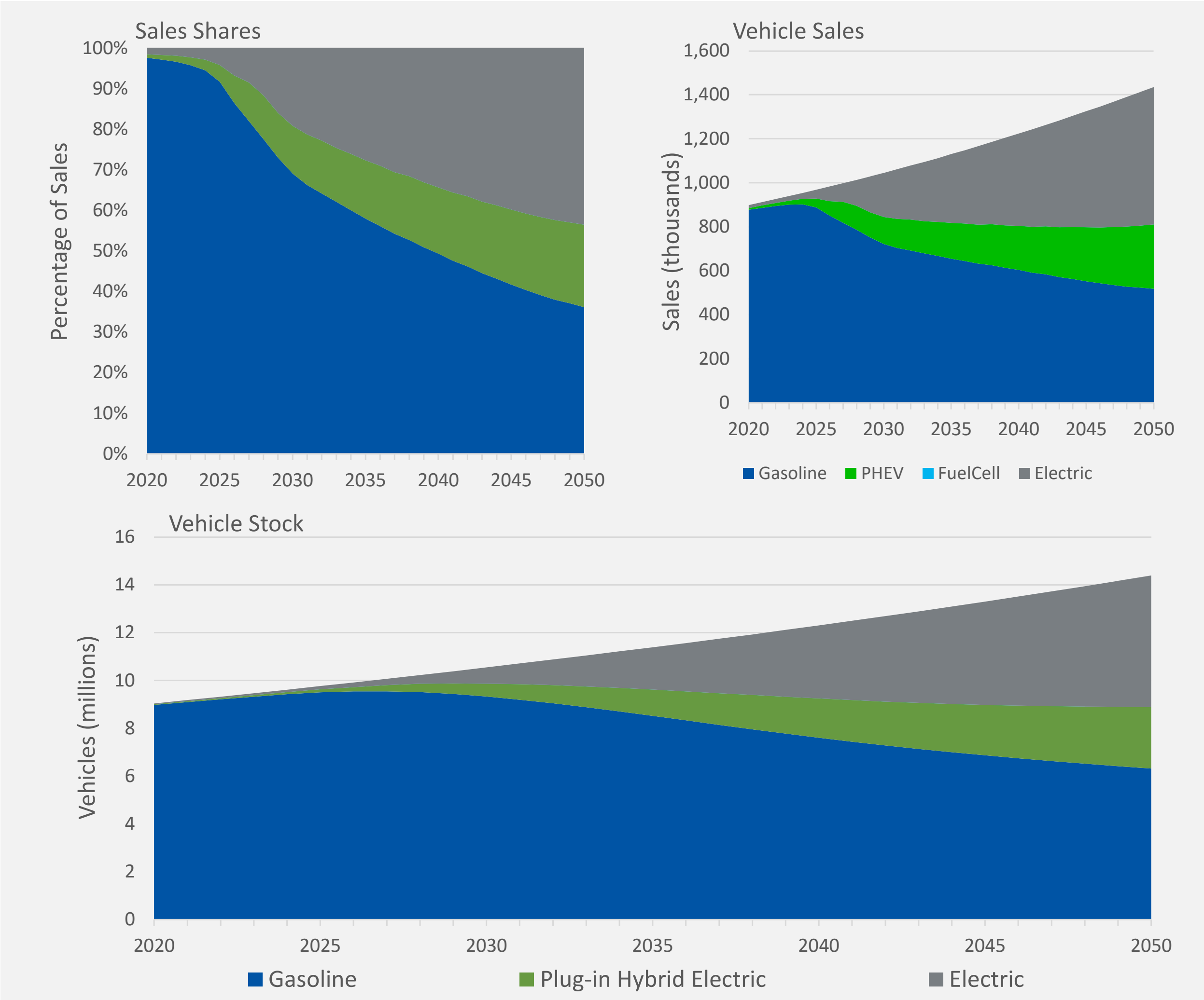
2.6 Reference Case Technology Mix and Infrastructure Projections

Figure 12 depicts the reference case projections for LDV market share (upper left), sales (upper right), and vehicle stock (bottom) by vehicle type. As discussed in the section Market Trends in Vehicle Total Cost of Ownership, light-duty EVs are projected to reach cost parity with ICEVs within this decade. However, constraints in charging access, limited public charging availability, long charge times, and range anxiety all contribute to the persistence of ICEV sales in the reference case. Assuming no new policies are introduced, a full phase-out of ICEVs will not materialize for decades beyond 2050.

EVs are projected to account for 14% of new LDVs purchased in 2025, rising to 32% in 2030, 51% in 2040, and 64% in 2050. EVs are projected to represent 54% of the LDV stock in 2050. The EV market is projected to remain divided between BEVs and PHEVs over time, with the ratio of BEVs to PHEVs rising from about 1:1 in 2020 to over 2:1 in 2050. The hybrid EV market share is expected to peak at 1.7% in 2039, as buyers who might choose a hybrid EV are diverted toward BEVs and PHEVs.

EV sales will grow rapidly between 2020 and 2025 due in large part to the existing Advanced Clean Cars rules (also known as the California ZEV regulations) that require automakers to increase ZEV sales. Though the current Advanced Clean Car rules expire in 2025, the reference case suggests that EV sales will continue to increase moderately absent further regulations due to factors including decreasing battery costs, increasing EV model availability, and increasing charging availability.

Figure 12. Projections for Light-Duty Vehicles by Fuel Type (Reference Case)



In the reference case, medium- and heavy-duty EVs account for 2.7% of MHDV sales in 2025 and increase to 28% of MHDV sales in 2050. Additionally, the vehicle population grows at rates ranging from 0.2% year-over-year for motorhomes, refuse trucks, and light-commercial trucks to 2.4% for transit and intercity buses and for combination unit trucks. The resulting vehicle stock is expected to increase, as shown in Figure 13.

Figure 13. Medium- to Heavy-Duty Vehicle Stock by Vehicle Type (top) and Fuel Type (bottom) (Reference Case)

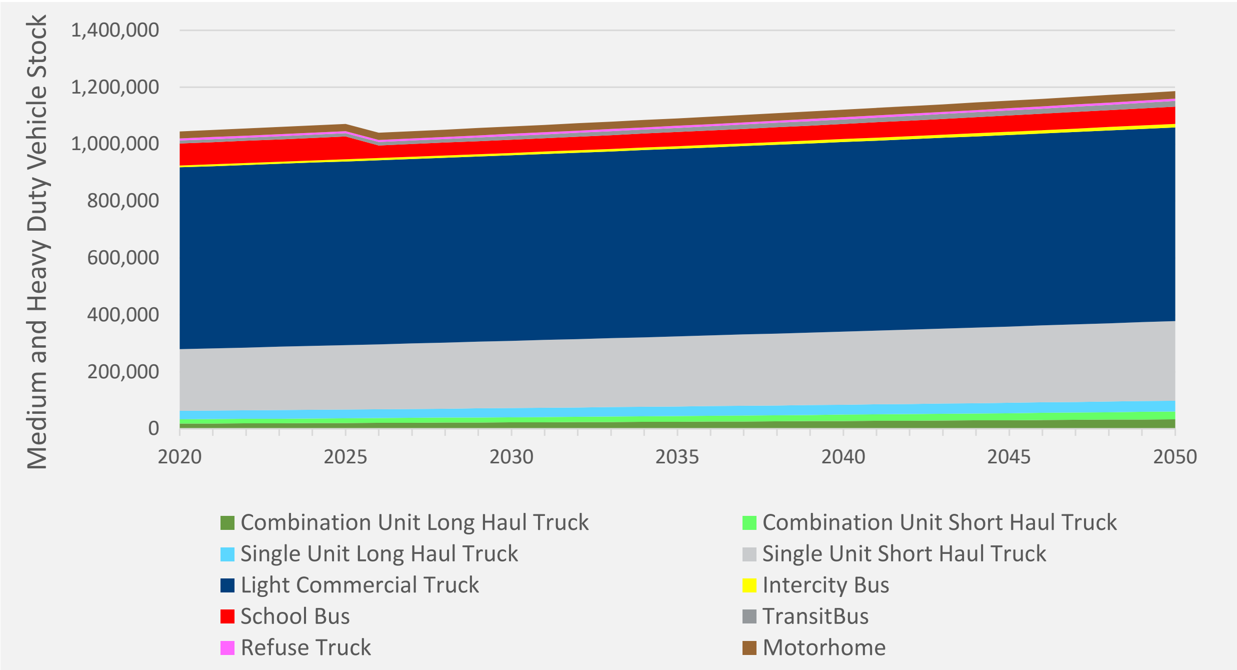
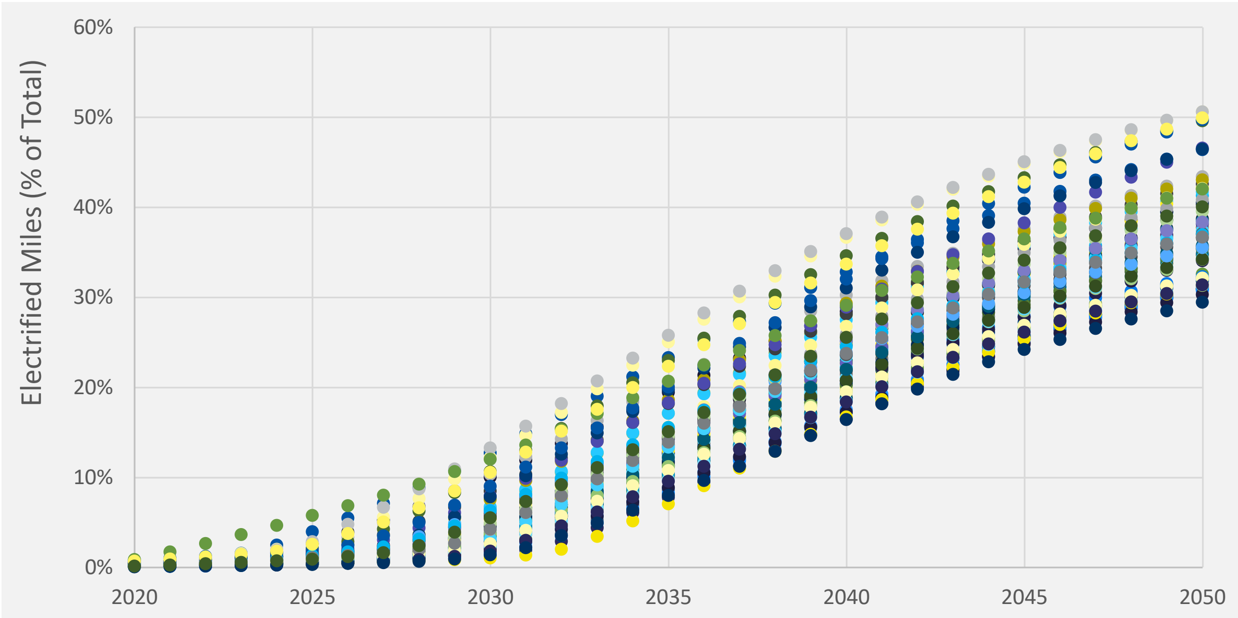


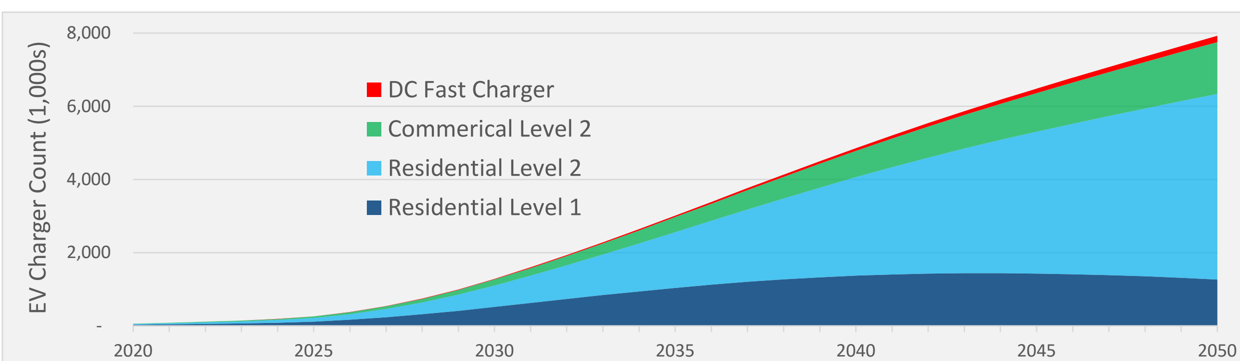
Figure 14 shows the share of electrified miles (including LDVs and MHDVs) in the reference case by county. Each dot in the figure is a separate county. The figure highlights how counties will differ in their uptake of EVs and the resulting level of electrified miles, with the top counties reaching about 50% and the bottom counties reaching about 30% in 2050.

Figure 14. Reference Case Share of Electrified Miles, by County



The number of charging plugs needed to support New York State's EV population is another important consideration for the development of public policy incentives and goals. The project team projected charging infrastructure for the reference case vehicle population using assumptions about the number and utilization of chargers of four typologies: residential Level 1, residential Level 2, commercial Level 2 (comprising workplace Level 2, fleet chargers, and public/commercial Level 2), and public direct-current fast charging (DCFC) equipment (Figure 15). MHDV chargers are not shown in this figure.

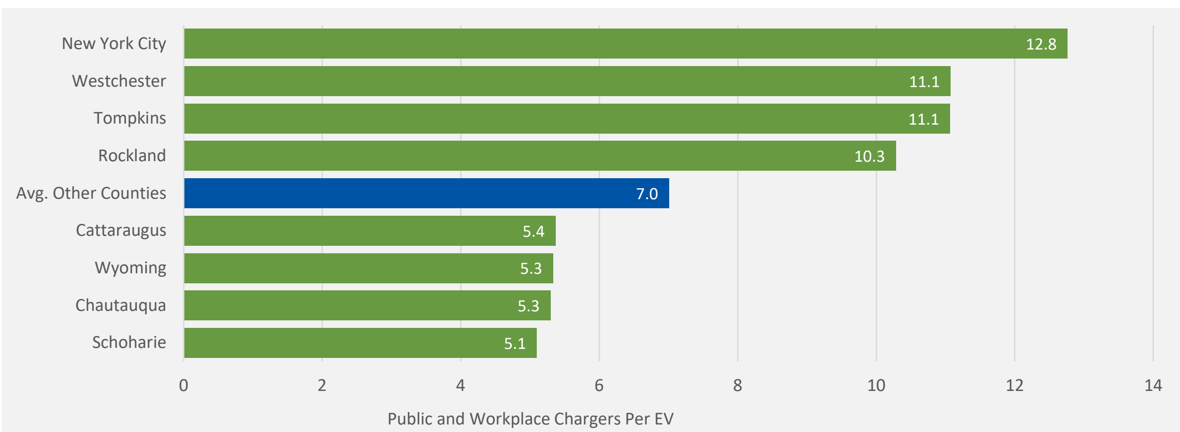
Figure 15. Reference Case Electric Vehicle Charger Counts for Light-Duty Chargers



Overall, residential Level 1 and residential Level 2 chargers will comprise an estimated 80% of all plugs in 2050, with approximately 1.5 million workplace Level 2, public Level 2, and DCFC plugs. These projections were customized for New York State based on detailed data of the State housing stock, VMT, existing charging infrastructure, and assumptions about charger use, power levels, and session times.

Figure 16 depicts the projected number of public and workplace chargers per 100 EVs by county for the highest, lowest, and average counties in 2050. Differences in the expected numbers of chargers per EV are primarily due to differences in the share of vehicle buyers with access to home charging. For example, in counties with a higher population density (such as the counties in New York City), the projected number of public chargers per EV is higher to serve the relatively large share of EV owners without access to home charging. For the average county in New York State in 2050—depicted by the blue bar—the projected ratio is seven public chargers per 100 EVs.

Figure 16. Projected Public and Workplace Chargers Per 100 Electric Vehicles by County in 2050

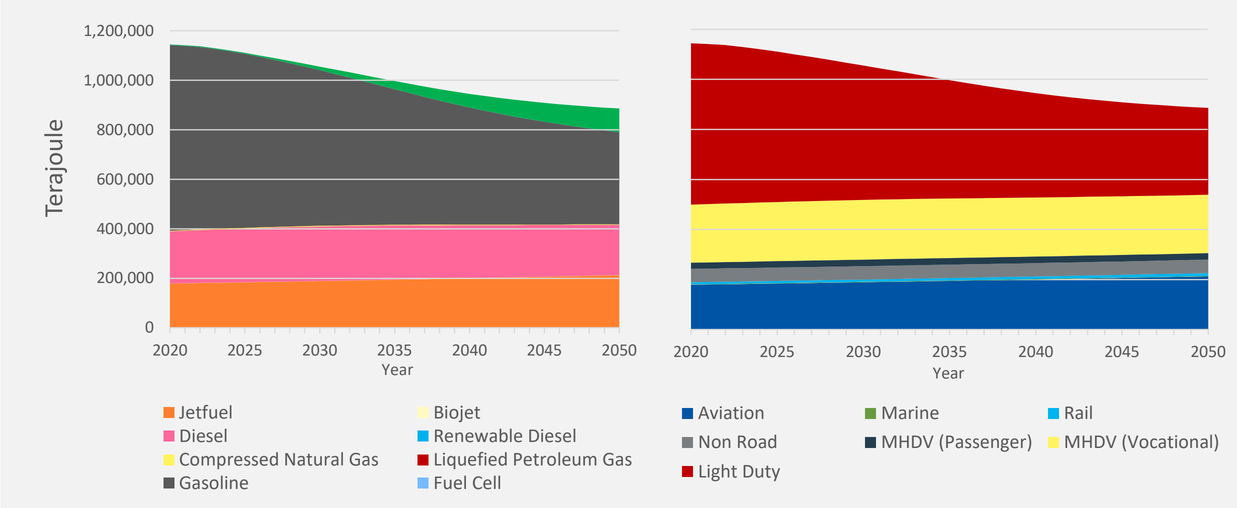


Note: Public and workplace chargers include public Level 2, workplace Level 2, and public DCFC. The figure includes counties with public-charger-per-EV rates in the upper and lower extremes. The blue bar reflects the average of the remaining counties, which varied little in their projected rates of public chargers per EV.

2.7 Reference Case Final Energy Demand

The energy profile of the reference case—illustrated in Figure 17 is driven by multiple changing factors, including improving vehicle fuel efficiency, increasing VMT, and increasing transportation electrification. Overall, the final energy demand is expected to decline at an annually compounding rate of 1.03% per year. The largest reductions in energy use occur in LDVs, and the largest increases occur in aviation.

Figure 17. Final Energy Demand by Fuel Type (left) and Subsector (right) (Reference Case)



The trend of declining energy demand will happen in spite of the increased VMT described above. A key reason is the efficiency gains anticipated across all powertrain and fuel combinations in both the LDV and MHDV subsectors. Figure 18 and Figure 19 illustrate how, for a particular vehicle type (such as gasoline-powered vehicles in the LDV category or transit buses in the MHDV category), average real-world fuel economy rises over the decades.

Total energy demand is further dampened by substantial fuel switching from ICEVs to EVs in the LDV subsector. Such fuel switching equates to significant energy demand reductions due to the efficiency differentials between powertrains. For example, in 2025, the average real-world fuel economy of a gasoline vehicle is estimated to be 25 miles per gallon gasoline equivalent (MPGGe); for a full BEV in that same year, it is estimated to be 101 MPGGe. These two types of efficiency gains—fuel switching and fuel economy—outpace the projected increases in VMT and result in moderate overall reductions in total energy demand.

Figure 18. Real-World Average Fuel Economy of Light-Duty Vehicles

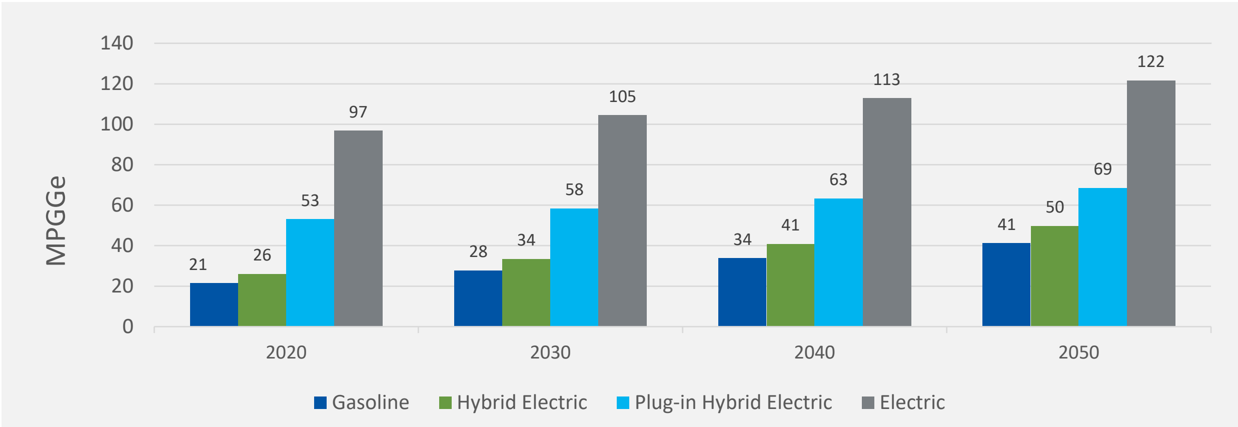
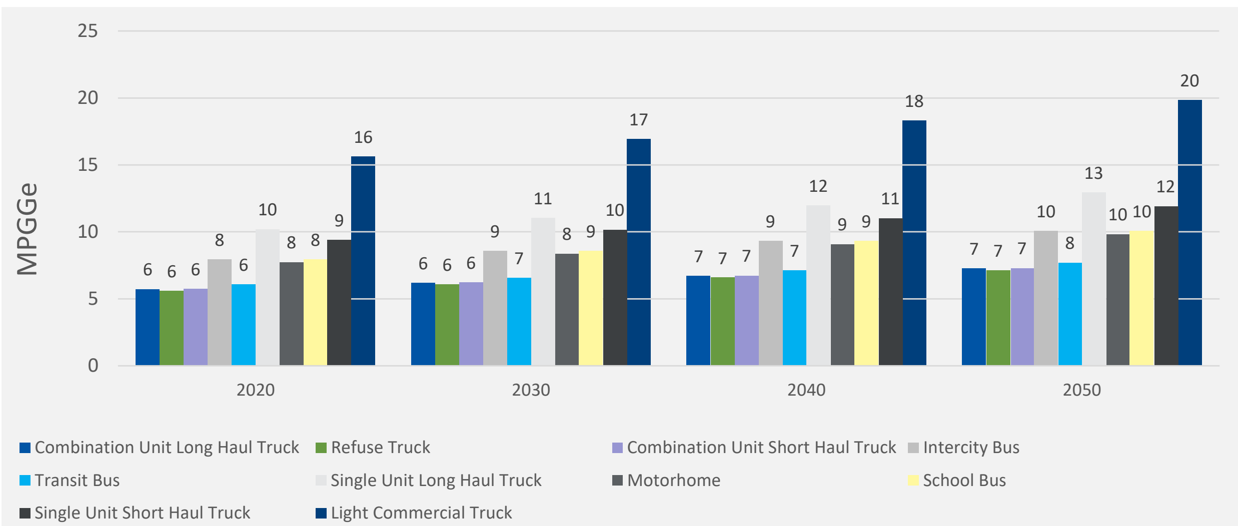


Figure 19. Real-World Average Fuel Economy of Diesel Medium- to Heavy-Duty Vehicles



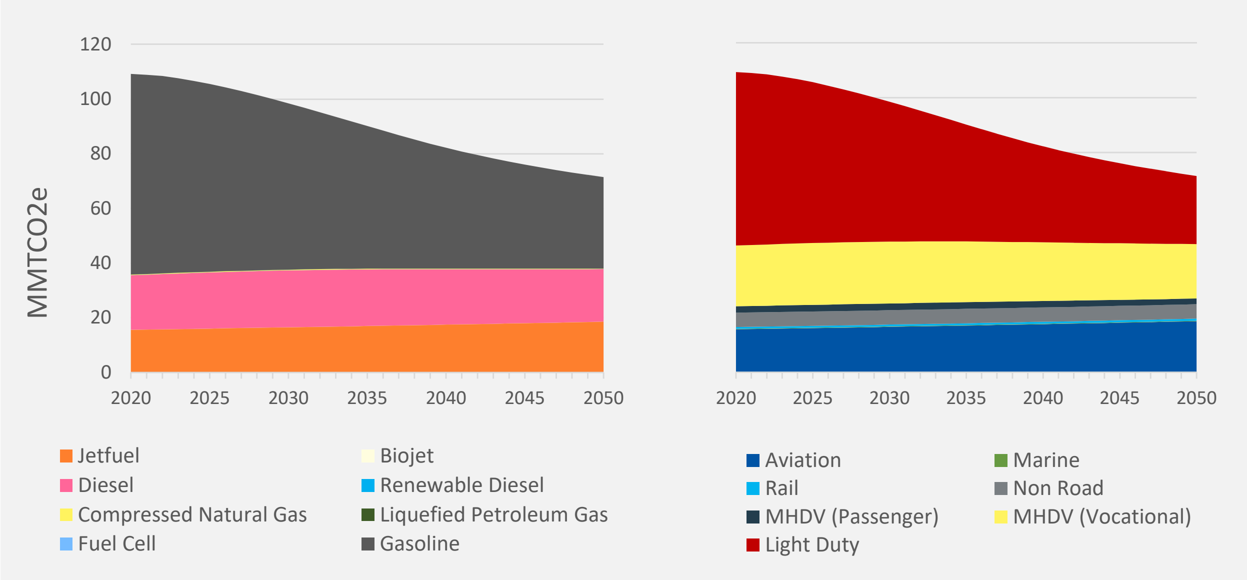
2.8 Reference Case Greenhouse Gas Emissions

Transportation GHG emissions decline by 1.5% per year between 2020 and 2050. The primary drivers of these GHG reductions mirror the drivers of final energy demand: improving vehicle efficiency, increased VMT, and increased transportation electrification.

Use of biofuels does not change appreciably in the reference case since current State and federal policy does not encourage biofuels sufficiently for them to gain notable market share. Even if new policies did make biofuels more attractive, they would not be a source of significant GHG emission reductions in the transportation sector based on New York State's Climate Act accounting (see callout box). Similarly, in accordance with the accounting methods embedded in New York State's Climate Act, all EV-related GHG emissions are attributed to the electricity sector. When looking at the transportation sector in isolation, this means replacing an ICEV with an EV is effectively the same as removing the ICEV from the road.

As shown in Figure 20, emissions decrease in the reference case between 2020 and 2050. These reductions are driven primarily by the LDV subsector, which slowly electrifies and increases in vehicle and system efficiency over time. Other sectors are relatively flat as the increased service demand is offset by increases in vehicle and system efficiency. Despite these substantial reductions in emissions, the projected level of annual statewide GHG emissions in 2050 in the reference case is 71.45 MMTCO2e, only 28.5% below the 99.95 MMTCO2e in 1990.

Figure 20. Greenhouse Gas Emissions by Fuel Type (left) and Subsector (right) (Reference Case)



2.9 Modeling Uncertainties

The projections for technology adoption, emissions, and energy use presented above are the results of a series of modeling frameworks and inputs. It is important to keep in mind that all future projections are uncertain and are driven by the underlying modeling decisions and model structure. Therefore, the themes and impacts across the mitigation scenarios can be more helpful than the exact numbers themselves.

Two key drivers of results in the reference case are the assumed income growth and the treatment of New York City travel demand growth. As noted above, per-capita personal income is assumed to grow exponentially at a statewide level of 1.4% per year in inflation-adjusted dollars, though this growth varies at the county level. Income growth rates used in the modeling are based on 50 years of historical data between 1969 and 2019. At the county level, income growth rates for this same 50-year period ranged from a low of 0.78% per year to a high of 2.58% per year in inflation-adjusted dollars.

However, if the modeling were to use linear growth rates instead of exponential growth rates, expected income in 2050 would be lower in 51 of the 62 counties in New York State. The most dramatic example is Manhattan, which has 60% lower household income in 2050 when using linear versus exponential growth. At an aggregate level, if the modeling used a linear growth rate instead of an exponential growth rate, the weighted statewide income would be 27% lower by 2050. Modeling of this alternative scenario shows that linear income growth rates result in a statewide on-road VMT 13% lower in 2050 compared to the exponential income growth rates used in this Roadmap, which would result in a significant difference in emissions and energy use and would impact the degree of difficulty in meeting Climate Act goals.

A second uncertainty in the modeling results is the treatment of the New York City metropolitan area, which accounts for approximately 60% of the State's population. Since New York City is unique in the United States in the travel preferences of its residents and in the physical characteristics and constraints of its urban form, a special-built model for New York City would likely improve the accuracy of GHG projections in this Roadmap. In particular, the travel demand model used in this Roadmap—the VE-State model—is based on travel behavior of the United States that does not constrain growth in travel demand because of traffic congestion or represent travel preferences similar to those seen in New York City. Again, this likely impacts Manhattan the most among all counties because of its density. It was not possible to manually correct for this in this modeling exercise, thus, VMT and emissions from the New York City metro area are probably overstated for the reference case and subsequent mitigation cases.

3 Decarbonization Policies and Mitigation Cases

GHG emissions are expected to decrease steadily through 2050 in the transportation sector under the reference case, but in the absence of additional State policy these reductions fall short of meeting the goals set in the Climate Act. Though New York State has already invested in significant actions to achieve its current trajectory, additional policies are needed to achieve the State's ambitious 2030 and 2050 GHG emission reduction goals for the transportation sector. These policy options are discussed in the following sections.

3.1 Policies for Transportation Decarbonization

Many policies and programs (herein referred to as policies) can promote transportation decarbonization. This Roadmap began with a comprehensive process to identify available policy levers available to New York State. The project team then selected a set of high-priority policies based on screening criteria. These high-priority policies are scenarios that are modeled using various policy combinations and magnitudes in each mitigation case.

3.1.1 Policy Identification and Selection

Based on literature review and case studies, the project team developed an inventory of over 90 policies that could reduce emissions from the transportation sector in New York State. More than two dozen State government staff, industry experts, and invited stakeholders helped narrow this inventory to a select set of high-priority policies using a weighted, multi-criteria scoring system. The full inventory and policy descriptions are provided in the next section.

3.1.2 High-Priority Policies for Transportation Decarbonization in New York State

This section summarizes the high-priority policies selected and characterizes each along three dimensions:

- Demonstrated effectiveness of the policy at reducing GHG emissions.
- Financial and economic implications of the policy to the State.
- Projected social equity and public health effects.

Table 4 lists the high-priority policies selected for the Roadmap. The following sections present qualitative characterizations for each according to these three dimensions.

Table 4. High-Priority Policies and Characterizations on Key Impact Categories

Policy
Carbon pricing
Clean Fuel Standard
Vehicle and equipment adoption standards
Vehicle purchase incentives*
Charging and fueling infrastructure investment
Utility rate design
Smart Growth incentives
Complete Street policies
Increased shared mobility services
Vehicle-Miles Traveled (VMT) fees**
Congestion pricing**
Employer Telework and Transportation Demand Management (TDM) programs
Outreach and Education

* Including feebates

** Impact is dependent upon fee amount

3.1.2.1 Carbon Pricing

Carbon pricing policies provide a long-term economic signal to consumers and investors to shift away from fossil fuels by pricing a fuel's carbon emissions. New York State already participates in the Regional Greenhouse Gas Initiative (RGGI), a cap-and-invest program in the electric power sector, but there is no similar program for the transportation sector in the State at this time.[31] A carbon price can be applied broadly across technologies, economic sectors, or geographic areas, allowing emission reductions to be achieved wherever least-cost opportunities exist.

Adopting a carbon price, results in higher prices for high-carbon fuels, such as gasoline and diesel, and encourages a transition to ZEVs and other modes of transit that are less carbon-intensive, like public transit. Travel demand is relatively inelastic to gasoline price fluctuations; raising fuel prices through carbon pricing can be expected to generate only moderate GHG reductions by discouraging discretionary vehicle travel.[32,33] A carbon price facilitates cost-effective GHG reductions either by establishing markets that enable trading of emissions allowances between regulated entities or by pricing emissions at the social marginal cost of the pollutant. Administrative costs can be relatively low and can be shared across jurisdictions where systems are integrated. Furthermore, a carbon pricing policy typically generates proceeds that can be returned to affected parties as a dividend or invested into projects that further policy objectives.

Environmental justice advocates note that a carbon price may not result in pollution reductions in areas that are already vulnerable or have historically had high levels of pollution.[34] Additionally, the impacts of carbon pricing policies on consumers can be regressive, with greater impacts on disadvantaged communities that already face higher energy burdens. To address equity concerns, the investment of carbon price proceeds and associated benefits can be directed toward disadvantaged communities, as is required under New York State's Climate Act, which allots at least 35% of spending to benefit disadvantaged communities.[35]

Case Study: Oregon's Clean Fuels Program

Oregon's Clean Fuels Program (CFP) set a carbon intensity target of 10% below 2015 levels by 2025.[36] In 2020, an executive order by Governor Kate Brown directed DEQ to develop rules to extend the CFP to 2035 and target 25% below 2015 levels, making the CFP goals the highest in the nation.[37] By the third quarter of 2020, the CFP had reduced GHG emissions from the Oregon transportation sector by about 5 MMT CO_2e below the 2015 level. About 50% of the low carbon credits within the market were from ethanol, 40% from biomass-based diesels (biodiesel or renewable diesel), and 6% from electricity. Through 2019, the CFP has had minimal impact on retail prices (under three cents for E10 and B5), though this may change as the reduction targets increase.[38]

Like New York State, Oregon imports 100% of its petroleum. Alternative fuel use, increased investment in infrastructure, and novel technologies all reduce the state's reliance on imported petroleum. By setting long-term 25-year goals, credits are generated and banked for the future, which is expected to increase investments today. This longer period encourages utilities and the private sector to invest in low-carbon fuels and infrastructure such as renewable natural gas and diesel, biofuels, and EV charging infrastructure.

3.1.2.2 Clean Fuel Standard

A clean fuel standard regulates the carbon emission intensity of transportation fuels, setting a target that declines over time compared to current levels. Each fuel distributor must meet the average emissions intensity target through the sale of less carbon-intensive fuels, such as electricity, advanced biofuels, renewable natural gas, and green hydrogen, or through the purchase of credits from other entities that have generated these credits through their own sales of low-carbon fuels.

A clean fuel standard may be especially effective at supporting decarbonization of heavy-duty vehicles (HDVs) because the HDV sector will continue to be reliant on liquid fuels well into the future, even under aggressive electrification scenarios. A clean fuel standard that generates investment in low-carbon fuels and infrastructure will encourage the development of markets and supply chains for low-carbon fuel products to meet this need.[39]

Similar to a carbon price, a clean fuel standard requires a relatively moderate allocation of administrative resources to administer the policy. Unlike a carbon price, clean fuel standards do not create a fund that can be re-invested. Instead, they generate proceeds for fuel providers to invest in expanding low-carbon fuels, which can further bring down costs to consumers for using those fuels. For example, establishment of a clean fuel standard could generate proceeds for electric utilities in the State, and sales of these credits could reduce additional costs needed to finance utility-sponsored EV rebates, EV charging stations, or other low-carbon investments.

A clean fuel standard policy can result in improved health outcomes when low-carbon fuels encouraged by a clean fuel standard emit fewer harmful local air pollutants. At the same time, the burden of increased fuel prices may disproportionately fall on low-income drivers and small, independent truck drivers and operators who may have less efficient vehicles and be less able to afford alternatively fueled vehicles.[40] To mitigate this impact, fuel price increases can be limited by caps on the price of clean fuel standard credits, as is done in California's Low Carbon Fuel Standard program. Also in California, utilities are required to invest proceeds from the sale of certain credits in projects that support transportation electrification in California's disadvantaged and low-income communities. In addition, vehicle purchase incentive programs can address equity considerations through program design. For example, California's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) provides vehicles domiciled in disadvantaged communities (DACs) an increased incentive of 10%.

3.1.2.3 Vehicle and Equipment Adoption Standards

Vehicle and equipment adoption standards establish mandatory requirements or nonbinding guidance to increase the sales of zero-emission vehicles over time. Section 177 of the Clean Air Act permits other states to adopt California standards. In 1993, New York State adopted the California ZEV Program.[41]

The ZEV Program provides a long-term market signal and threat of penalty for noncompliance to encourage fuel switching toward ZEVs. Regulators in California are currently undertaking the process to establish standards for post-2025 LDV models that would target 100% ZEV sales for new passenger cars and light trucks by 2035. New York State established goals through legislation in September 2021 targeting 100% ZEV sales by 2035 for new LDV and new MHDV by 2045, and in December 2021 New York State Department of Environmental Conservation adopted California's Advanced Clean Trucks (ACT) rule, which establishes increasing MHDV ZEV sales by model year and vehicle type from 2025 to 2035 and continuing beyond.[42] Additionally, in September 2021, Governor Hochul announced a target of 100% ZEV sales for new off-road vehicles by 2035.

These policies have limited short-term impact on GHG emissions, but the resulting increase in ZEV market share can significantly reduce transportation-related emissions in the long run as standards tighten and the vehicles in the State turn over. Given that ZEV Program compliance is not guaranteed (manufacturers can opt to pay a fine instead of earning program credits), complementary policies such as additional investment in incentives, charging infrastructure, and education and awareness may be needed to support the mandate. Though sales mandates like those implemented through the ZEV program are not costly to administer (the costs are comparable to those of administering the current ZEV Program policies through 2025), the cost for implementing these supporting policies should be considered as well. Furthermore, State regulatory authority does not extend to all parts of the transportation sector (e.g., aviation, marine, rail, small off-road engines) and additional approaches will be necessary.

Vehicle and equipment adoption standards, such as those implemented through the Advanced Clean Cars and Advanced Clean Trucks, primarily affect model availability and purchase choices of new vehicle buyers. Many low-income drivers do not buy new cars, so the direct impact on many of these drivers is delayed. Disadvantaged communities will benefit from these standards insofar as they affect air pollution levels and reduce the amount that consumers spend on transportation fuels, but distributional impacts of ZEV mandates have not been widely studied.

Case Study: TNC Electrification

In 2020, Uber and Lyft, the two largest transportation network companies (TNCs) in the United States, both committed to electrifying their services by 2030.[43,44] Before the COVID-19 pandemic, TNC trips accounted for roughly 5% of global distance traveled in 2019, and Bloomberg New Energy Finance estimates that this share could increase to 16% by 2040.[45] Thus, electrifying a full-time TNC vehicle that drives the industry average of 40,000 miles per year can have nearly three times the emissions benefits of a typical passenger vehicle.[46]

In 2019, Lyft deployed 200 EVs in Denver through its Express Drive rental program, representing the largest single deployment of EVs in Colorado's history and one of the largest ever nationwide.[47] Based on preliminary data, Lyft claims that EV drivers in their Express Drive program are saving an average of $70 to $100 per week on fuel costs, though they do not specify if the savings come from drivers who have access to home charging.[48]

New York City has taken a unique approach to TNC electrification by restricting new registrations of gas-powered vehicles through its TNC licensing process. In August 2018, the New York City Council voted to stop issuing new licenses for TNC vehicles to protect the wages of taxi drivers and slow the surge of new TNC drivers.[49] The cap was set to expire in August 2019 but was instead extended indefinitely with an added exemption for EVs (which was subsequently repealed). Under the new cap, anyone wanting to license their vehicle to drive for a TNC must have either an all-electric or wheelchair-accessible vehicle.[50] The regulation, which also limits the amount of time drivers can cruise without passengers, simultaneously aims to encourage adoption of EVs and reduce congestion and vehicle miles traveled from TNC vehicles. The Taxi & Limousine Commission (TLC) will review, twice a year, whether any additional licenses should be granted.[51]

Though the EV exemption was subsequently removed, since the transportation company Revel had filed for a TNC license while the exemption was in effect, TLC was legally required to review and process Revel's application and allowed Revel to operate a new TNC service featuring 49 all-electric Teslas in lower Manhattan, which launched in August 2021. Its employee drivers can charge these vehicles at a Revel-owned charging station in Manhattan or the more-than-2,000 Tesla-compatible charging stations citywide.

3.1.2.4 Vehicle Purchase Incentives

Vehicle purchase incentives address one of the most significant cost barriers faced by consumers when purchasing low- and zero-emission vehicles. Incentives provide pricing-based market signals and aim to accelerate the adoption of ZEVs while the market matures, and cost premiums come down. New York State implements incentives under the Charge NY initiative, which includes NYSERDA's existing Drive Clean Rebate program, offering up to $2,000 per vehicle, and the New York Truck Voucher Incentive Program, which offers incentives for electric, FCEV, compressed natural gas (CNG), and other low-emission truck and bus models that vary by weight, class, and vehicle type.

Vehicle purchase incentives that can be realized by consumers at or near the time of their purchase decisions can be more effective at increasing ZEV adoption than a low carbon fuel standard (LCFS) or carbon price, where cost impacts and savings are indirect and may accrue over the life of the vehicle.[52] Research also suggests that incentives must be sufficiently large (i.e., above $1,000) to influence purchase decisions.[53]

Providing vehicle purchase incentives can be costly, however, particularly as sales of ZEVs continue to increase. These fiscal costs can be mitigated by designing incentives as feebates, which combine incentives for ZEVs with fees for higher emitting vehicles. Feebates can be designed to be revenue-neutral, though maintaining continued revenue neutrality will require recalibration of incentive and fee levels at regular intervals as the market shifts from one dominated by high-emission vehicles to one where lower-emission vehicles are more prevalent.

In the current market, ZEV sales are primarily new car sales, and new car sales are more concentrated among higher-income households (both ZEVs and ICEVs). Thus, without intentional policy design, vehicle purchase incentives for new cars accrue primarily to these higher-income consumers. To address these distributional equity concerns, incentives can be designed to differentiate vehicle purchase incentive levels based on applicant income or to offer higher incentive levels to households in areas designated as disadvantaged communities. For example, California's Clean Vehicle Rebate Project provides rebates based on income eligibility criteria. Consumers with household incomes less than or equal to 400% of the federal poverty level are eligible for an increased rebate amount of $2,500 over the standard rebate of $2,000 for a battery electric vehicle.[54] Another means to address the potential distributional impacts of vehicle purchase incentives is to prioritize incentives for zero-emission buses, which are used more heavily among lower-income households.[55]

Additionally, only sales or leases of new ZEVs are eligible under New York State's Drive Clean Rebate. By contrast, Oregon and California extend incentives to the purchase of used EVs, which are more commonly purchased by low-income individuals.[56] Expanding eligibility for ZEV incentives to used vehicle sales can support broader adoption among low- and moderate-income households, but even this may not be particularly effective in the near term as there is very limited availability of used ZEVs.

3.1.2.5 Charging and Fueling Infrastructure Investment

Infrastructure investments provide financial support for the infrastructure needed to supply low-carbon fuels such as electricity, hydrogen, liquid biofuels, and renewable natural gas to vehicles. This financial support most often comes in the form of incentives, rebates, and financing but could also include direct installation by governments or utilities.

Charging and fueling infrastructure investments can support ZEV adoption by reducing range anxiety, increasing charger availability, and enabling infrastructure in locations and for market segments in which private industry is not investing. Investments in public supply infrastructure are impactful and cost-effective. The addition of one public charger per 100,000 people has been found to result in a 7.2% increase in BEV sales and 2.55% increase in PHEV sales, and a similar analysis quantified an even higher estimate of a 13% increase in overall EV sales.[57,58] Likewise, increasing the number and capacity of hydrogen refueling stations has a direct impact on FCEV sales by addressing insufficient fuel availability, a key barrier to greater sales.

Determining the level of investment across chargers and fueling infrastructure will depend on the New York State's policy goals and the existing transportation infrastructure. Supporting adoption of FCEVs is expected to require substantially greater infrastructure investment due to the current lack of State public or private stations.[59]

Though charging infrastructure investments can be financed by government, in New York State regulators have assigned electric utilities a leading role in these initial efforts.[60] Utility investment of ratepayer funds to advance transportation electrification can be prudent for ratepayers and society insofar as EVs increase the use of existing system assets by charging at off-peak times, which can potentially bring down rates for all ratepayers. Utility charging infrastructure investments can also be deployed in tandem with ongoing utility efforts to upgrade and modernize the grid.

Where infrastructure utilization is anticipated to be low, infrastructure investments are less profitable for the private market. This poses a risk of underinvestment that may inequitably limit availability and access to ZEV infrastructure, such as for rural areas where vehicle density is low and in low-income communities with currently low rates of ZEV ownership. Similarly, renters and residents of multi-unit dwellings often face barriers to installing home charging infrastructure. Directing investments in public charging and fueling infrastructure to the areas likely to see lower private investment can help fill these market gaps and ensure new technologies are accessible to all.

3.1.2.6 Utility Rate Design

Utility rate design can encourage vehicle charging during periods when there is less electric grid demand and/or lower wholesale energy prices, which can reduce charging costs for consumers. Rate design options might entail introduction or greater adoption of time-of-use (TOU) rates, variable or critical peak pricing, or peak day pricing, all of which aim to better align retail prices with real-time grid prices.[61] Where properly designed, these rates can offer attractive financial benefits to customers who are able to adapt charging behavior to lower cost periods, particularly as these off-peak periods change as deployment of transportation and building electrification technologies increase. To the degree that grid carbon intensity is correlated with the time-differentiated factors underlying these utility rates, careful management of peak periods in rate design could generate greater carbon reductions.

With currently low EV adoption rates, sites like fast-charging stations and MHDV fleet yards are likely to see low-charger utilization in the near term but will still incur high-demand charges. Utility rate designs like the demand subscription embedded in Pacific Gas and Electric Company's Business EV rate can improve the economics of EVSE installations and further the case for EV adoption.[62] Additionally, make-ready funding that supports electrical service infrastructure upgrades at existing MHDV fleet yards can make EV adoption at the fleet level more attractive while also reducing localized air pollutants as these fleets electrify.

Implementing new electric utility rate designs is not anticipated to have a material impact on the State budget because this measure does not rely on tax proceeds or public funding streams. Furthermore, the guiding principles of utility rate design, such as cost-reflective pricing and financial sufficiency, should mitigate the risk that changes to rates might induce adverse economic impacts.

It should be noted that existing utility rates have been designed with consideration for policy priorities expressed in related regulation and legislation. Utilities are also required to conduct cost-benefit analyses when proposing new rates, which impacts rate design. For example, demand charges were developed to support the policy objectives of reducing overall utility system costs and protecting utility customers, including low-income customers, from cost shifts and bill increases. These objectives should be considered alongside benefits of potential changes to utility rates.

3.1.2.7 Outreach and Education on ZEVs

The novel nature of ZEV technology in conjunction with a lack of awareness of available incentives, TCO savings, and other benefits of ownership are barriers to adoption.[63] Research has shown that states with high EV consumer awareness also exhibit higher EV sales.[64,65] Outreach and education campaigns can increase EV and FCEV awareness through partnerships with dealerships, social media campaigns, major employer partnerships, and online cost calculators. Improved signage for Alternative Fuel Corridors raises awareness of ZEVs and the availability of fueling infrastructure. Similarly, auto shows and ride-and-drive events in which consumers and fleet managers can test drive the vehicles give New Yorkers hands-on experience with the technology and function of EVs and FCEVs.

Beyond outreach and education to increase familiarity and comfort with ZEVs, efforts are needed to increase awareness around options for using other transportation modes and improving system efficiency as well as understanding of new policies, programs, and regulations implemented and how best to respond to them. Many projects are underway in New York State that aim to, for example, educate users on bicycling best practices, introduce users to shared e-scooter and e-bike pilots, and collect user feedback on existing and future mobility needs.

Although outreach and education will require some initial administrative investment, these efforts are likely to have significant impact in the short term while ZEV market share and the share of travel on alternative modes remain relatively low. As ZEVs and alternative modes become more commonplace, potential buyers will be more familiar with ZEV technology and travelers will have a better knowledge of their options for transit, shared mobility, and other travel options, so the necessity of and cost to facilitate campaigns will taper.

3.1.2.8 Smart Growth Policies

Smart Growth, or mobility-oriented development, policies encourage reduced trip lengths and shifts to more VMT-efficient modes of travel. Such policies include funding, streamlined permitting, and tax breaks, among other mechanisms, to incentivize transit-oriented development, higher-density and mixed-use development, infill or brownfield development, improved transit and active transportation (bike and pedestrian) infrastructure, and neighborhoods with a range of housing and transportation options.

Smart Growth development helps to alleviate the first- and last-mile problem (or longer in rural areas), where lack of or inconvenient access to public transit and active transportation modes reduces utilization of these modes and creates barriers to mobility. Smart Growth development works in concert with investments in and incentives for robust transit, active transportation infrastructure, and widely available micro-mobility to address the first- and last-mile problem. Given the difficulty of individually modeling policies involving micro-mobility and transit investment because of their nuanced interactions, higher-density, and mixed-used development was explicitly modeled; this type of development, in turn, drives outcomes such as lower VMT over time.

Smart Growth plans generally have a positive net impact on municipal finances because the cost of infrastructure development is outweighed by growth in property tax proceeds and other indirect benefits. However, Smart Growth can incur net costs if design standards result in more expensive construction. Local governments bear most of the financial burden for Smart Growth and transit-oriented development, but State governments can help determine what types of financing tools local governments can use, including tax-increment financing, special assessments, and other mechanisms.[66]

In some instances, Smart Growth has led to the gentrification of underdeveloped areas of some cities, by directing new housing development and/or better transportation infrastructure to those areas. However, Smart Growth strategies can promote social equity by increasing housing availability and access to jobs while reducing household transportation costs. Recent Smart Growth projects have emphasized protections to ensure affordability and prevent displacement of existing residents, such as instituting affordable housing requirements and making new housing available first or at a discounted price to existing residents. Such Smart Growth strategies can also reduce VMT per capita (e.g., by enabling mode shift from cars to active or public transportation) and therefore reduce air pollution. The challenge is to monitor Smart Growth implementation and adjust incentives and regulations to ensure that equity as well as VMT goals are achieved.

3.1.2.9 Complete Streets Policies

Complete Streets policies are holistic approaches that aim to design and operate city streets to better serve all road users, including pedestrians, bicyclists, and transit passengers, who are often underserved by traditional street designs. Complete Streets, for example, include the construction of or improvements to bicycle lanes, busways, and pedestrian walkways. A city or municipality that adopts a Complete Streets policy encourages travelers to shift to transportation modes that are less carbon-intensive, reducing VMT per capita. New York State could develop a Complete Streets policy like that adopted by Nevada in 2017, which integrates provisions for all road users into the planning, design, construction, maintenance, and operation of new and retrofit transportation facilities through the development of appropriate design features.[67]

Compared to Smart Growth policies that influence both mode choice and trip length, Complete Streets policies and strategies focus only on mode choice. As such, they can have a more immediate, though limited, effect on GHG emissions from VMT. California Air Pollution Control Officers Association (CAPCOA) has found that areas with Complete Streets are associated with a 1% to 2% reduction in VMT per capita.[68] In accordance with the NYS Complete Streets Law, New York State Department of Transportation has developed an integrated approach to identify the need for Complete Streets design features on capital projects, including locally administered projects. A project-level evaluation tool, Capital Project Complete Streets Checklist, aids in identifying access and mobility issues and opportunities in a defined project area. Recognizing that there may be opportunities to address bicycle and pedestrian mobility and safety improvements in certain maintenance projects (e.g., pavement re-surfacing, pavement marking), the checklist encourages inclusion of Complete Street features when designing this type of project as well.

A Complete Streets strategy may require more right-of-way and paved width to accommodate the same amount of traffic as a conventional street design. However, the cost impacts are marginal, on the order of 10% or less on construction costs for new streets. The costs of retrofitting existing streets depend on the starting condition of the street infrastructure, and these costs can be partially offset in the long term through increased property values and commercial activity along the improved streets. Research has found that Complete Streets in New York City resulted in increased retail sales compared to their corresponding borough and neighborhood sites before Complete Streets improvement.[69]

Complete Streets can have positive impacts on public health by reducing pedestrian and bicycle crashes through improved infrastructure and traffic calming measures and by reducing air pollution through less congestion and more frequent, reliable transit service. Furthermore, enhanced bicycle and pedestrian infrastructure encourages more people to use active transportation options for exercise, recreation, and commuting.

Furthermore, Complete Streets policies are expected to bring equity benefits due to their emphasis on designing streets accessible for all types of users. Monitoring of the design, implementation, and operation of Complete Streets should ensure a balanced and equitable result that avoids or otherwise compensates for potential gentrification effects.

Case Study: Massachusetts's Complete Streets

Under its Complete Streets Funding Program, municipalities in Massachusetts can apply for up to $400,000 in funding for the construction of transit system improvements that make city streets more accessible for alternative forms of transportation.[70] Example projects include everything from separated bicycle lanes, new crosswalks, and new bus stops to street lighting, improved traffic signal timings, bicycle facilities, or improved connection to transit stations.

Nearly 90% of municipalities in Massachusetts have completed the Complete Streets training and over half of participating cities and towns have gone on to receive funding to construct a Complete Streets project.[71] In addition to awarding over $55 million for project construction, Massachusetts Department of Transportation has awarded over $7.3 million for technical assistance for a total of $62.3 million of support for cities and towns in Massachusetts from 2016 to 2021. Massachusetts has added over 17 miles of new or reconstructed sidewalks, over 17 miles of new bike lanes, 492 curb ramps compliant with the Americans with Disabilities Act of 1990, 67 rectangular rapid-flashing beacons, and 70 new or improved crosswalks.[72] Other improvements have included bike racks, bus shelters, and speed feedback signs.

Infrastructure gaps disproportionately impact low-income and non-white households whose residents are more likely to rely on walking, biking, and public transit. To address this, nearly two-fifths of all program funding has been awarded to municipalities with median incomes below the statewide median. Of 478 projects, 169 have addressed needs in Environmental Justice Communities, defined by the State of Massachusetts as communities that have a median income equal to or less than 65% of the statewide median, are at least 25% non-white, or where at least 25% of households have no one over the age of 14 who speaks English only or very well.[73]

3.1.2.10 Increased Shared Mobility Services (Transit and Micromobility)

Increasing shared mobility services involves supporting and investing in mobility options such as public transit, shared micro-mobility and micro-transit services. These services enable and encourage travelers to choose more VMT-efficient modes of travel. Like the Complete Streets strategy, a Shared Mobility Services strategy focuses on changing the mode travelers choose. This strategy can be quickly implemented and has immediate effects on VMT, though it is limited to focusing only on mode choice as a means of VMT management.

Encouraging widespread use of shared modes of travel such as mass transit, micro-transit (i.e., small-scale, on-demand services), and shared micro-mobility devices (i.e., bikeshare and e-scooters) requires making these modes affordable, convenient, reliable, fast, and connected both digitally and physically. Strategies for Smart Growth and Complete Streets can also further incentivize shared mobility services as attractive options.

Though New York City is a national leader in terms of transit mode share, the rural, suburban, and smaller urban areas in New York State will require a large injection of investment and innovation to significantly increase shared mobility services. Strategies for effective shared mobility services may include the following:

- Expanding frequency, operating hours, and reliability of existing public transit services using existing infrastructure.
- Developing partnerships and new service models that create connected networks of rail, bus, van, bike, scooter, and other modal options.
- Developing integrated fare payment and passenger information platforms.
- Reimagining governance so public transportation agencies, cities, counties, and regional organizations can collaborate based on aligned policies and consistent rules.[74]
- Constructing the infrastructure needed to run successful service, including bus lanes, mobility hubs, enhanced bus stops and stations, and bike and scooter lanes.

New York State is taking steps to explore mobility management. In Upstate New York, the Shared Mobility Network project educated stakeholders, conducted feasibility studies, and coordinated between private mobility companies, transit agencies, cities, and MPOs from 2015 to 2018, leading to $7 million in capital and operating investments primarily into bikeshare and carsharing programs.[75]

Case Study: Mobility-as-a-Service

A paradigm shift is starting to take hold in the United States—and is gaining steam rapidly abroad—as transportation agencies and transit operators recognize the need to evolve into *mobility managers* by implementing the Mobility-as-a-Service (MaaS) concept. MaaS integrates multiple transportation options through on-demand service and an integrated payment platform. For example, a rural or suburban resident might use an app to use a ridehailing service to take them from their home to a transit station, board a train into a downtown, then use a bikeshare to get to their final destination. Full implementation of the MaaS concept entails one app providing the information, request, ticketing, and payment for this entire trip.

There are numerous MaaS pilot projects currently being deployed in the United States. Two representative examples are the San Francisco Bay Area's integrated transit payment system, Clipper Card, and, in Texas, the City of Arlington's on-demand microtransit service. The Bay Area's Clipper Card integrates payments for 24 transit services across a nine-county region, the Bay Wheels bikesharing system, and Bay Area Rapid Transit (BART) daily parking. Similar innovations are being advanced in rural and suburban areas of California, with the San Joaquin Council of Governments (SJCOG) recently launching its EZhub mobile ticketing app that integrates cashless payments for seven transit services. New York City's OMNY program integrates subway and bus fare payment, and may be expanded to integrate other regional mobility options. The City of Arlington, Texas, has become the first U.S. city in the U.S. to run a 100% on-demand microtransit service, overcoming years of opposition to more traditional mass transit investments.

Though existing transit agencies were not the managing entities for these programs, the project resulted in awareness of and receptivity to the idea of forming Mobility Development Corporations as a potential next step.[76] In addition to the need to prepare for new technologies, agencies across all regions of New York State have already identified and requested transit service and infrastructure improvements but lack the funding to implement. Increased collective action among the public and private sector as well as a higher degree of investment will be required to harness and accelerate the adoption of shared mobility technologies.

3.1.2.11 Road-User Charges (RUCs)

A tax or fee based on the number of miles traveled by a vehicle, also known as a road-user charge (RUC) or mileage-based user fee (MBUF), is among the most effective strategies for managing VMT because it affects all three aspects of VMT management: mode choice, trip length, and number of trips. It can be effective at changing behavior both immediately and long term (as long as the RUCs are meaningful and remain in effect) and can be adjusted to changing conditions. The income raised by RUCs can be used to address road maintenance, provision of alternative modes, equity impacts, or other agency goals. RUCs could also help reduce vehicle congestion across all vehicle types and improve air quality in historically high-traffic areas.

RUCs are being studied and piloted in states, including Utah and Oregon, as potential replacements for fuel taxes. If replacing vehicle registration fees, RUCs may be less predictable. If replacing gasoline taxes, RUCs could raise proceeds from more fuel-efficient ICEVs and EVs that would otherwise pay less than vehicles have historically paid. However, unlike a gasoline tax, a RUC does not necessarily provide an incentive to drive a more fuel-efficient or alternative fuel vehicle, though it could be designed to do so. For example, if a RUC were to be combined with a gasoline tax or adjusted based on the emissions of a vehicle, it would provide an incentive to drive a more fuel-efficient or alternative fuel vehicle.

The economic impact of RUCs varies based on the cost of the fee per mile and the number of miles driven, which may disproportionally burden rural residents who tend to drive longer distances and lower-income vehicle owners who drive for work (e.g., for TNCs). However, these drivers already face a higher cost of gasoline taxes, so it is unclear whether a RUC would be any more or less burdensome than the status quo. A RUC would also require substantial investment by the implementing agency to administer and at higher cost and complexity than gas tax administration, which typically costs approximately 1% of revenue collected. Various estimates for RUC system costs as a share of revenue range from 1.7 to over 6%, though this increased cost could be offset by reduced costs for administering road tolls.[77,78] Other considerations include the accuracy, privacy, and data security issues surrounding the reporting of VMT by vehicle owners in order to calculate and collect the fee.

3.1.2.12 Employer Telework and Travel Demand Management

Employer telework and travel-demand management (TDM) measures encourage commuters to use more VMT-efficient means of commuting. TDM measures include ridesharing programs, subsidized transit passes, bike lockers, showers, marketing of TDM measures to employees, and subsidized vanpools.

The GHG emissions impact of teleworking depends on several key factors, such as the degree to which workers relocate to suburban or rural areas where VMT is typically higher. One day of teleworking for a single employee represents a 20% reduction in commute-related GHG emissions per week, although this may be offset by employees choosing to live farther away from work or in more rural areas where overall VMT tends to be higher. Trip reduction reduces VMT, and thus GHG emissions, so teleworking can also result in commute cost savings among workers and reduce peak-hour traffic, which may in turn result in lower congestion and fewer peak-hour crashes.

With more people working from home or sharing rides, reduced peak hour demands may enable local and State transportation agencies to serve more daily passengers, cars, and commercial vehicles with the same infrastructure. However, a reduction in travel could reduce transit fare, toll fees, and parking proceeds. The cost of employer-based TDM and teleworking is generally borne by the private sector, though meeting participation targets that are sufficient to reduce VMT may require financial incentives to employers to offer telework or TDM services.

Employer telework is not universally applicable, as some jobs are considered essential in-person services (such as healthcare) or require specialized on-site equipment (such as manufacturing). Some employers have expressed concerns that the informal interactions in an office space generate new ideas that would be lost if employees worked from home. TDM programs work best with large employee pools—more than 100 employees in a pool. Smaller employers and employers in more rural areas generally do not have the resources or the number of employees needed to cost-effectively support a TDM program.

Moderate- to high-income jobs typical of white-collar work are the most amenable to teleworking. Such employees are more likely to live in regions with superior internet service, and they often have the necessary computing facilities already installed in their homes. Thus, teleworking trends highlight the equity disparity in access to high speed, broadband service, particularly among lower-income households. Complementary policies to continue increasing broadband penetration across the State in disadvantaged communities will enable more lower-income households to take advantage of teleworking policies.

Case Study: Utah's Telework Program

Utah's 2018 *A New Workplace* pilot program provided training, standardized policies, and digital tools to enable suitable state employees to work from home three to five days per week. After the pilot demonstrated cost savings, increased employee productivity, and reduced emissions, Utah expanded the program across all agencies in July 2019 with an initial target to reach 30% of eligible staff.[79] The Governor's Office of Management and Budget set targets to avoid 1,300 pounds of local air pollution per month, reduce the state's need for office space by 63,900 square feet, create 200 jobs in rural Utah, and retain 56 employees all while maintaining or increasing productivity.[80] But after less than a year into the implementation of *A New Workplace*, the COVID-19 pandemic struck, and 40% of total state employees were directed to work from home.[81] With actual enrollment nearly double what was anticipated, the program has significantly exceeded its targets. The Governor's Office of Management and Budget estimates that *A New Workplace* has led to a reduction of 2,627 pounds of local air pollution per month, allowed the state to exit over 90,000 square feet of real estate, created 207 new jobs in rural Utah, and helped retain or recruit 135 employees.[82]

As of January 2021, the state had spent $3.5 million facilitating the transition to remote work including upgraded digital security, bandwidth enhancements to support increased video conferencing, and software such as virtual private networks and virtual desktop infrastructure to grant remote workers access to government servers.[83] With these safeguards in place, the Governor's Office of Management and Budget reported an average increase in predetermined performance metrics of 20% over the course of the initial pilot program while also achieving high levels of employee satisfaction.

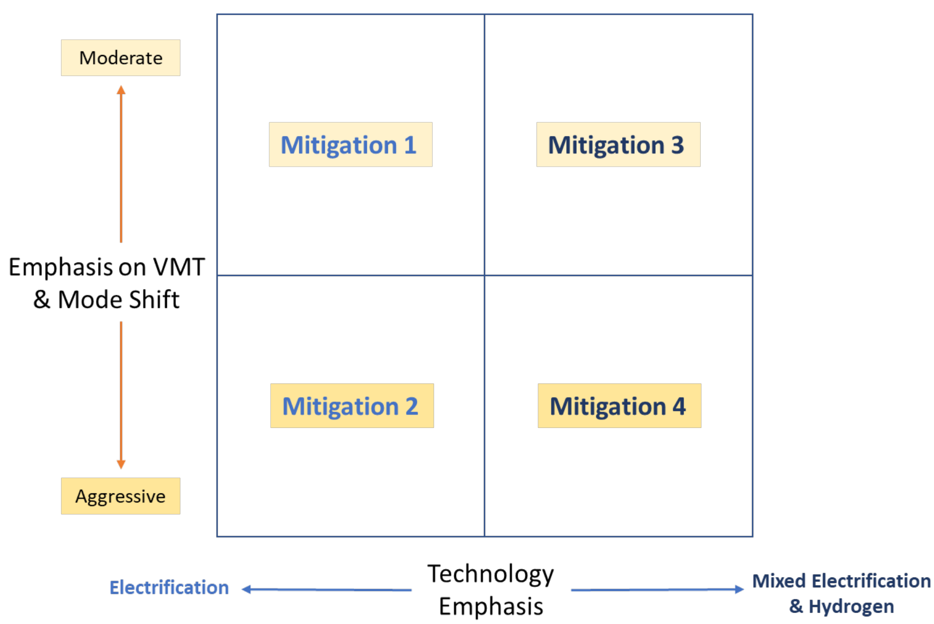
State legislatures in New York and New Jersey have both introduced bills to encourage continued remote work at state agencies following the COVID-19 pandemic. New York Senate Bill 5536 would require each agency to establish a telework policy and program, citing the benefits of decreased congestion and increased worker productivity.[84] New Jersey Senate Bill 3017 would require all State employers to accommodate remote work arrangements.[85]

3.2 Structure of Mitigation Cases

Mitigation cases, or potential future scenarios, were developed for this analysis to illustrate the various sets of policies that can be implemented by State and/or local authorities to meet the transportation-related GHG emission reductions necessary to comply with the Climate Act. The four mitigation cases illustrate different sets, and combinations of, policy pathways that are in line with the New York State's emission reduction targets.

The mitigation cases vary along two axes, reflecting differing emphases among the Roadmap's core decarbonization strategies, as illustrated in Figure 21.The X-axis indicates the level of electric vehicle use versus hydrogen.[86] The Y-axis captures the level of VMT management and mode shift strategies, from aggressive (bottom) to moderate (top).

Figure 21. Illustration of Design of Mitigation Cases



Though the four mitigation cases differ in their emphasis on certain policies, they are equally consistent with the State's emissions targets and result in similar emission reductions in future years. Aside from their comparable projected GHG emissions, each individual mitigation case generates different impacts on cost, criteria pollutants, technology risk, equity, social benefits, and other external factors.

3.2.1 Mitigation Case 1

Mitigation Case 1 illustrates a technology emphasis on electrification paired with moderate VMT and mode shift policies.

Fuel-switching & efficiency	**Near-term (2020–2030)** • Rebates, incentives, and sales targets for automakers combine to make electric LDVs price competitive with ICEVs between 2025–2030 on a TCO basis and between 2028–2035 on an upfront vehicle cost basis. • Public investment supports very expansive deployment of EVSE, including in areas that are underserved by the private market, enabling near-immediate transition in consumer purchase choices. **Medium-term (2030–2050)** • Market actors leverage experience with LDV electrification to catalyze MHDV electrification. By 2030, approximately 25% of all MHDV sales are electric, although the fractions vary by vehicle type. By 2045, 100% of all MHDV sales are electric. • Federal equipment standards require that 50% of all short-haul flights and 50% of all non-road vehicles be electric. • Subsectors that cannot easily be electrified due to technology availability, cost, or the use cases of the vehicles, such as long-range freight and long-haul aviation, switch to low-carbon liquid fuels.
VMT management & mode shift	**Near-term (2020–2030)** • Investments in pedestrian and bike infrastructure and expanded transit service affect mode choices, driving some shifts toward use of public transit and active transportation. • Smart Growth principles are embedded in land use decisions throughout the State. **Medium-term (2030–2050)** • The accumulation of local planning decisions favoring mixed-use and transit-oriented development begin to manifest in reduced trip distances, as people and goods need to move shorter distances to destinations.

3.2.2 Mitigation Case 2

Mitigation Case 2 illustrates a technology emphasis on electrification paired with a more aggressive set of VMT and mode shift policies.

Fuel-switching & efficiency	**Near-term (2020–2030)** • Rebates, incentives, and sales targets for automakers combine to make electric LDVs cost competitive with ICEVs. • Public investment supports expansive deployment of EVSE, including in areas that are underserved by the private market, enabling a shift in consumer purchase choices. **Medium-term (2030–2050)** • Market actors leverage experience with LDV electrification to catalyze MHDV electrification. By 2030, approximately 25% of all MHDV sales are electric, although the fractions vary by vehicle type. By 2045, 100% of all MHDV sales are electric. • Federal equipment standards require that 50% of all short-haul flights be electric. • Subsectors that cannot easily be electrified due to technology availability, cost, or the use cases of the vehicles, such as long-range freight and long-haul aviation, switch to low-carbon liquid fuels.
VMT management & mode shift	**Near-term (2020–2030)** • Investments in pedestrian and bike infrastructure and expanded transit service affect mode choices, driving unprecedented shifts toward use of public transit and active transportation. • Smart Growth principles are at the center of regional, state, and local transportation planning, funding mechanisms are aligned with these principles, and funds are invested aggressively in projects that realize this new land use approach. **Medium-term (2030–2050)** • The State's focus on mixed-use and transit-oriented development manifests in reduced trip distances, as people and goods need to move shorter distances to destinations, and Mobility-as-a-Service offerings make micro-mobility and transit use more convenient and reliable.

3.2.3 Mitigation Case 3

Mitigation Case 3 illustrates a mixed technology emphasis that includes electrification and hydrogen, paired with moderate VMT and mode shift policies.

Fuel-switching & efficiency	**Near-term (2020–2030)** • Generous rebates and incentives combine to make hydrogen fuel cell and electric LDVs price competitive with ICEVs. • Public investment supports high availability of hydrogen infrastructure and moderate deployment of EVSE, enabling transition in consumer purchase choices. **Medium-term (2030–2050)** • Equipment standards spur 50% of medium-duty and 100% heavy-duty vehicles convert to hydrogen fuel cell electric vehicles (HFCEVs) and require that 50% of all short-haul flights and 25% of all non-road vehicles be fueled by hydrogen.
VMT management & mode shift	**Near-term (2020–2030)** • Investments in pedestrian and bike infrastructure and expanded transit service affect mode choices, driving some shifts toward use of public transit and active transportation. • Smart Growth principles are embedded in land use decisions throughout the State. **Medium-term (2030–2050)** • The accumulation of local planning decisions favoring mixed-use and transit-oriented development begin to manifest in reduced trip distances, as people and goods need to move shorter distances to destinations.

3.2.4 Mitigation Case 4

Mitigation Case 4 illustrates a mixed technology emphasis that includes electrification and hydrogen, with a more aggressive set of VMT and mode shift policies.

Fuel-switching & efficiency	**Near-term (2020–2030)** • Generous rebates and incentives combine to make hydrogen fuel cell and electric LDVs price competitive with ICEVs. • Public investment supports substantial availability of hydrogen infrastructure and moderate deployment of EVSE, enabling transition in consumer purchase choices. **Medium-term (2030–2050)** • Equipment standards spur 50% of medium-duty and 100% of heavy-duty vehicles convert to HFCEVs and require that 50% of all short-haul flights be fueled by hydrogen.
VMT management & mode shift	**Near-term (2020–2030)** • Investments in pedestrian and bike infrastructure and expanded transit service affect mode choices, driving unprecedented shifts toward use of public transit and active transportation. • Smart Growth principles are at the center of regional, State and local transportation planning, funding mechanisms are aligned with these principles, and funds are invested aggressively in projects that realize this new land use approach. **Medium-term (2030–2050)** • The State's focus on mixed-use and transit-oriented development manifests in reduced trip distances, as people and goods need to move shorter distances to destinations.

4 Direct Impacts of Mitigation Activities

The policies applied in the mitigation cases use the three-core decarbonization strategies: fuel-switching, mode shift, and VMT management. By 2050, the decarbonization policies drive fuel consumption toward electricity, low-carbon liquid fuels, and hydrogen fuel cells (see section 5.1). The resulting impact on VMT is described in section 5.2. These factors, in turn, result in GHG emissions pathways, presented in section 5.3.

4.1 Technology and Fuel Adoption

By 2050, mitigation cases 1 and 2, with their focus on electrification, show a substantial shift in the fuel mix, compared to the reference case (Figure 22). This shift is primarily driven by the rapid acceleration of EVs in the LDV and MHDV subsectors, as well as the introduction of biojet into the jet fuel mix. EVs account for a majority of vehicle sales in the LDV subsector by 2028 and 2029 in M1 and M2, respectively. Additionally, EVs account for the majority of the vehicle stock by 2033 and 2034 for M1 and M2, respectively (e.g, Figure 23). Similarly, for both M1 and M2, EVs account for a majority of vehicle sales in the MHDV subsector by 2033 and a majority of the vehicle stock by 2040.

Figure 22. 2050 Share of Fuel Sources by Case (% TJ). All Columns are for 2050 Except 2020

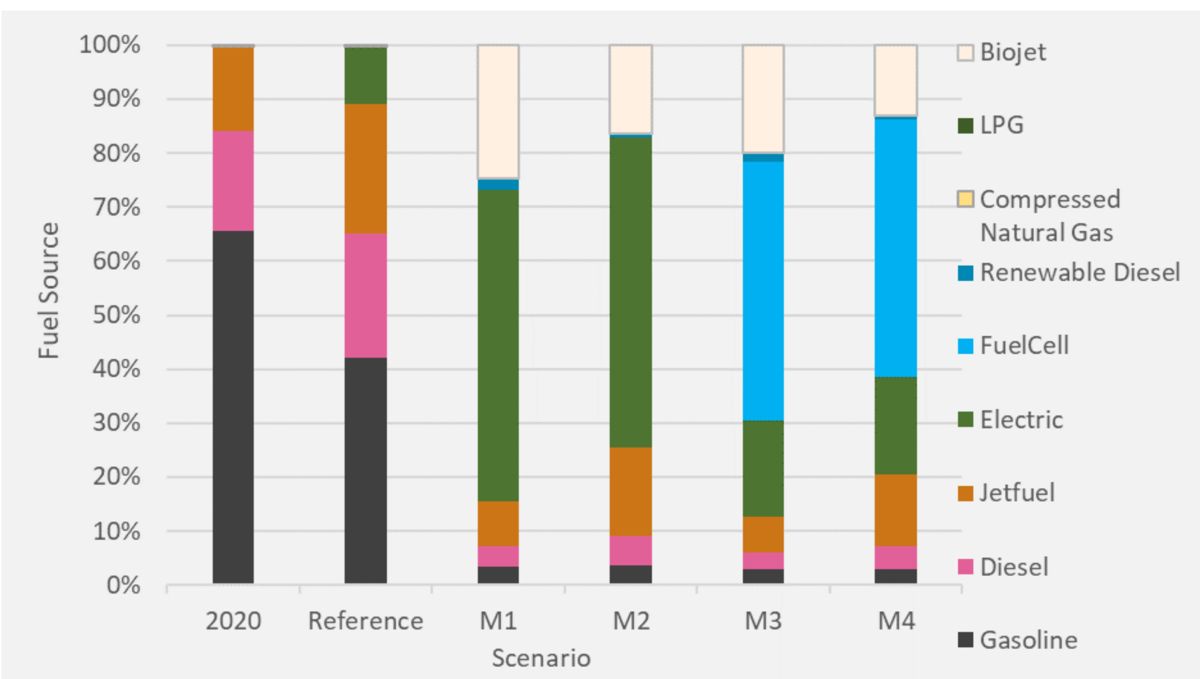
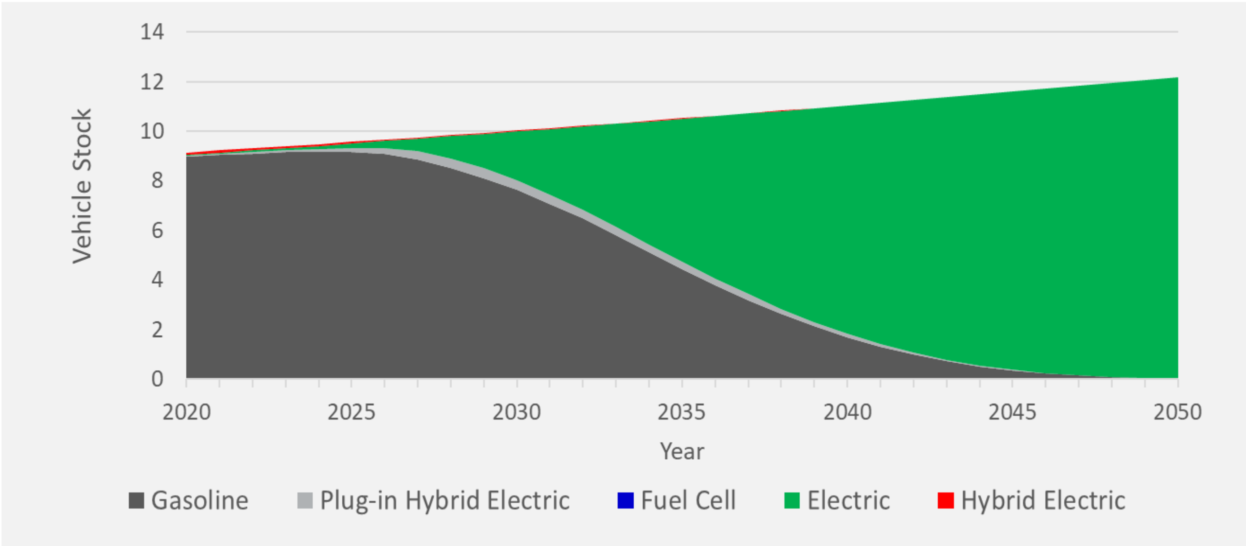
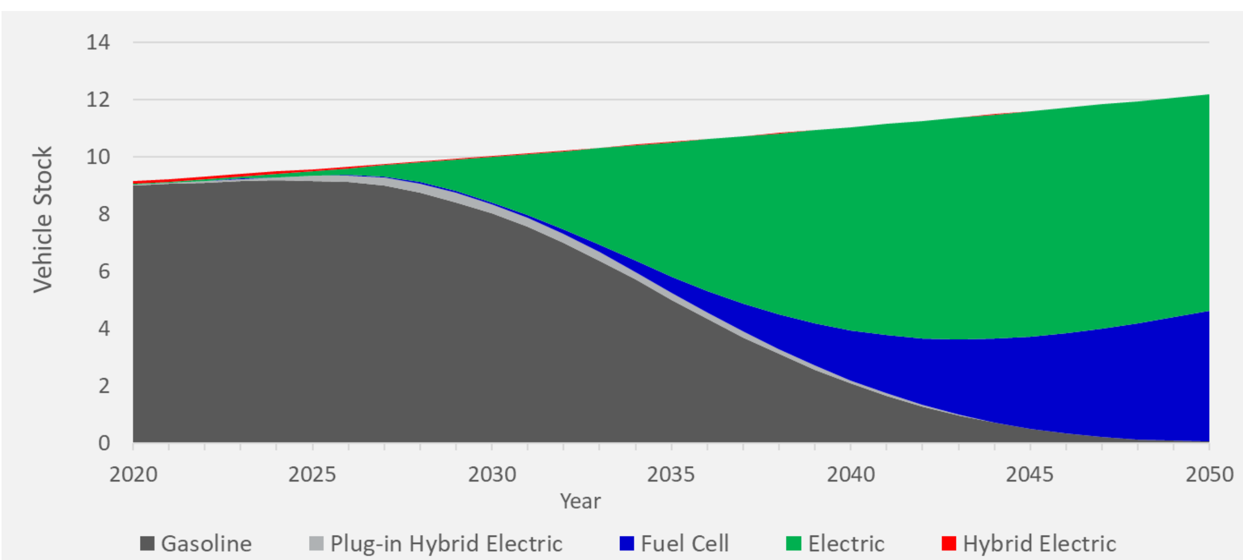


Figure 23. LDV Stock by Fuel Type (Mitigation Case 1)



In comparison, mitigation cases 3 and 4, with their focus on a more balanced mix of hydrogen and battery electric vehicles, show more diversity in the set of technologies that will be present in the State's vehicle fleet by 2050. In the LDV subsector, EV market share becomes the majority share by 2030 for both scenarios. By 2037, EVs account for the majority of LDV vehicle stock in both M3 and M4. However, FCEV sales begin to increase rapidly in the mid-2030s and in the 2040s this vehicle technology absorbs market share from EVs as well as from gasoline vehicles (Figure 24).

Figure 24. LDV Stock by Fuel Type (Mitigation Case 3)



Similarly, increased availability of hydrogen fuel, fueling infrastructure, and vehicle purchase incentives combine to drive substantial adoption of FCEVs in the MHDV subsector. Nonetheless, battery electric vehicles make up 47% of the MHDV market and about 45% of the entire MHDV stock in 2050 even in mitigation cases 3 and 4.

4.2 Vehicle Miles Traveled

VMT declines in the mitigation cases relative to the reference case but *rises* relative to 2020 across all vehicle categories. The primary factors that lower VMT in the mitigation cases relative to the reference case are policies focused on smart growth, travel demand management, and transit expansion. Overall, statewide on-road VMT is 12.5% and 14% lower in the M1/M3 and M2/ M4 cases, respectively, in 2050 compared to the Reference Case. Overall, the findings highlight the challenge of managing VMT growth. As stated in the modeling uncertainties section, projected VMT growth in 2050 can vary significantly depending on factors such as population growth and household income (Table 5).

Table 5. Summary of Annual VMT Growth Rates by Vehicle Category, 2020 to 2050

Vehicle Category	Ref	M1	M2	M3	M4
All On Road Vehicles	**1.29%**	**0.84%**	**0.77%**	**0.84%**	**0.77%**
Light-Duty Vehicles	1.3%	0.8%	0.7%	0.8%	0.7%
Combination Unit Long Haul Truck	1.7%	2.0%	2.0%	2.0%	2.0%
Combination Unit Short Haul Truck	1.7%	2.0%	2.0%	2.0%	2.0%
Single Unit Long Haul Truck	0.8%	0.9%	0.9%	0.9%	0.9%
Single Unit Short Haul Truck	0.8%	0.9%	0.9%	0.9%	0.9%
Light Commercial Truck	0.9%	0.2%	0.3%	0.2%	0.3%
Intercity Bus	0.9%	2.2%	3.5%	2.2%	3.5%
School Bus	1.3%	1.3%	1.3%	1.3%	1.3%
Transit Bus	0.9%	2.2%	3.5%	2.2%	3.5%
Refuse Truck	0.9%	0.2%	0.3%	0.2%	0.3%
Motor Home	0.9%	0.2%	0.3%	0.2%	0.3%
Total On-Road VMT in 2020 (Billion Miles)	126	126	126	126	126
Total On-Road VMT in 2030 (Billion Miles)	143	137	136	137	136
Total On-Road VMT in 2050 (Billion Miles)	185	162	158	162	158

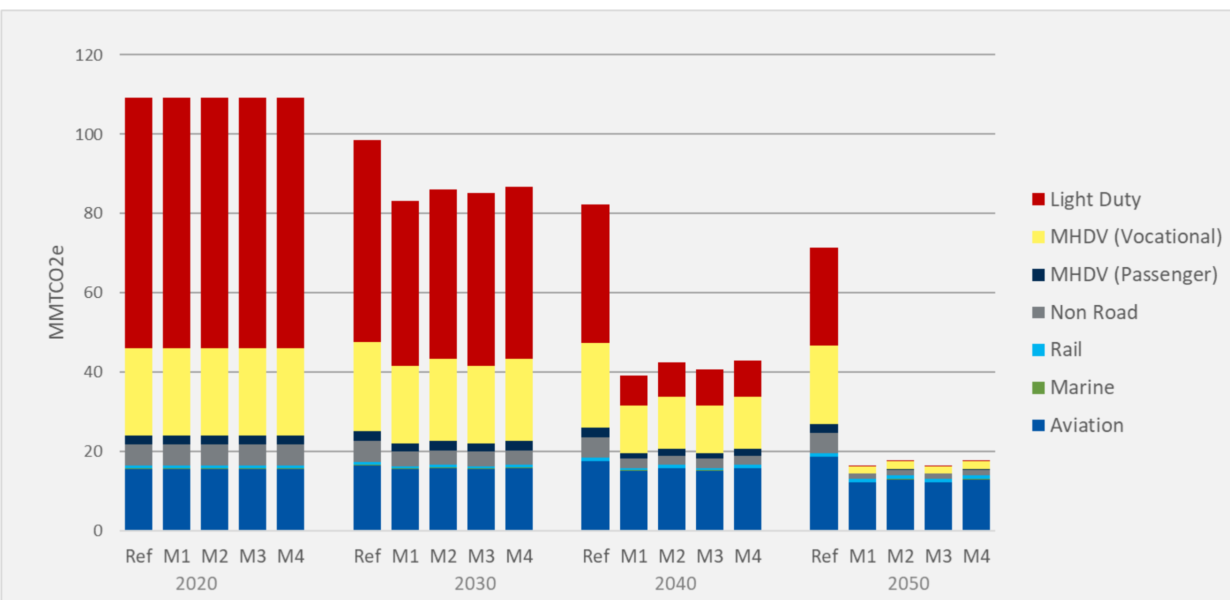
Average household VMT declines in the mitigation cases relative to the reference case. The heaviest VMT reductions occur in the New York City metro region and Long Island. County-level differences in VMT are driven primarily by the availability of low-cost alternative modes (such as the subway and bus transit). In other words, regions with the ability to take advantage of transit and active modes in the future are more likely to shift away from personal vehicles.

4.3 Emission Results

As with the reference case, a combination of technology, fuel adoption and VMT trends determine the GHG impacts in each case. Figure 25 shows that these mitigation cases look very similar to each other in each future decade. Several reasons explain this similarity. All four cases assume New York State aligns with the Advanced Clean Cars II and Advanced Clean Truck regulations and the targets established in the September 2021 legislation, which imply that all new LDV sales will be zero-emission vehicles by 2035 and all MHDV sales are zero emissions by 2045. Due to the GHG accounting in the Climate Act, electric vehicles and FCEVs have the same carbon footprint (zero) when counting only transportation emissions (those emissions are counted in other sectors). Furthermore, the VMT differences between the mitigation case are slight, even though the VMT management policies embedded in the cases differ.

To meet New York State's climate goals, it is important to reduce transportation sector emissions down to 12 MMT to 20 MMT by 2050. It is projected that sizeable emission reductions occur by 2030 then accelerate as technologies mature and policies are implemented, driving significant further reductions by 2050. Across all mitigation cases, emissions remain at the higher end of that range, which does not leave much room for error or underperformance. Note that aviation emissions still account for over half of residual emissions in 2050 in all cases.

Figure 25. GHG Emissions by Subsector across Cases and Future Years



All mitigation cases include substantial mode shift and implementation of VMT management measures through long-term land use decisions. Still, the higher emphasis on technology adoption for GHG reductions in mitigation cases 1 and 3, rather than changes in land use patterns and VMT, produces somewhat larger annual reductions in earlier years relative to mitigation cases 2 and 4. This is because VMT management policies require longer to take hold than shifts in technology choices, which are driven by equipment lifetime and replacement cycles. In 2030, emissions in all four scenarios are lower than in the reference case but not by enough to meet the transportation sector's share of the Climate Act's targets. To achieve the target 2030 emissions reductions, additional policies, or more vigorous implementation of the modeled policies, would need to be adopted.

The Climate Act, and this Roadmap, focus on annual emission levels as a principal metric. Nonetheless, climate impacts are driven by the concentration of emissions that accumulate in the atmosphere. Thus, emission trajectories in which persistently lower annual emissions are achieved sooner will generate more climate benefits than trajectories in which reduction activities are delayed to the later years of the State's timeline.

The State's cumulative contribution to the global atmospheric concentration of GHGs is an important consideration when weighing potential reduction pathways. The modeling in this Roadmap shows only slight differences between the cumulative emissions of the four mitigation cases. In the reference case, 2,806 MMTCO2e are emitted between 2020 and 2050. Among the four mitigation cases, M4 has the highest cumulative emissions of 1,999 MMTCO2e and M1 has the lowest at 1,918 MMTCO2e.

5 Social, Health, and Economic Impacts of Mitigation Activities

While the mitigation cases achieve similar magnitudes of GHG emission reductions over time, they differ in their impacts on New Yorkers. This chapter explores the other potential impacts of mitigation activities, differentiating the mitigation cases in terms of their effects on public health, state government finances, total expenditures in the state, social equity, economic activity, and the electric distribution system.

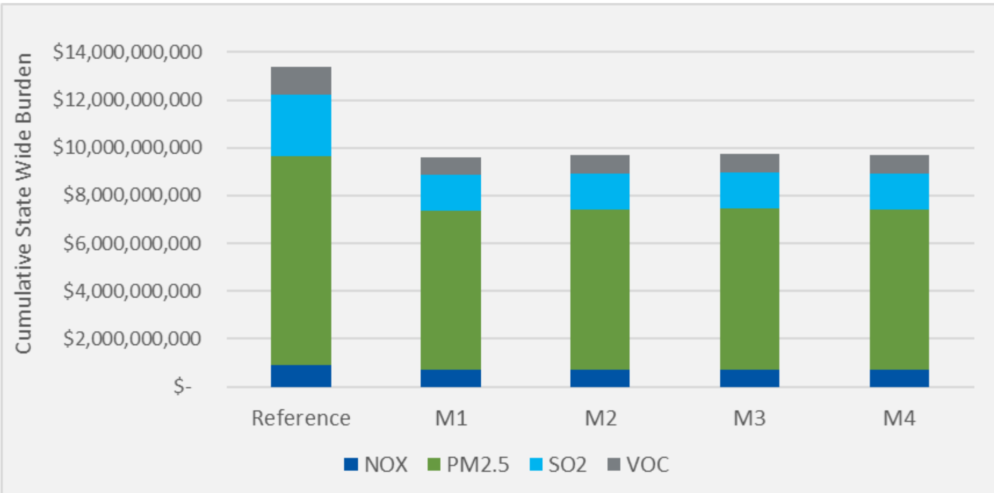
5.1 Health Impacts

In addition to emitting greenhouse gases, ICEVs emit criteria pollutants such as nitrogen oxides (NO_X), particulate matter, sulfur dioxide, and volatile organic compounds (VOCs) through burning of fossil fuels and tire and brake wear. Increased levels of air pollution negatively affect human health.[87] These health effects can be quantified using a combination of emissions, air quality, and epidemiological models and data.[88] The health outcomes are translated to monetary values through multipliers that account for the cost of hospitalizations and the Value of Statistical Life (VSL).[89,90] Notably, in this Roadmap, only emissions from on-road sources were quantified, not emissions associated with upstream fuel production and delivery or emissions from aviation, marine, non-road, and rail subsectors.

Today, the majority of on-road vehicle emissions in New York State are generated from LDVs mainly due to the larger number of LDVs in the State. In particular, sports utility vehicles (SUVs) and crossovers produce a majority of the emission impacts from on-road vehicles. PM2.5 represents one of the largest pollutant types.[91] It is difficult to quantify health effects resulting from emissions across the state, since localized pollution hotspots may exist, especially sulfur dioxide and nitrogen oxides, from diesel MHDVs in dense urban areas. The share of the health burden is projected to shift toward MHDVs as the LDV sector shifts toward EVs.

Across Mitigation Cases, tailpipe emissions and the related value of emissions-based health effects decline to nearly zero from LDVs by 2050 due to widescale adoption of EVs and FCEVs. Particulate matter emissions from tire and brake wear remain the largest source of emissions. Similarly, tailpipe emissions from MHDVs decline dramatically across all Mitigation Cases, although ongoing use of low-carbon liquid fuels in this subsector results in some residual emissions in 2050. Figure 26 illustrates the cumulative statewide value of the health burden of these emissions from 2020 to 2050 under the reference and mitigation cases. The value of the difference in cumulative health outcomes is about 30% lower in mitigation cases. PM2.5 emissions represent the majority of health impact over time.

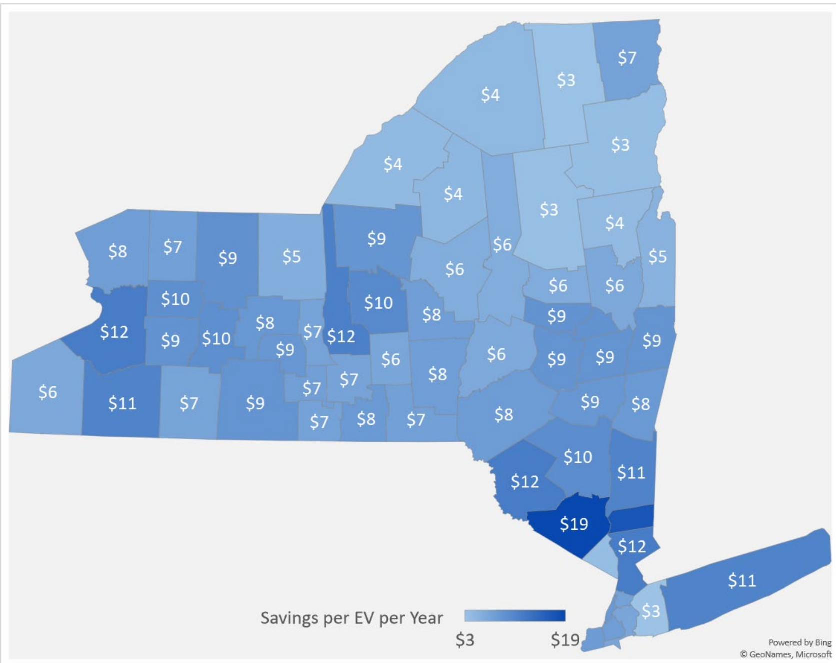
Figure 26. Comparison of Cumulative 2020–2050 Statewide Value of Health Outcomes ($2020) for Key Pollutants under Each Case



The magnitude of the cumulative health value in Figure 26 is nearly identical across Mitigation Cases. This result is driven by the similar pace of the transition to EVs and FCEVs across Mitigation Cases. Indeed, all Mitigation Cases assume New York State complies with the Advanced Clean Cars II and Advanced Clean Truck regulations and achieves the goals set in the September 2021 legislation, in which all new LDV sales are zero-emission vehicles by 2035 and all MHDV sales are zero-emission vehicles by 2045. Accordingly, the slight differences between Mitigation Cases along other dimensions (such as VMT, mode share, and the use of biofuels) does not result in major differences in the cumulative health burden.

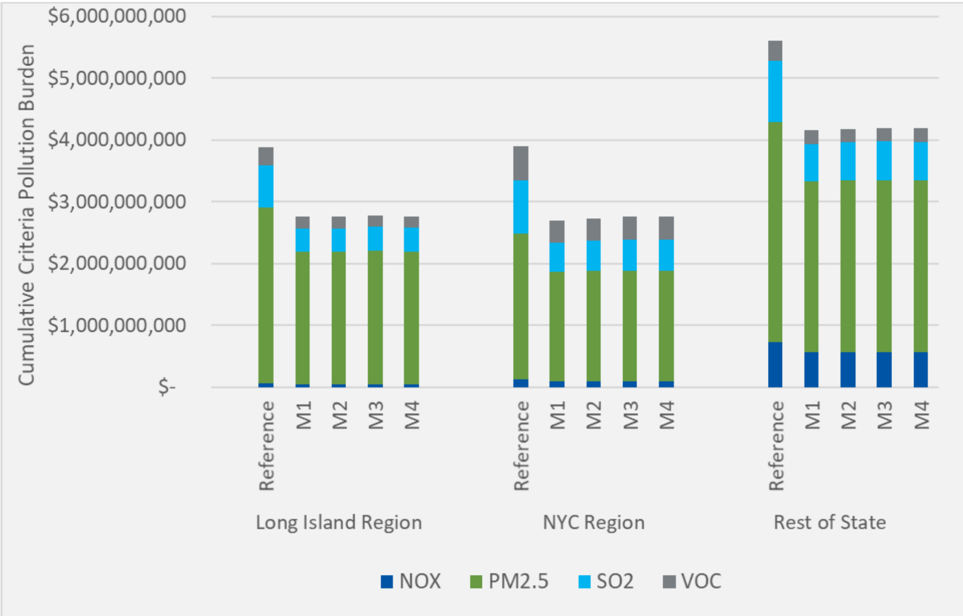
Regionally, the effects of the Mitigation Cases on health outcomes vary since the impact on concentration effect on populations is highly localized. One approach to conceptualize regional differences is to consider the change in value from replacing an average mid-size, gasoline-powered sedan with an equivalent BEV sedan using today's technology (Figure 27). Note these are societal benefits, not specific to the BEV owner. The county-level variation in Figure 27 is driven by several factors, including the ambient air quality, population, underlying health of local population, local meteorological conditions, and proximity of residents to transportation emission sources.

Figure 27. Annual Change in Value of Health Outcomes ($2020) by County per Internal Combustion Engine Vehicle Replaced with EV



When the State is divided into three large regions, the lowest cumulative health effects between 2020 and 2050 are in the New York City region,[92] as shown in Figure 28, which may be related to the relatively low numbers of vehicles per capita relative to other regions. However, this trend may not fully capture more concentrated pollution impacts that are highly localized.

Figure 28. Cumulative 2020–2050 Pollution Burden ($2020) for New York Regions under Each Case



5.2 Equity Impacts

This section discusses the impact of the Mitigation Cases on different socio-economic groups. In urban areas, housing is more expensive and low-income households and historically disadvantaged households tend to live in areas with longer commute times or in areas with fewer transit and mobility options.[93] Both factors increase the costs of transportation for those households. In rural areas, a key challenge to these groups is the lack of density and long distances between destinations, which make affordable transportation options like transit, walking, and biking impractical. Additionally, as discussed in section 2.3. Social Equity and Co-Benefits, due to the outsized burden of transportation costs on disadvantaged communities, policies that apply a uniform price signal to all consumers have a disproportionate impact on low- and moderate-income households, perpetuating existing inequities.

Figure 29 shows the fraction of trips by households in three income categories. The leftmost column in each income group illustrates today's mode share. The next three in each group illustrate mode share for the year 2050. M3 and M4 cases mirror M1 and M2, respectively, and are not shown. Figure 29 shows a slight shift across all cases and income levels toward greater active trips, even in the reference case. In mitigation cases, all income groups shift toward greater transit trips, although the shift is most pronounced in the low-income group. The VE-State model does not provide outputs by travel time so no conclusion can be made regarding how travel times change in mitigation cases.

Figure 29. Mode Share (% Trips) by Household Income Group by Trip Type

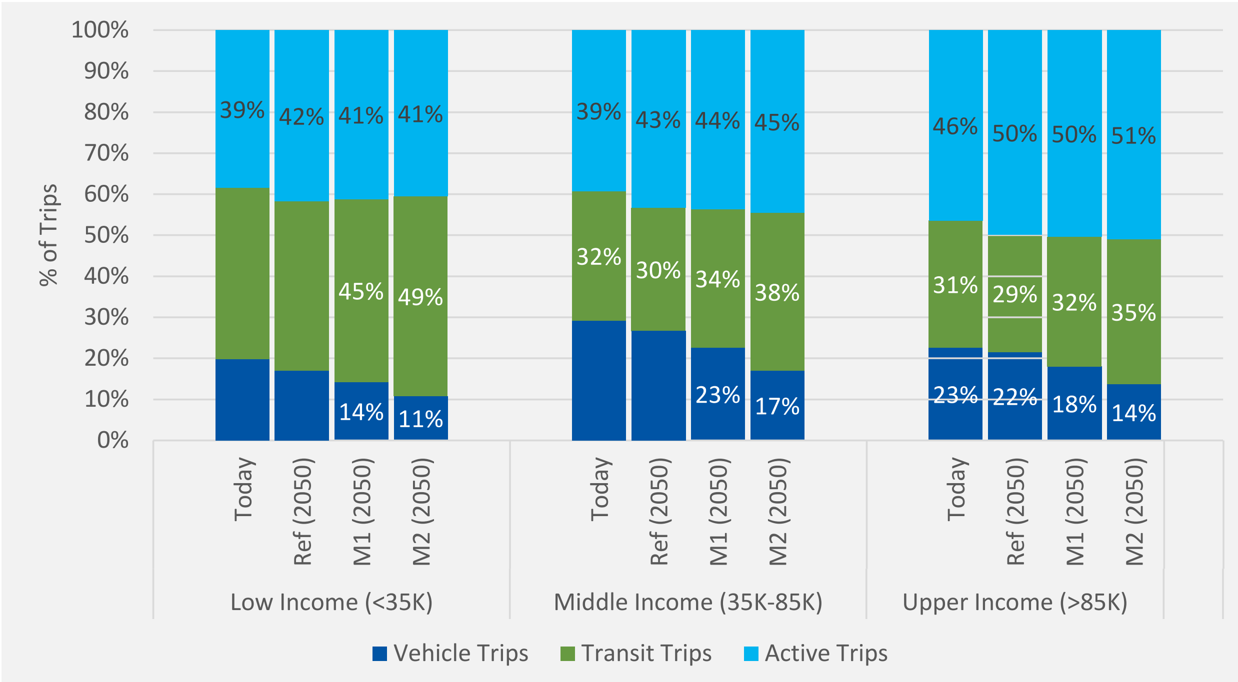
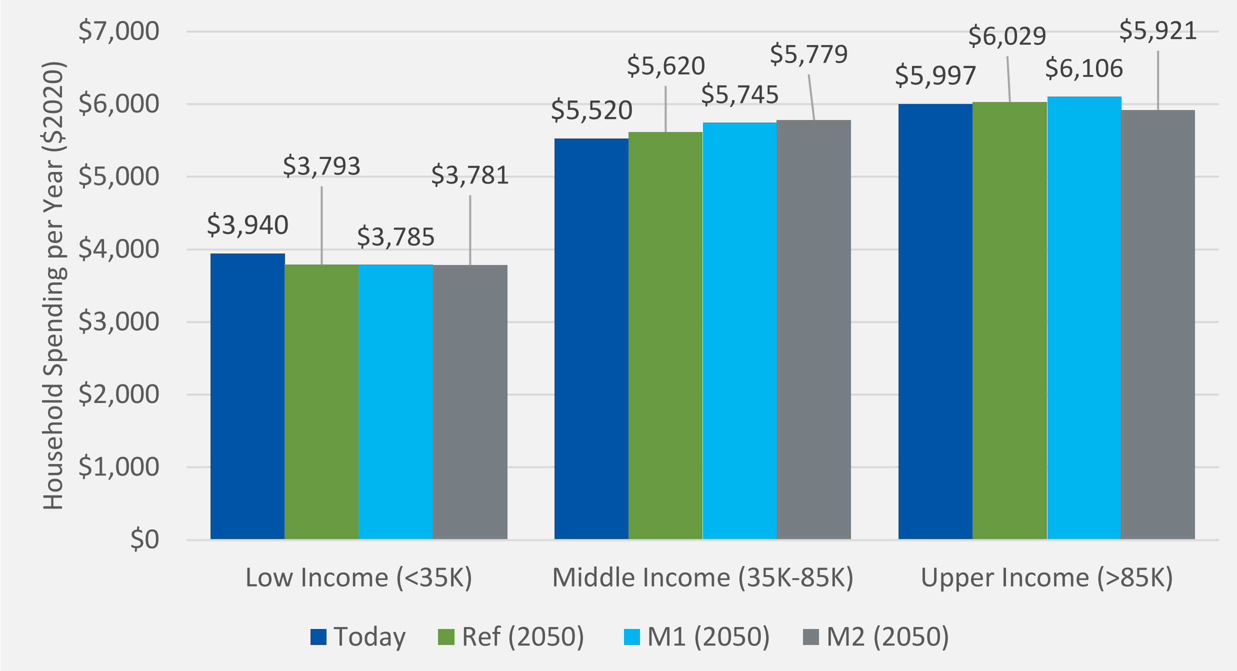


Figure 30 shows the annual household spending on transportation-related expenses in constant $2020. Compared to today and the reference case, household spending declines slightly for lower income households in M1 and M2. Middle- and upper-income households see a mix of increases and decreases in the future, although all changes are very slight. Household spending is driven by competing forces. Travel costs decline in the future across income levels due to the shift to transit and active modes in the future and the reduction in the cost per mile of driving (primarily from electrification). However, the total number of trips and vehicle miles traveled *increases* in the future across all cases. The net impact of these competing forces is relatively minor changes in transportation spending, but because incomes are expected to increase significantly over this period, transportation expenses would represent a lower percentage of overall household spending over time. This will be particularly impactful for lower income New Yorkers, where the percentage of total after-tax income spent on transportation will fall from approximately 40% in 2020 to approximately 18% in 2050.

Figure 30. Average Household Spending on Transportation, by Income Group



At the county level, other insights emerge. Figure 31 illustrates how VMT changes in the M2/M4 Cases relative to the reference case. The X-axis is the median household income in the county today. The figure demonstrates that counties with the highest median income levels tend to have the largest declines in VMT. This relates to several factors. First, counties with higher income tend to also be more urbanized. In mitigation cases, strategies that aim to reduce VMT—such as transit expansion—are most feasible in dense urban areas. Second, discretionary travel (or nonessential travel) tends to be more common among upper-income households.[94] A similar figure for the M1/M3 Cases is not shown but exhibits similar behavior.

Figure 31. Change in VMT per Household in 2050 between Reference and M2/M4 Case, by Median Household Income Level

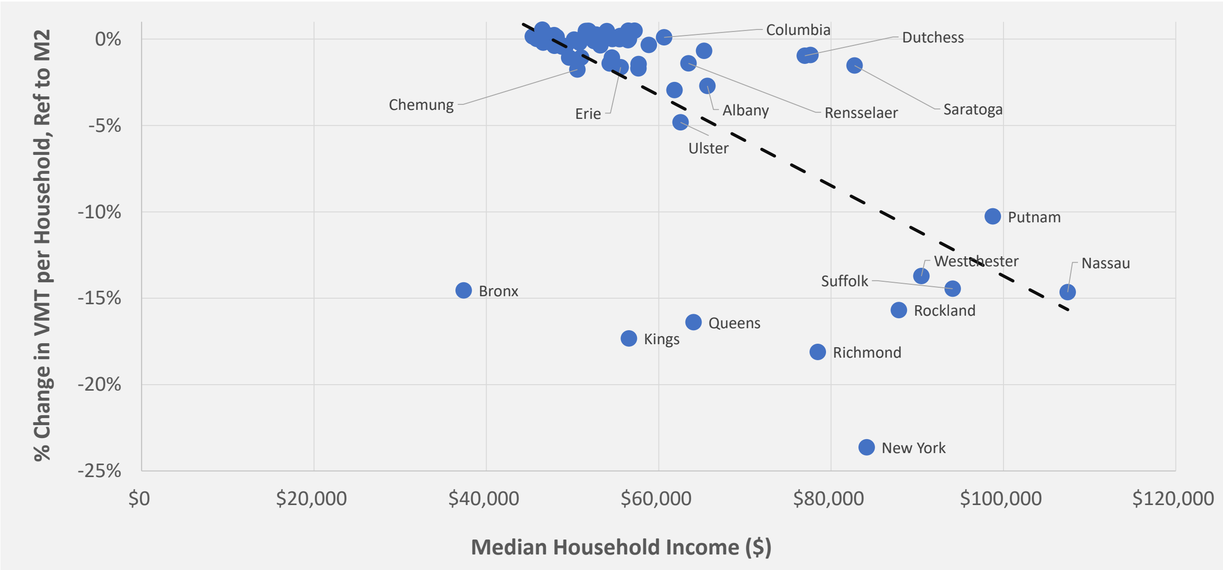
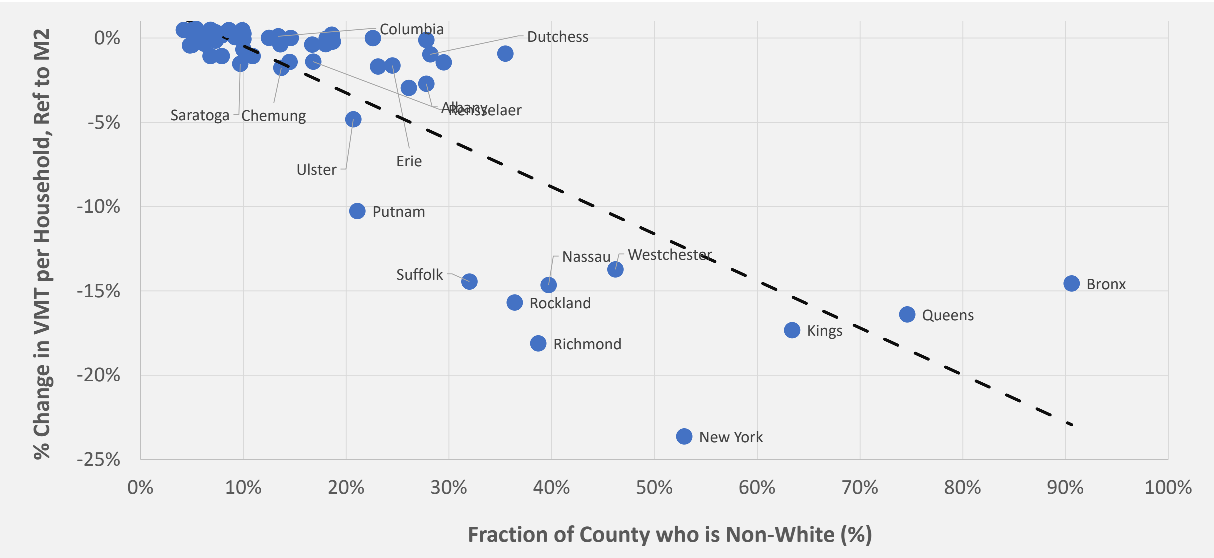


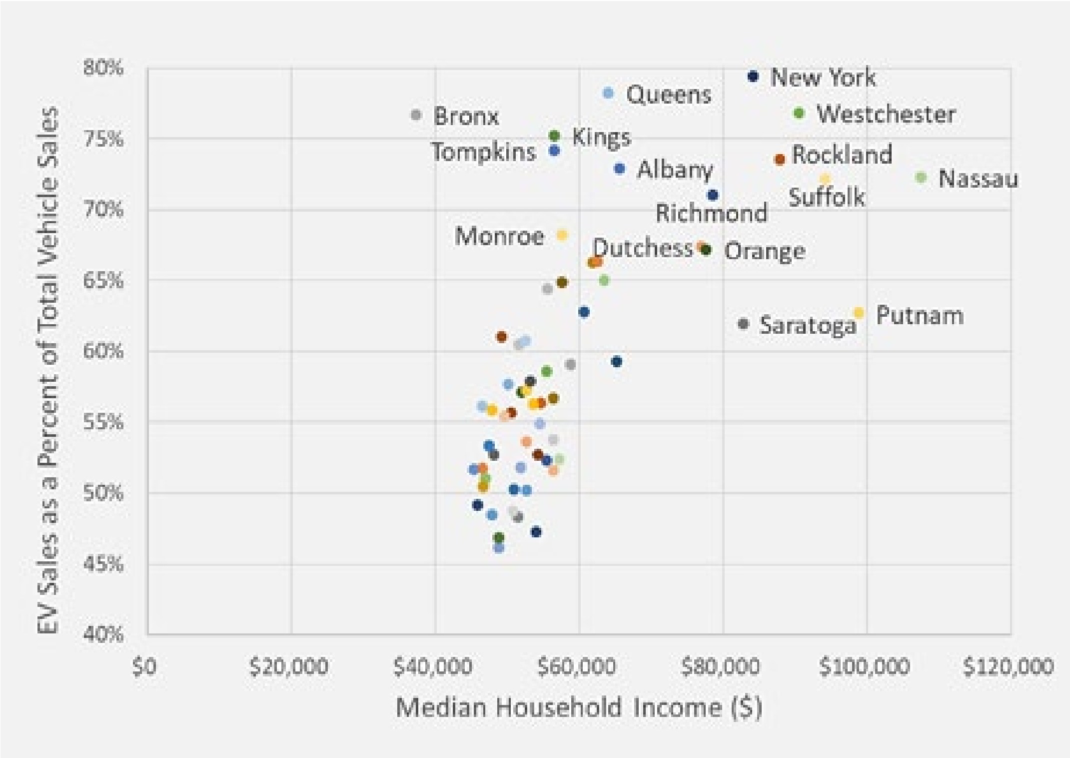
Figure 32 provides a similar illustration but changes the X-axis to the percentage of non-white residents in a county in 2020. As with income, race is strongly correlated with urban density. Again, counties with greater density tend to have more low-carbon transportation options and are better able to take advantage of increased transit, walking, and biking, so they see larger differences between the reference case and Mitigation Case 1, and even larger differences between the reference case and Mitigation Case 2. M1/M3 Cases are not shown but exhibit, although dampened, similar trends.

Figure 32. Change in VMT per Household in 2050 Between Reference and M2/M4 Case, by Percentage, Non-White



The fraction of transportation electrification also varies by income and race. For example, Figure 33 shows the new EV sales share by median household income in M1, the high-electrification case. The strong positive relationship between income and EV uptake is widely acknowledged. However, the 35 percentage point difference between the lowest-uptake counties and highest-uptake counties in 2030 is notable, especially given that by 2035, all counties have 100% EV or FCEV sales in the mitigation cases per the Advanced Clean Cars II regulation and September 2021 legislation. To address this potential discrepancy in EV adoption based on income, it will be critical to develop policies that support EV adoption in lower income communities to ensure that New Yorkers in the least affluent parts of the State are not delayed in realizing the benefits of rapid transportation decarbonization. These policies can help ensure that transportation electrification proceeds in an equitable manner.

Figure 33. M1 EV Sales Share in 2030 against County-Level Income



Policies that uniformly increase the cost of high-carbon or high-VMT transportation, like a carbon tax and VMT fee, respectively, may disproportionally impact households that lack access to alternative travel modes, such as rural and lower income households, and as a result are least likely to be able to reduce VMT going forward and are most likely to continue to be impacted by these higher costs. This is similar to the impact of the current gasoline tax, so it is not unprecedented, but policymakers should expand their efforts to ensure that mitigating policies are put in place to address potential inequities in these areas.

5.3 Total Expenditures

This section compares expenditures in New York State on on-road vehicle ownership (upfront, fuel, and maintenance costs), and refueling station infrastructure across the reference and four mitigation cases. These expenditure estimates only account for these costs and not for other transportation-related spending such as transit ridership. Here, the term expenditure refers to all payments relating to the ownership and operation of on-road vehicles by households, workplaces, fuel providers, fleet operators, and the public sector. Table 6 defines the expenditure categories for vehicle ownership.

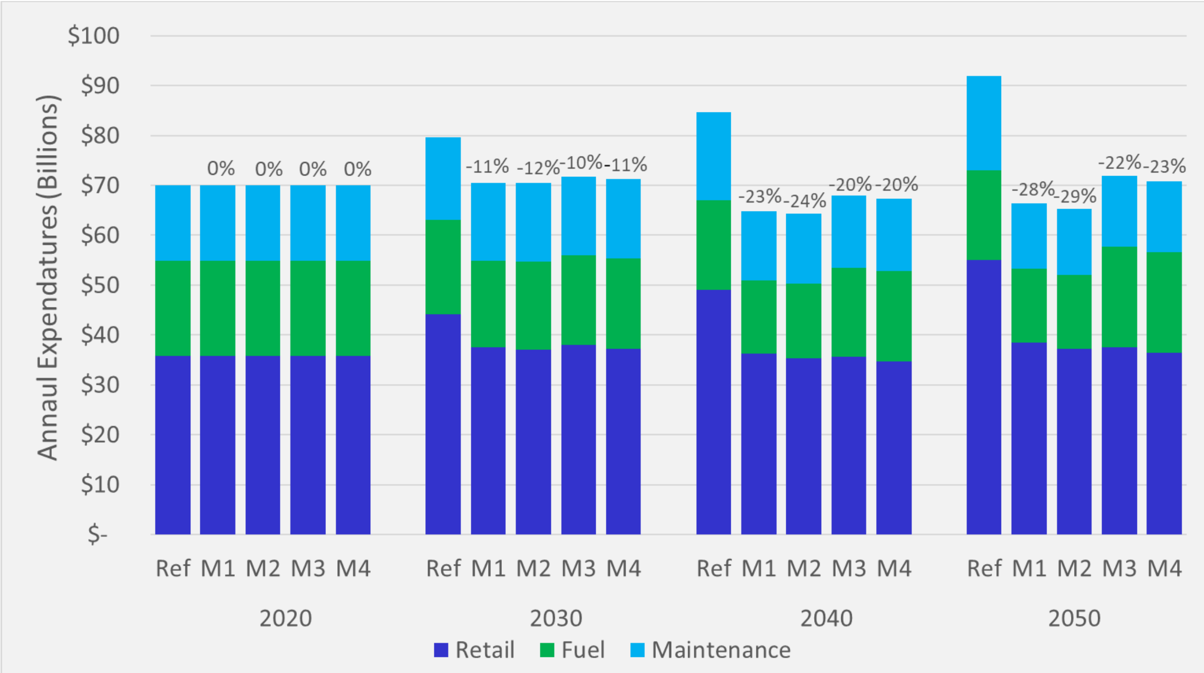
These expenditures are estimates, meant to provide a relative magnitude of spending in each case. These underestimate the total expenditures on all transportation because they do not include the expenses incurred for off-road subsectors, including aviation, rail, maritime, and other types of equipment. Indirect and induced impacts of these expenditures are discussed in the next section under economic impacts.

Table 6. Expenditure Categories and Examples for Vehicle Ownership

Expenditure Category	Description	Example in Category
Upfront vehicle expenses	Expenditures on upfront vehicle purchases of new on-road vehicles. Used vehicle sales are not tracked. Vehicle purchases in aviation, marine, rail, non-road sectors are not tracked due to lack of data.	Purchase of a new EV by a household.
Fuel expenditures	Expenditures on fuel by households and fleet operators. Expenditures include fuel purchases in on-road, LDV and MHDV subsectors.	Purchase of gasoline by a fleet operator for an ICEV.
Maintenance expenditures	Expenditures on maintenance by households and fleet operators. Expenditures include maintenance only for on-road vehicles. Aviation, marine, rail, and non-road subsectors are not included.	Maintenance payments for a privately owned ICEV.

As shown in Figure 34 below, by 2050 total expenditures on vehicle ownership are lower in the four mitigation cases than the reference case, due to a combination of factors including fewer on-road vehicles, reduced per-vehicle costs, lower projected VMT, and a shift away from vehicle ownership to walk, bike, and transit trips in each of the mitigation cases. Mitigation Cases 3 and 4 have slightly higher vehicle expenditures than Mitigation Cases 1 and 2, averaging 1.4%, 4.8%, and 8.2% more in 2030, 2040, and 2050, respectively, because of the assumed higher fuel and maintenance costs of hydrogen FCEVs compared to EVs. Overall, Mitigation Case 2 features the lowest cumulative vehicle expenditures between 2020 and 2050 at $2.238 trillion, slightly lower than Mitigation Case 1 at $2.256 trillion, due to lower VMT and a higher ICEV stock (and, thus, more gasoline fuel use). Mitigation Cases 3 and 4 have cumulative expenditures of $2.326 trillion and $2.303 trillion, respectively.

Figure 34. Total Expenditures on Vehicle Ownership



Despite lower vehicle ownership expenses in the mitigation cases by 2050, refueling station capital costs will increase. Table 7 describes expenditure categories for refueling infrastructure tracked across the scenarios. These expenditures would presumably be borne by a mix of private and public sector investment, some of which would be recouped through fuel sales tallied above. Therefore, it would be inaccurate to try to add the expenditures in Figure 34 with those in Figure 35 to get the total expenditures on transportation. Note the expenditure associated with installation of new refueling stations for gasoline, diesel, and other liquid fuels are not captured in these estimates but are expected to be small relative to the scale of expenditure on electric and hydrogen fueling infrastructure.

Table 7. Expenditure Categories and Examples for Refueling Infrastructure

Expenditure Category	Description	Example in Category
Charging for Non LDV	Expenditures on charging stations for MHDVs. Category includes estimated cost of charging equipment, installation, land, and utility make-ready. Operational charger costs are not included.	Expenditure by multiple entities on DCFC station capital, installation, and utility make-ready.
Public charging (LDV only)	Expenditures on publicly accessible LDV charging stations by fuel providers, fleet operators, and the public sector. Category includes estimated cost of charging equipment, installation, land, and utility make-ready.	Expenditure by a city government to install public Level 2 chargers.
Private charging (LDV only)	Expenditures on privately accessible LDV charging stations by households, workplaces, multi-unit dwelling owners, fleet operators, and the public sector. Expenditures include charging for on-road vehicles only. Category includes estimated cost of charging equipment and installation.	Expenditure by a household to purchase and install a residential Level 2 charger.
Hydrogen refueling stations	Expenditures on publicly accessible hydrogen refueling stations by fuel providers, fleet operators, and the public sector. Expenditures include charging for on-road, aviation, marine, rail, and non-road subsectors. Category includes estimated cost of refueling equipment.	Expenditures by public sector to install refueling stations.

Expenditures on charging and hydrogen refueling infrastructure, illustrated in Figure 35, are much higher in the mitigation cases than in the reference case because a much larger number of those refueling stations are required to support these projected technology transitions. Mitigation Cases 3 and 4 have lower capital costs due to the lower projected costs of the hydrogen refueling network compared to electric charging network across all sectors. Figure 36 shows the number of EV chargers installed by mitigation case, with M3 and M4 seeing fewer chargers installed due to the number of FCEVs. Over the 30-year time horizon, cumulative expenditures on EV and hydrogen infrastructure are $87 billion for the reference case, and $322 billion, $267 billion, $199 billion, and $195 billion for M1, M2, M3, M4, respectively.

Figure 35. Total Expenditures on Refueling Station Capital and Installation

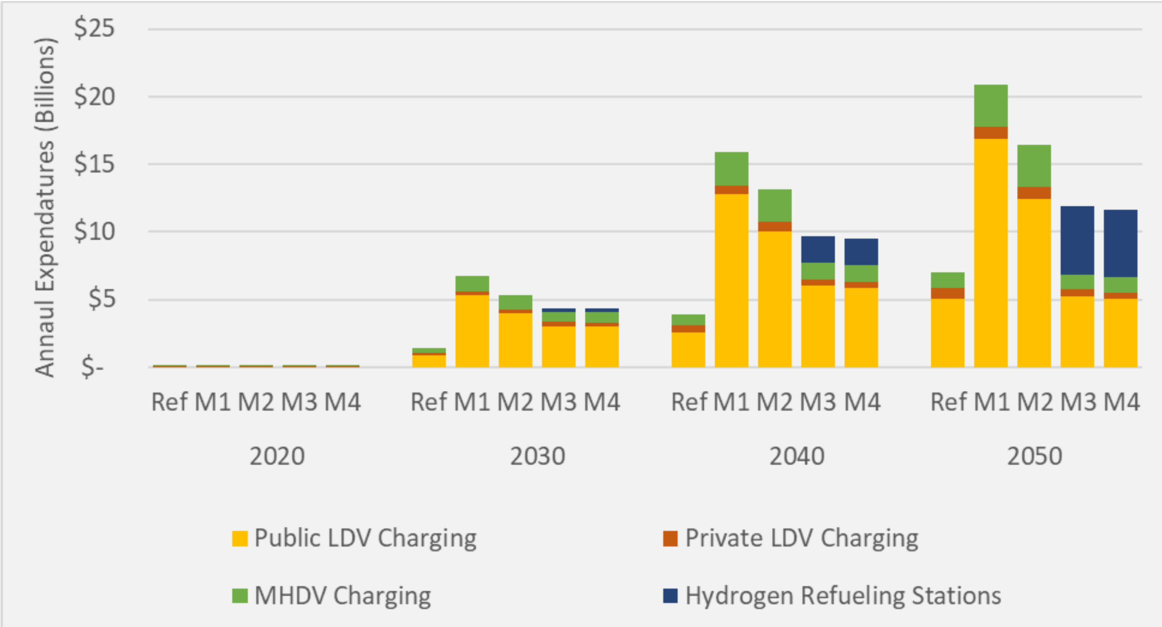
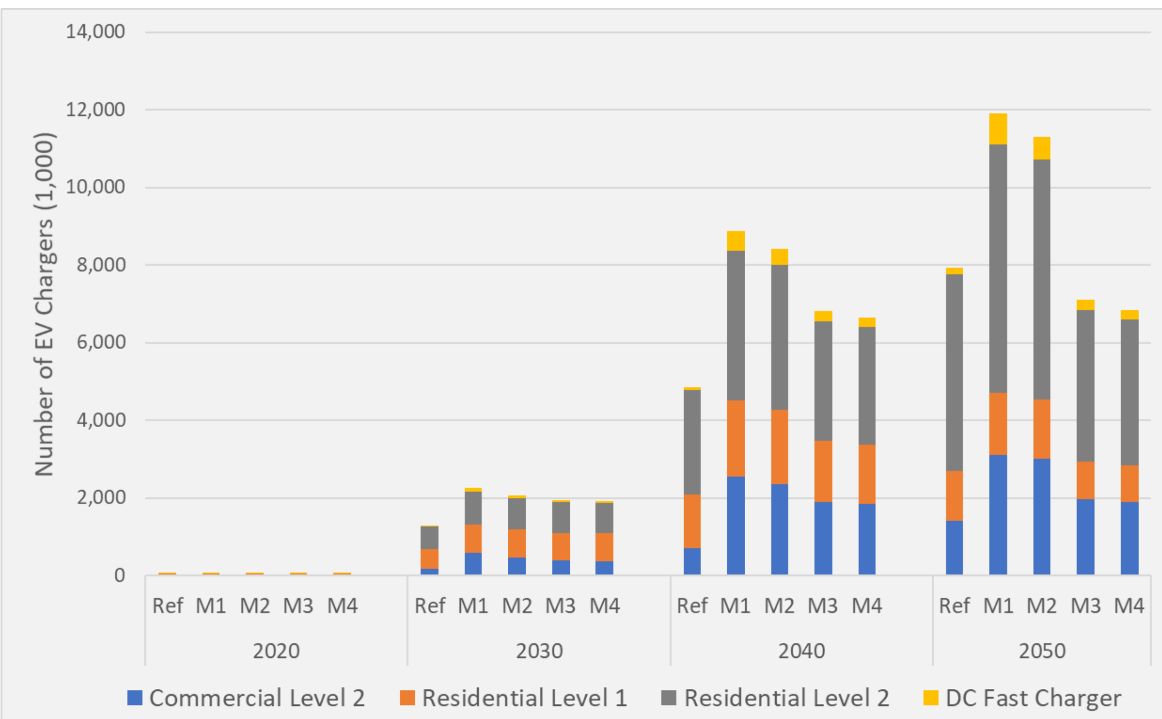


Figure 36. Total EV Charger Count



5.4 Economic Impacts

Clean transportation policies are projected to have broad impacts on economic activity in New York State. For example, a 2019 study estimated total societal economic benefits of $2.8 billion to $5.1 billion in aggregate from achieving New York State's 2025 EV target.[95] These are primarily driven by benefits from individuals saving on fuel expenditures, offset by the higher upfront cost of EVs over their ICE vehicle counterparts (at least in the near-term). Even in a scenario with low oil prices, societal benefits are estimated to outweigh costs, although the relative size of the benefits differs by region of the State.

Direct government spending produces ripple effects across the economy, affecting supply chains and household spending. For instance, government spending on EV incentives can increase EV demand, affecting not only automotive manufacturing but also automotive dealerships and transportation of durable goods. These changes in demand will affect the labor income of workers in these industries, who will then re-spend funds. As money cycles through the economy, the economic impact decreases over time through leakage or spending on imports or other services from outside of New York State.

The purpose of the macroeconomic impact analysis is to quantify the broader statewide effects of the mitigation scenarios relative to the reference case. Cadmus used IMPLAN ("IMpact Analysis for PLANning") software to analyze each of the mitigation cases. The economic impact analysis includes two major components: changes to direct transportation sector spending and household income compared to the reference case. More information about the modeling methodology can be found in appendix D–Policy Database, Details, and Analysis. Direct transportation sector spending decreases on net in all four mitigation scenarios due to decreased demand for vehicles, maintenance, and fuel. The negative transportation sector spending translates to cost savings for households, so household income is net positive for each mitigation scenario.

At its core, IMPLAN captures how various parts of the economy are connected. It describes what industries buy and sell to each other and to households and the government. By inputting a direct change to one industry, the model estimates impacts on connected industries. The model produces results for the following four variables:

- **Employment—**A full or part time job lasting one year, consistent with the definition used by the U.S. Bureau of Economic Analysis and Bureau of Labor Statistics. As a person can have more than one job, this is not a count of employed persons.
- **Labor income—**The combination of employee compensation (wages, salaries, benefits, payroll taxes) and proprietor income (e.g., self-employed individuals).

- **Output—**The total value of annual production of each industry or commodity (e.g., total revenues adjusted for inventory changes). Example: A baker sells $10,000 worth of cake products. The output is $10,000.
- **Value-add—**The increase in value an industry creates. Example: A baker sells $10,000 worth of cakes. The baker pays $3,000 in shop costs and $4,000 for ingredients. The value-add is $10,000 minus $7,000 in costs (intermediate inputs), or $3,000.

5.4.1 Results and Discussion

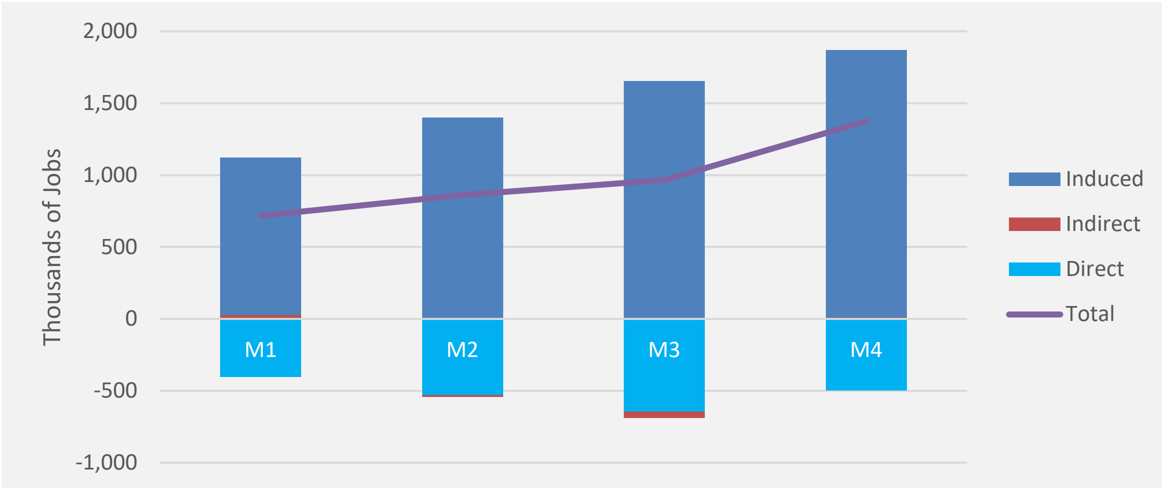
The economic impacts are overall net positive for all scenarios, as shown in Table 8. This is largely due to decreased imports (i.e., vehicles, petroleum products) and increased local production of goods and services (i.e., electricity, charging/refueling infrastructure). The mitigation scenarios result in substantial cost savings to households, which were modeled as increased household income. Spending of household income in the local economy further drives positive economic outcomes in New York State. M4 had the strongest impacts because it had the largest household income increase and the least negative total direct industry impacts. See appendix E for details on modeling methodology and list of IMPLAN inputs.

Table 8. Economic Indicators by Scenario

Scenario	Employment (thousands)	Labor Income (billions of $)	Value Added (billions of $)	Output (billions of $)
M1	717	$65	$128	$218
M2	860	$72	$147	$240
M3	966	$168	$270	$361
M4	1,374	$202	$322	$456

Figure 37 shows the employment impacts by mitigation scenario. Direct effects refer to employment changes resulting from changes to transportation sector spending, which, as noted above, are negative for each scenario. Indirect effects arise from business-to-business purchases in the transportation sector supply chain; these are relatively small for each scenario because most of the supply chains for transportation are outside New York State. Induced effects refer to employment changes resulting from changes to household incomes due to the changes in each scenario, which, as noted above, are positive for each scenario. The reduction in direct transportation spending has a negative impact on employment in each scenario, but this negative impact is more than offset by job increases in other parts of the economy from increased consumer spending.

Figure 37. Cumulative Employment Impacts by Mitigation Scenario



M4 has the highest total cumulative employment impacts, at just under 1.4 million jobs over 30 years. Compared to total 2019 employment, which IMPLAN shows to be 12.8 million jobs in one year for NYS, this represents an increase in employment of about 0.3% per year. The other scenarios result in a slightly lower increase of 0.2% higher annual employment.

Figure 38 shows the value-add by mitigation scenario. As with employment, M4 is the greatest, with a net value-add of $322 billion. Induced impacts are largest for M4 compared to the other scenarios. In addition, the direct impacts for M1 and M2 are negative, while they are positive for M3 and M4. This difference is due to the higher multiplier associated with the hydrogen pipeline infrastructure spending in M3 and M4.

Figure 38. Cumulative Value-Add Impacts by Mitigation Scenario

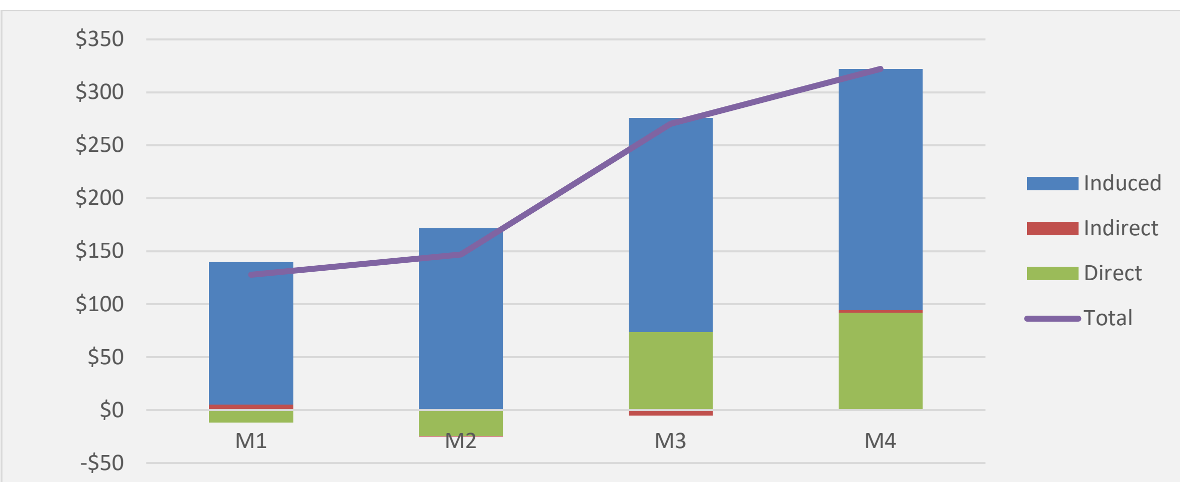
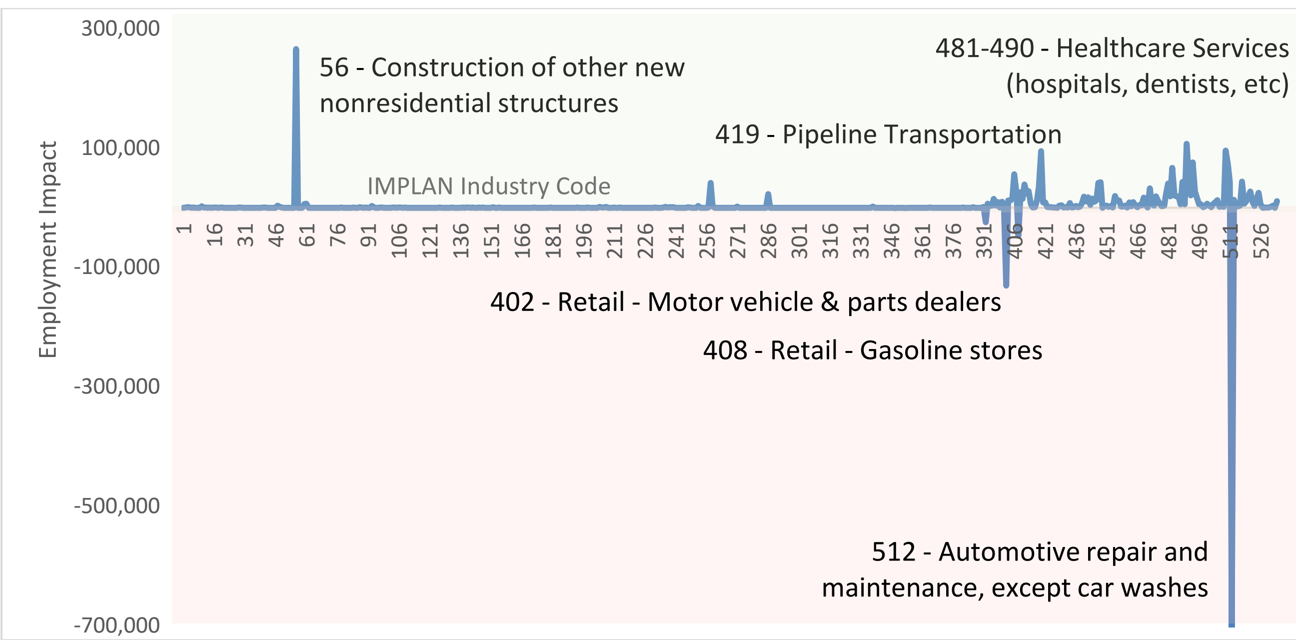


Figure 39 shows the change in employment by industry for M4, illustrating positive impacts are generally distributed over a wide range of services (e.g., healthcare and restaurants), with a few spikes for direct investments (pipeline and construction of parking areas). In-State electrical sector jobs is IMPLAN code 46, which has only a minor increase in employment. Negative impacts are concentrated in a few industries, such as vehicle retail and automotive maintenance/repair. The other mitigation scenarios follow similar trends, with smaller positive impacts distributed over more industries and negative impacts concentrated among automotive/fuel retail and maintenance.[96] The largest industry decline is in automotive maintenance/repair. For context, the total automotive maintenance and repair employment in New York State over 30 years is 2.75 million job-years so the decline in Figure 39 represents approximate a 25% decrease.[97] Although the mitigation scenarios all show a decline in vehicle purchases, vehicle maintenance, and fuel, only the vehicle maintenance industry is local so declines in that sector reflect primarily in-State impacts. Negative impacts from decreased imports of vehicles and fuels accrue out of State.

Figure 39. Cumulative Employment Impacts by IMPLAN Industry (M4)



5.5 Fiscal Impacts to the State

Not all transportation decarbonization policies are equal in their effect on government budgets. Policies like a carbon price and gasoline tax can generate proceeds, while vehicle purchase incentives and rebates incur costs. Policies can also be implemented or adjusted in ways to be revenue-neutral, either by facilitating transfers between groups or by providing refunds to citizens from the income generated by the policy.

As illustrated in Table 9, the estimated fiscal impact on New York State differs under the four mitigation cases due to differences in their policy mix. This table summarizes the cumulative fiscal costs to the State in current 2020 dollars and excludes revenue-generating policies like a RUC. Policies under Mitigation Cases 2 and 4 require the highest overall investments of $60.7 billion and $60.2 billion by 2050, respectively, whereas policies in Mitigation Cases 1 and 3 incur the lowest total costs, $41.2 billion and $39 billion, respectively.

Table 9. Cumulative Fiscal Costs to the State*

Scenario	Cumulative Cost, 2020 2050 ($2020 Billions)	Cumulative Cost per Capita ($2020 and 2020 population)	Cumulative Cost per Ton of C02e ($2020 Billions)
Mitigation 1	$41.0	$2,043	$21.4
Mitigation 2	$60.2	$3,005	$30.3
Mitigation 3	$38.6	$1,933	$19.8
Mitigation 4	$59.7	$2,979	$29.9

* Does not include proceeds from policies that generate revenues, like carbon taxes.

Table 10 disaggregates the costs into sub-costs. The major drivers of the cumulative costs are transit expansion and TDM measures (including bicycle and pedestrian infrastructure), and to a lesser degree vehicle incentives, charging/fueling incentives, and active transportation expansion (bike, e-bike, and pedestrian). The estimates of each are briefly described below:

- **Incentives (LDV)–**EV incentives are modeled to phase out by 2030 from current levels in a linear fashion. For FCEVs, incentives phase out between 2023 and 2035 starting at $4,500 and declining to $0 in a linear fashion. Only 75% of consumers receive rebates. Low- and moderate-income households receive an addition $1,500 per vehicle through 2035.
- **Incentives (MHDV)**–Incentives are modeled to cover 35% of the upfront cost difference between ZEVs and their ICEV counterparts. In 2020, 90% of consumers receive rebates. By 2035, 60% of consumers receive rebates.

- **Incentives (EVSE)**–Modeling assumes that New York State provides rebates for all EV charger types. Rebates range from $300 for single-family detached houses to $50,000 per plug for DCFC and MHDV chargers. Rebates phase out by 2030 for LDV chargers and by 2035 for MHDV chargers.
- **Incentives (Hydrogen Station)**–Modeling assumes that New York State fully funds 10% of all hydrogen station capital costs required by 2050, with the majority of funding coming between 2025 and 2035.
- **Smart Growth (Transit Expansion)**–Modeling assumes that New York State funds the expansion of transit service along existing bus and rail lines, with costs based on operations and maintenance budgets of today's MTA service. Expenditures occur over 15 years between 2025 and 2040.
- **Smart Growth (Mixed Use Development)**–Modeling assumes that New York State changes zoning laws and provides training and outreach to ensure developers can comply with new rules. Note that this does not include any tax incentives required to promote this development.
- **Smart Growth (Bike, E-Bike, Pedestrian** –Modeling assumes that spending on bike, pedestrian, and e-bike infrastructure increases. Assume an average cost of $25,000 per bike lane mile and multi-use path.
- **Travel Demand Management (TDM) Measures**–Modeling assumes that New York State provides $150 per year for people who earn up to the median statewide income (50% of workforce) to use alternative travel modes for commuting. Modeling assumes an uptake of 50% of eligible participants.
- **Other Policies and Programs**–Modeling assumes that New York State funds a widespread education and awareness campaign to bolster uptake of new technologies such as EVs. Funding for FCEV education and awareness is lower than EVs since vehicle refueling is similar to ICEVs.

Fiscal costs of Smart Growth (Transit Expansion) represent the single largest estimated cost to the State. Costs of Smart Growth (Transit Expansion) reflect the cost of increasing the intensity of transit along existing transit corridors, rather than building new infrastructure. LDV incentives in Mitigation Cases 3 and 4 cost over $2 billion more than their Mitigation 1 and 2 counterparts due to the higher incentives provided for FCEVs compared to BEVs. On the other hand, the EVSE installation incentives for MHDV require roughly $2 billion more under M1 and M2 than in M3 and M4, which are only partially offset by incentives for hydrogen refueling stations in M3 and M4. This is primarily due to the cost of incentivizing a larger number of EV chargers across the state in M1 and M2 and at higher incentive levels compared to the cost of supporting a smaller number of hydrogen refueling stations, construction of which is assumed to become self-sufficient over time.[98]

Table 10. Cumulative Fiscal Costs by Mitigation Scenario, 2020–2050 ($2020 Billions)

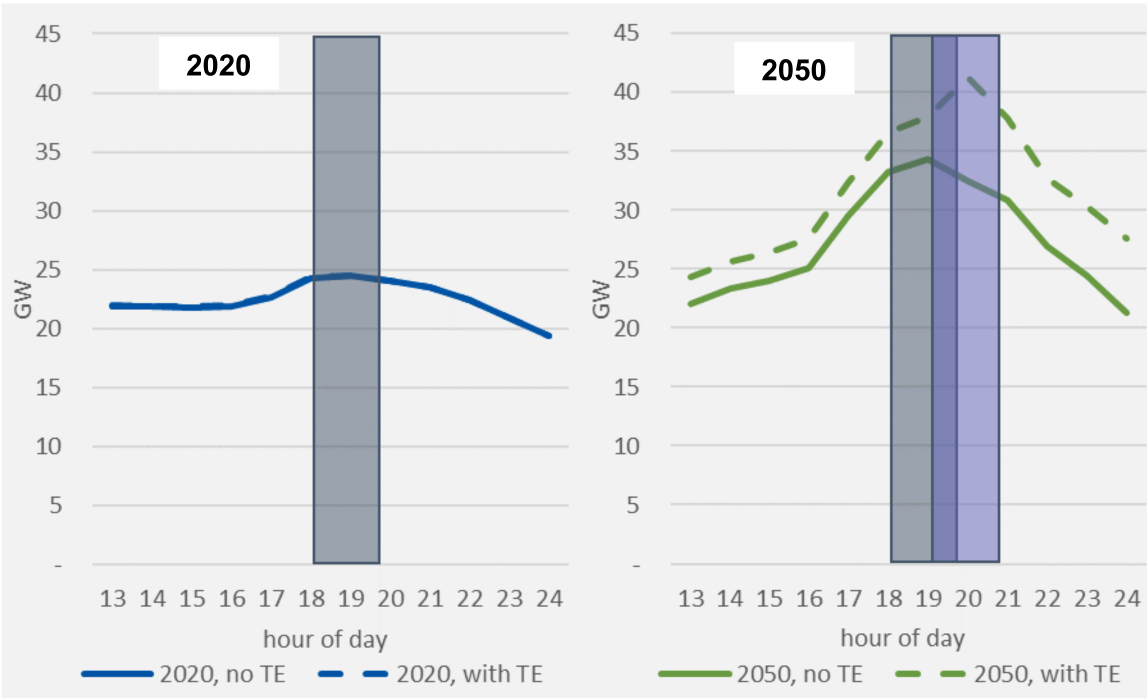
Fiscal Costs	Mitigation 1	Mitigation 2	Mitigation 3	Mitigation 4
Cumulative Cost	**$40.96**	**$60.23**	**$38.59**	**$59.71**
Incentives (LDV)	$0.55	$0.48	$2.66	$2.58
Incentives (MHDV)	$2.08	$2.13	$2.09	$2.13
Incentives (EVSE)	$5.50	$3.64	$1.02	$1.02
Incentives (Hydrogen Station)			$0.42	$0.42
Smart Growth (Transit Expansion)	$22.92	$34.38	$22.92	$34.38
Smart Growth (Mixed Use Development)	$7.02	$7.37	$7.02	$7.37
Smart Growth (Bike, E-Bike, Pedestrian)	$2.54	$5.09	$2.54	$5.09
TDM Measures (e.g., employer carpooling)		$7.07		$7.07
Other Policies and Programs	$0.35	$0.07	$0.35	$0.07

5.6 Electric Distribution System Impacts

Observations on LDV charging behavior suggest that unmanaged, normal EV charging periods can overlap with the current system peak of the electricity grid. At the local level, this increased load could negatively impact distribution networks and power quality, requiring potentially expensive upgrades to the system. The impact of EV charging on distribution systems is expected to be exacerbated at sites with high-powered charging and where many EVs are concentrated at specific locations, such as clusters of residential LDV charging or fleet depots. If charging behavior is left unmanaged, as transportation electrification increases this new load could drive the electricity system toward steeper peaks, necessitating adding costly upgrades including electricity generation capacity and infrastructure enhancements. The speed and degree of ramp-up required to serve steeper local and system peaks could increase costs and be technically difficult for grid operators to plan for and accommodate.

Figure 40 shows the effect of transportation electrification load on the magnitude and timing of the system peak. The gray bands in both figures bound the original timing of the system peak in the reference case without transportation load, between 6:00 and 8:00 p.m., which holds for 2020 through 2050. When unmanaged transportation load is included in the analysis for 2020, there is no meaningful effect on the system peak because the amount of electrified transportation is small. Even with the moderate levels of transportation electrification projected in the reference case, by 2050 unmanaged transportation loads increase and shift the total system peak later into the evening hours, between 7:00 and 9:00 p.m., indicated by the area in the purple band. This figure shows the winter load shape, but the pattern holds for the summer load shape as well.

Figure 40. Winter Peak Day Profiles, Unmanaged Transportation Electrification (TE) Load (Ref Case)[99]



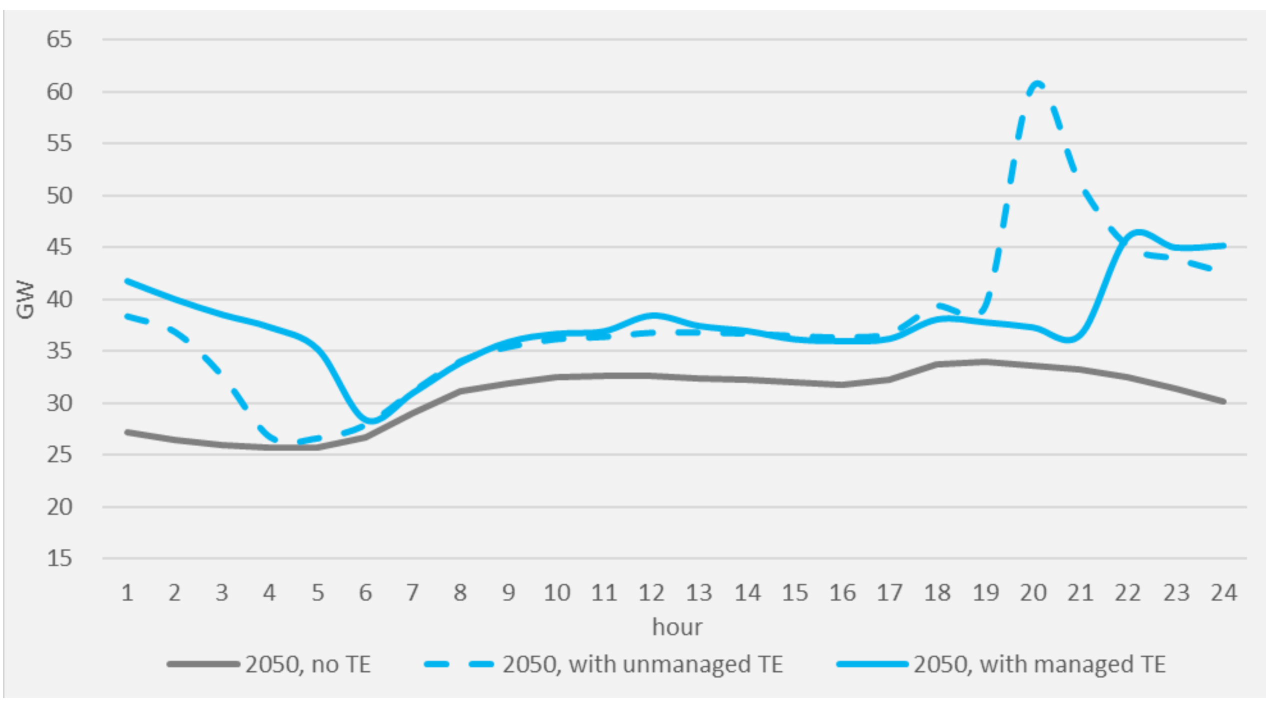
Note: Dashed lines indicate total system load inclusive of that from transportation electrification (TE).

Managed charging measures can help shift EV charging activity to address system-level concerns as well as site-specific peaks. "System peak avoidance," the primary approach applied in this analysis, focuses on managing EV load around the NYISO system net load after integration of customer-sited, behind-the-meter generation and storage resources. Additionally, measures to address site-level peak demand, referred to as "demand management," are modeled for some MHDV charger use cases, where applicable. As renewables continue to scale up in New York State, managed charging protocols can also shape behaviors to take advantage of daytime solar or late-night wind resources, maximizing integration of renewables.[100]

Managed charging measures and flexible loads can have a significant impact on residential charging of LDVs and depot charging of medium- and heavy-duty fleet vehicles.[101,102] For purposes of this analysis, modeling used time-of-use (TOU) signals based on periods designed around system peaks to shift charging away from system peaks. For the LDV subsector the analysis draws from real-world data, incorporating some of the unique factors that characterize charging behavior both regarding decisions to participate and in the sensitivity of drivers' responses to price signals. For the MHDV subsector, fleet managers are assumed to be rational actors that will minimize costs to the extent feasible within the constraints of their operations. Given this, we do not assume 100% of the State's medium- and heavy-duty fleet will adopt managed charging measures, but those that do are modeled as fully responsive to the price signals from the TOU rate. Additionally, the analysis applies site-specific demand management for MHDV loads by distributing vehicle daily energy demand evenly over the entire time a vehicle is in the yard.

Figure 41 illustrates the potential timing and magnitude of flexible load that could be achieved with managed charging measures. The system peak with unmanaged transportation load, represented by the dashed blue line, includes a 20 GW surge in electricity demand between 7:00 and 8:00 p.m. When the managed charging measures are applied the increase is reduced by more than half by shifting the added load later into the evening, as indicated by the more moderate rise of the solid blue line by 9 GW between 9:00 and 11:00 p.m. The lower and later peak can lessen the need for additional electrical capacity and infrastructure upgrades, resulting in cost-savings. Note that despite their distinct forms, both load shapes illustrated by the blue lines provide the same total energy over the course of the day. As technologies and policies continue to develop over the next 30 years, it is likely that additional tools for managing EV load will become available that will further enable the flattening of EV electricity demand. Examples include real-time rates or dynamic pricing, low-cost energy storage, and direct load control through grid-integrated technologies.

Figure 41. Effect of Managed Charging Measures on System Peak (Mitigation Case 1)



Managed charging measures can enable efficient load growth while mitigating upward pressure on electricity prices. In conjunction with this Roadmap, NYSERDA commissioned a Transportation Electrification Distribution Impacts (TEDI) study, which found that by 2050 the annual capital costs associated with unmanaged transportation electrification load will be 1.1 to 4.8 times greater than the costs associated with a scenario in which managed charging measures are applied. While the Roadmap utilizes findings from the TEDI study, further details including managed charging assumptions and projected scenarios can be referenced in the separate TEDI report.

Table 11 presents the projected incremental dollars per kilowatt-hour (kWh) electricity rates that would increase in each scenario in order to cover projected distribution system costs with and without additional transportation electrification loads. These cost impacts translate to 2050 rates that are between 0.5 and 6% above today's rates, whereas without any transportation electrification rates rise by less than 0.5% in the reference and mitigation cases. In all cases, managed charging measures create notable savings on these costs. Notably, these impacts are aligned with, though significantly lower than, results from a similar 2019 analysis that estimated rate impacts from $0.0024 to $0.0475 per kWh, depending on levels of EV adoption and optimization of charging patterns.[103]

Table 11. Statewide Average Incremental Rate Impact ($/kWh)

Parent Scenario	Transportation Scenario	2021 2025	2026 2030	2031 2035	2036 2040	2041 2045	2046 2050
Reference Scenario	Unmanaged TE	$0.00	$0.001	$0.001	$0.001	$0.002	$0.003
Reference Scenario	Managed TE	$0.00	$0.00	$0.001	$0.001	$0.001	$0.002
Reference Scenario	No TE	$0.00	$0.00	$0.00	$0.00	$0.001	$0.001
High Distribution Impact Scenario	Unmanaged TE	$0.00	$0.001	$0.005	$0.007	$0.008	$0.009
High Distribution Impact Scenario	Managed TE	$0.00	$0.001	$0.003	$0.004	$0.004	$0.005
High Distribution Impact Scenario	No TE	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Low Distribution Impact Scenario	Unmanaged TE	$0.00	$0.00	$0.001	$0.001	$0.001	$0.002
Low Distribution Impact Scenario	Managed TE	$0.00	$0.00	$0.00	$0.00	$0.001	$0.001
Low Distribution Impact Scenario	No TE	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00

Although previously conducted sensitivity analyses found the share of EV sales to be insensitive to changes in gasoline prices, these analyses did not assume any variation in electricity rates. An additional sensitivity analysis that incorporated the High Distribution Impact Scenario's unmanaged TE load rate impacts found minimal effect on consumers' decisions to invest in EVs. In the worst case, the increase in electricity rates resulted in a 0.0012% drop in EV sales in 2033.

Implementing managed charging measures such as those illustrated above is generally cost effective for vehicle operators. The additional cost of paying for a networked charger is paid back through savings on fuel costs. For example, a customer served by National Grid that uses 650 kWh per month in general electricity consumption and 360 kWh per month for off-peak EV charging might save approximately $175 per year compared to the base rate.[104] This whole-house rate does not require that EV load be separately metered, avoiding that additional cost. EV drivers can schedule charging activity around the TOU signals through their charger or through onboard vehicle technology. Other managed charging programs provide payments to drivers for avoiding charging during critical system peaks, such as Green Mountain Power's Rate 72.[105]

Case Study: SmartCharge New York

Con Edison's program, SmartCharge New York, encourages electric vehicle (EV) drivers and fleets in New York City and Westchester to charge at periods of low electricity demand to reduce stress on the electrical grid. The SmartCharge program was initially funded with $6 million through Con Edison's 2017 rate case with a target to reduce system peak by 1.5 megawatts in the first year and one megawatt per year in the next two years relative to forecasted load.[106] EV charging demand is generally easier and less expensive for utilities to meet if it occurs during off-peak periods when the grid has more transmission and generation capacity available. So far, the program has had the desired effect of encouraging charging at off-peak times, with over 70% of charging done by vehicles in the program occurring during the off-peak hours.[107] Based on the initial success of the program, Con Edison is focused on expanding to cover more drivers. Con Edison is exploring partnerships with vehicle manufacturers, like Honda and Tesla, to enable direct data collection through the vehicle's onboard telematics and bypass the need for a third-party device. Beginning in the summer of 2021, Con Edison rolled out a pilot project that enables Tesla drivers to participate without installing a device by pulling data directly from Tesla's on-board telematics. Getting trucks and buses to participate may be more challenging than passenger vehicles because they are often part of vocational fleets that may have less flexible charging schedules than individual drivers. Nonetheless, managing the charging of these vehicles will be crucial to minimizing the grid impacts of EVs. In 2018 the Public Service Commission approved Con Edison to expand program eligibility to medium- and heavy-duty vehicles.[108] Following the decision, 25 electric buses from the MTA and several privately owned Fuso eCanter electric box trucks have joined the program. Such innovative programs that incentivize trucks and buses to charge during off-peak hours can help New York integrate an increased number of these vehicles while reducing their impact on the electrical grid.

5.7 Blue Ribbon Task Force on Electric Vehicles

In the 2020 State of the State address, New York State announced the creation of a Blue-Ribbon Task Force (BRTF) on Electric Vehicles to identify research and development opportunities and expand the transportation innovation economy across New York State. The BRTF was led by Nobel Laureate Dr. Stanley Whittingham and NYSERDA, who convened several panel discussions with New York State and global EV experts. The panels were comprised of leaders from across the EV industry, including representatives from various public agencies, utilities, automakers, academics, and other industry groups.

These groups brought their exceptional and diverse expertise, experience, and perspectives together to identify areas for increased research and development investment, economic development opportunities, and competitive advantages within NYS that could be further developed and leveraged as part of an ambitious effort to bolster EV adoption and industry expansion in the State.

In addition to assessments of current market trends, technological developments, and policy support, the task force members discussed a range of topics and identified several promising areas for further study. Key findings, promising avenues for exploration, and recommendations from the members are summarized below.

5.7.1 Global Markets and Trends

New York State has taken an aggressive and comprehensive approach to GHG reduction and has made electrifying transportation a major component of that effort, recognizing the increasingly viable economic development opportunities surrounding EVs. Transitioning to EVs has become an important global priority over the last several years as policy makers around the world focus on reducing carbon emissions from transportation. Simultaneously, EVs are increasingly attractive to consumers and are featured in central roles in the long-term strategies of most mainstream automakers.

The growth of EV development and sales is highly dynamic and driven by emerging technologies and markets. There have been significant advances in energy storage cost and capacity, battery recycling, motor efficiency, and other areas, but electrifying transportation is still in its relatively early stages and remains reliant on upfront capital and public policy support. It is critical to contextualize New York State EV economic development opportunities within a global market, but equally important to understand the more localized factors that shape the EV economy, and the ways that those factors may be leveraged to effectively position NYS relative to the broader market.

Overseas EV markets such as China have been particularly proactive in using industrial policy and seed capital to advance a vibrant EV and EV-component manufacturing industry. The Chinese government has invested heavily in firms in the EV industry to build manufacturing capacity and develop a robust supply chain and has offered generous incentives to EV buyers, although incentives have been phasing out and are expected to be eliminated at the end of 2022. In the U.S., California's approach to EV adoption has also included regulatory requirements and incentives for EV buyers, with an element of support for California-based manufacturers. Fueled by cap-and-trade policies, California's robust financial incentive programs allowed California to meet their 2020 emissions targets four years early and have continued to drive a strong and robust innovation economy in the State. Lessons learned from California and elsewhere can help demonstrate potential strategies for New York State in its goal to become a leader in the EV economy.

5.7.2 Current Status of the EV Economy and EV Research and Development in New York State

New York State can start building an EV economy from a strong base. The State's existing expertise and capacity for manufacturing, innovation, and research provide a robust starting point for all the components needed to create jobs around EVs. NYSERDA's 2021 New York Clean Energy Industry Report found that New York State already has about 9,000 jobs in the clean transportation industry, including more than 8,000 in hybrid and electric vehicles.[109] These subsectors grew by about 10% between 2019 and 2020 and have been consistently growing since 2016, when NYSERDA started compiling these reports. The report also looks at the potential for expanded EV manufacturing capacity, finding that potential EV supply chain manufacturers were concentrated in Erie, Monroe, and Suffolk counties, and account for one-third of all manufacturing jobs in the State. A survey of New York State manufacturers detailed in the NYSERDA report found that about two-thirds saw opportunities in the EV market and more than 40% felt that there was sufficient demand to build a profitable business focused on EVs. However, the same survey found that nearly 60% of respondents would need to make significant investments to serve the EV industry and about half would need to provide additional training to their staff.

Analysis by the BlueGreen Alliance has identified dozens of companies in the State that are already part of the automotive manufacturing supply chain, many of which are leaders in EVs.[110] This includes original equipment manufacturers and assemblers (such as Nova Bus, TransTech Bus, and Coach and Equipment), major suppliers (such as BAE Systems, Plug Power, and Bettergy), and dozens of other component manufacturers. Charging equipment is also built in New York State; Tesla builds many components of its superchargers at its Buffalo facility and startups like Brooklyn's HEVO Power are developing wireless charging technologies.

The State's research capabilities in the clean transportation area position the State to lead on EV innovation. Leading research on batteries and energy storage takes place in New York State, through world-recognized research facilities at Binghamton University, Stony Brook University/Brookhaven National Laboratory, corporate researchers, and other institutions. The New York Battery and Energy Storage Technology Consortium includes more than 185 members and facilitates battery research through testing, advocacy, and technical support. New York State also has a strong reputation for academic research on transportation, with experts at dozens of universities across the State, including the University of Buffalo, Cornell University, Clarkson University, NYU, City College of New York, and many others.

As a center of global finance, the State offers companies of all sizes access to capital for growing businesses and investing in expanded capacity. New York State's private financiers are rapidly expanding their investments in clean technology at the venture, private equity, and institutional investing levels. The State is uniquely positioned to leverage its experience financing other clean energy products, such as solar PV and energy efficiency retrofits, to invest in local and global EV markets. The New York Green Bank has committed to investing $100 million alongside private partners in clean transportation. And it supports startups in clean tech through NYSERDA's clean tech incubators and proof-of-concept centers and Empire State Development's New York Ventures program, centers for advanced technology, and other services for startups.

New York State's strong policy commitment to EVs is likely to attract the types of businesses that will thrive in such a policy environment. Its policies are helping to create the demand for EVs that many companies find attractive when choosing where to locate facilities. The State has committed to electrifying the State fleet, school buses, and many transit buses by 2035 and has adopted California's aggressive zero-emission vehicle purchase regulations. As the largest market on the East Coast for ZEVs, New York State's potential market pull makes it an attractive base for operations.

5.7.3 EV Research and Development Opportunities in New York State

It is critical to understand the current landscapes for EVs across technology, policy, and finance and to identify both pain points and opportunities for growth.

One of the greatest opportunities for New York State is to operationalize the best practices from ongoing projects that aim to scale EVs in and around New York City. New York City, with its strong public transit system, airports, and seaports, can provide an early testing ground for MHDV EV development and deployment. The MTA, DSNY, and many others have experience that could be invaluable to other organizations and can help illustrate the potential of EVs as viable alternatives to combustion engines, even in an urban environment with congestion, extreme temperatures, and other challenges. The unique aspects of the urban environment also provide an opportunity for stress-testing new technologies, such as electric TNC fleets, electric micro-mobility, and EV charging in grid-constrained areas, and a platform on which to bring new ideas to scale. This allows stakeholders to build out a comprehensive plan for a variety of pilot, product development and demonstration projects that can be tested and scaled across the State. Focusing efforts on challenges that are most acute in the State will both help achieve its EV goals and establish it as a leader for other places in the world facing similar challenges. Solving problems associated with urban EV use, such as wireless charging, in New York City will give solutions credibility elsewhere and will open up many new markets for New York researchers and companies. Similarly, the State can test and demonstrate new technologies for electric aviation and maritime transportation at its world-class airports and seaports.

The task force saw demonstrations of new technologies and business models as extremely important for supporting the commercialization process. Demonstrating emerging technologies in the field and collecting independent data is critical for attracting both customers and investors. De-risking these demonstrations and first product sales through grants helps match up customers and technology vendors and encourages end users to try out new products they might not otherwise consider. The task force recommended continuing and expanding NYSERDA’s longstanding support of demonstrations in this field. Going beyond demonstrations and finding ways to incorporate new products into State procurements, especially after completing demonstration projects, could also help these products enter larger markets more quickly. Facilitating long-term contracts or aggregate purchases of new, but tested, technology could help it get to scale rapidly and attract more investors.

The innovation economy in NYS poses opportunities not only for EV research and development (R&D), but also for innovative financing solutions. The financial instruments that underpin the EV industry, especially for capital-intensive, early-stage technological development, are as essential as EV technology itself. Moreover, lessons learned deploying financing strategies and instruments aimed at the sustainability space must be conveyed to a broader set of stakeholders. Major advancements are still needed to bring many projects up to the scale required to begin truly displacing the traditional combustion engines that still dominate transportation. Helping to operationalize many of these projects at scale was identified as a prime opportunity for public sector involvement.

One of the primary challenges identified by the panelists is the limited pool of options for battery reuse and recycling. Energy storage is not only essential to EV operations but is also an important component of projects involving grid resiliency, solar energy, and micro grids. These use cases indicate the importance of an energy infrastructure that is dependent on rare and expensive metals and processing. Developing a closed loop life cycle for many of these materials, by either increasing research capacities into alternatives or opening physical recycling plants, is an opportunity for New York State to ensure that the EV economy expands in a sustainable way and in a way that increases energy independence. In response to this problem the Chinese government mandated the recycling of EV batteries; it is clear that a solution to the problem is an essential component of long-term efforts to establish a sustainable EV economy in the State—and is an area that is particularly ripe for exploration in New York State due to its relative geographic distance from currently established recycling centers, which are largely in the west or mid-west regions of the U.S. Battery recycling poses a strong economic opportunity in part because it is expensive to ship batteries long distances, so regional hubs for battery recycling could become very attractive.

5.7.4 Opportunities for Growing the EV Economy in New York State

Growing the EV economy can be accomplished not only by supporting new technologies, but by taking a holistic view of both new and ongoing efforts to support electric vehicles. In an emerging sector like the EV market, which continues to be fueled by innovation, there is substantial overlap between the key factors identified for R&D and those identified for the economy more broadly. In a space as dynamic and growth oriented as EVs, it is essential to recognize the importance of innovation at all levels; from reducing red tape and increasing support for fleet procurement of EVs on the public side, to manufacturing and scaling for industry, and an expansion of relevant financial instruments.

The task force noted several important facets of the EV economy in the State that present opportunities due to their potential to both stabilize and grow the economy. Recognizing the dynamic nature of the supply and demand problem of EV adoption efforts and consumer adoption, and the need for prolonged and predictable market signaling, there are many avenues through which both the private and public sectors could encourage long-term sustainable growth in EV markets. Notably, both industry leaders and policy makers have already had substantial success and experience in these areas to build upon. The State's unique geographic and business climate, along with both urban and rural settings, allows NYS to be an ideal demonstration ground for both early and large-scale deployments. The State's push toward a clean grid makes it ideally situated to pursue both EV expansion and other electricity driven projects like hydrogen production.

With current manufacturing of EV components projected to fall short of global demand in the near term, the establishment of increased component manufacturing facilities in New York State would enable its companies to fill an important gap in the market with highly specialized production. As a global trade and transportation hub, the State gives manufacturers the opportunity to leverage their specializations on a broader scale.

The need for manufacturing specialization has already taken place to a large degree across the State, as evidenced by companies like the Raymond Corporation in Greene, NY, which produces electric forklifts tailored for use in manufacturing and warehouse environments. To be competitive in a global manufacturing environment, New York State companies often specialize in the hardest-to-manufacture components that add the most value to finished products. It may be unlikely for the State to be the site of major car assembly plants going forward, but by producing high-value components and focusing on broader manufacturing capabilities for industries where the State represents an outsized portion of the market, such as transit buses and school buses, New York State could establish hubs for an EV economy in certain subsectors. Power electronics offers one such opportunity, as the State has developed world-class centers for the development of silicon carbide chips and other advanced power electronic components used in the automotive sector.

This type of focus requires highly trained workforces. The task force noted a lack of specialized automotive workforce in the State, especially compared to some states in the Midwest that have developed workers with these skills for years. There is also a need for highly trained engineers and scientists; the academics on the task force report that their graduate students are in high demand, but there aren't enough of them to support an entire new industry. The need for workforce development and specialized training to support an EV economy represent an ideal opportunity to leverage the strong academic institutions that exist in New York State and their role in attracting and growing a talent pipeline.

EV charging provides opportunities for a wide range of tradespeople, including electricians, utility workers, and other building trades. Some will need to learn new skills, and programs like the Electric Vehicle Infrastructure Training Program (EVITP) are established training courses to teach new and existing tradespeople skills to install EV charging stations. There are likely to be opportunities for skilled tradespeople in a variety of settings, such as larger electrical contractors, EV-focused electrical contractors, electrical utilities, and EV charging maintenance companies. Companies like ChargerHelp, a Los Angeles-based company with offices in the State, are focusing on providing skilled labor to maintain charging stations, drawing on local workers from disadvantaged communities.

Local training programs developed by Hudson Valley Community College (which are being spread to other campuses around the State) are focused on training mechanics to work on EVs, a skill that will be highly desired in short order. Repair technicians are already in short supply and many technicians who have training working with internal combustion engines are not as well equipped to working on new cars, which have many more digital components. This shift is going to accelerate with EVs and workers with the appropriate trainings will be desperately needed.

From an administrative perspective, New York State must streamline its various programs to reduce administrative barriers and encourage growth for earlier stage companies. This opportunity was seen by the task force as central to ensuring that policy goals actually support economic activities in reality, not just in theory. Economic development policies should consider how to encourage technologies that are developed here are actually manufactured here, and how New York State can use its immense purchasing power to attract more manufacturing and jobs to the State. Developing policies to help match technology development companies with customers, either public sector or private sector, that can provide their first orders could be extremely helpful to these companies.

The task force also emphasized that building an EV economy in New York State should not only focus on serving environmental and economic needs, but also on social needs, including remedying long-standing inequalities and imbalances that disproportionately impact people of color and other historically marginalized groups. As part of the Climate Act efforts, the Climate Justice and Just Transition Working Groups will play important roles in identifying potential approaches to the EV economy in New York State. The Climate Justice Working Group is establishing criteria for identifying disadvantaged communities and ensure all New Yorkers are represented and benefit from investments and opportunities from the clean energy transition. The Just Transition Working Group is helping to inform an equitable transition for the State’s workforce, designing a strategic plan to transform its economy, create new jobs, and stimulate industry and innovation, especially for the EV market and transportation sector. Ensuring that policy encourages jobs to be located in historically marginalized communities will help create broader economic opportunity while also serving the needs of fleets and drivers in these communities, increasing the likelihood of EV adoption in these areas. Enabling local ownership of EV assets, such as charging stations, will help build wealth in these communities that were not empowered to take part in the wealth creation associated with previous technologies. Tailoring education and communication activities to residents of disadvantaged communities is important to help ensure they are not left behind in the transition to EVs.

6 Key Insights and Future Work

6.1 Insights

The current pace of action is insufficient. Since 1990, New York State's transportation sector GHG emissions have risen by approximately 10%. Under current policies and market conditions, in the absence of new federal or State policies (i.e., without actions such as the recently announced ZEV sales legislation from September 2021), the State is on a trajectory to reach a modest 4% reduction by 2030 and 32% reduction by 2050 relative to 1990 levels (the reference case). Moderate GHG reductions in the Reference Case are due to projected increases in on-road travel, along with a continued shift toward larger vehicles and sustained growth in aviation. These reductions are far from the 40% reduction needed by 2030 and the 85% to 90% reduction needed by 2050 to meet the State's climate goals.

Clean transportation actions need to address historical inequities in transportation. Disadvantaged, underrepresented, and historically excluded communities are disproportionately impacted by transportation emissions because residents typically live closer to sources of transportation emissions. As shown in the analysis presented in the preceding chapters, disadvantaged communities are less likely to reduce VMT than other groups in the mitigation cases. Furthermore, these communities typically spend more of their income on transportation than higher income households. Addressing these inequities requires increased support for these communities and inclusive policies and programs that ensure the benefits of clean transportation are experienced by all.

Deep reductions in transportation greenhouse gas emissions are possible, with aggressive action. The four mitigation cases discussed in this Roadmap demonstrate that meeting Climate Act climate goals by 2050 is feasible and requires an aggressive mix of policies. These cases focus on a variety of regulatory and technological solutions and travel demand reduction that both reduce emissions and promote vibrant communities. The mitigation cases reduce transportation GHG emissions by 13% to 17% by 2030 and 82% to 84% by 2050, relative to 1990 levels.

New Yorkers benefit from deep reductions in emissions, with varying impacts. Though projected GHG emissions are comparable, each mitigation case has different impacts on health, equity, expenditures, economic outcomes, fiscal requirements from the State, and the electricity distribution system.

- **Health:** Reductions in criteria pollutants through transportation electrification and reduction of VMT results in billions of dollars of savings in avoided health care costs across all mitigation cases. Overall, the health burden from transportation declines about 30% across mitigation cases compared to the reference case from 2020 to 2050.
- **Equity:** High-income households experience the largest percentage reductions in daily VMT and the largest shift toward non-vehicular modes in mitigation cases. Household spending rises slightly across all mitigation cases relative to today, although spending decreases for the lowest income group. Mitigation Case 2, with aggressive VMT management and mobility-oriented development policies, shows the steepest reductions in VMT and a greater shift away from vehicle trips when compared to Mitigation Case 1.
- **Expenditures:** Total statewide expenditures on transportation—including payments for vehicles, fuels, and maintenance by private and public consumers—are lower in the four mitigation cases than in the reference case by about 25% by 2050. Mitigation Cases 3 and 4 have slightly higher vehicle expenditures than Mitigation Cases 1 and 2, because of the assumed higher fuel and maintenance costs of hydrogen FCEVs compared to EVs. On the other hand, Mitigation Cases 3 and 4 have lower capital costs due to the lower projected costs of hydrogen refueling network compared to electric chargers and distribution system upgrades. When considering both vehicle and refueling infrastructure costs, the four mitigation cases have very similar total expenditures by 2050.
- **Economic outcomes:** All Mitigation Cases lead to a net increase in jobs and economic output, offsetting some job losses (e.g., in automotive repair). Mitigation Case 4 leads to the highest net positive impacts, but all mitigation cases will result in hundreds of billions of dollars in cumulative savings to customers from 2020–2050.
- **Fiscal requirements from the State:** Mitigation cases require financial support from the State, which varies between cases. Mitigation Cases 2 and 4 have the highest cumulative costs to the State of approximately $60 billion ($2020) by 2050. However, these costs are expected to be supported by revenue-generating carbon pricing mechanisms that can help reduce the need for State-sponsored subsidies for lower carbon fuels.
- **Electricity distribution system:** Widespread vehicle electrification requires upgrading and expanding the electricity distribution system in New York State, which imposes an additional cost on ratepayers. Results of a parallel study—the TEDI Study—stress the importance of managing new transportation load. The TEDI Study accounts for the potential timing and magnitude of new transportation electricity load and shows that if the new load is left unmanaged, distribution system costs may be 1.1 to 4.8 times greater, with an estimated cost increase of $0.002 to $0.009 per kWh during the 2046–2050 period. If new a load is managed, expected cost increases are negligible, averaging $0.001 to $0.002 per kWh. Note, these estimated costs do not capture expected load flexibility benefits to the grid from transportation electrification.

In this Roadmap, every level of government plays a crucial role in transportation decarbonization. Cities, electric utilities, and local governments are already rising to the challenge and will play increasingly important roles to ensure more walkable streets, cleaner vehicles, and the development of vibrant communities. In addition to reducing GHGs, these efforts will slash pollution from existing gasoline and diesel fuel use statewide, with the greatest benefits going to the disadvantaged communities of the State that are often located adjacent to ports, railyards, freight distribution centers and freeways.

6.2 Future Work

The Roadmap examines a variety of considerations for New Yorkers in achieving transportation emission reductions, but several topics merit further investigation given their outsized importance in altering conclusions above.

- **Expansion of clean transportation manufacturing.** As demonstrated in other states, a thriving manufacturing sector that produces low-carbon transportation technologies could benefit the State's economy and catalyze public support for clean transportation. The topic of incentivizing new manufacturing capabilities in New York State was not explored in this Roadmap but could be in a future study.
- **New York City--specific modeling.** As noted above, a key uncertainty in this Roadmap is the characterization of travel behavior in New York City. The model used in this study for travel demand (VE-State) is built on national data sets that may not accurately predict outcomes in such a unique travel environment as New York City. Future work should focus on better incorporation of the City.
- **EV infrastructure requirements.** Based on current literature, the level of public charging infrastructure needed to support expected EV adoption in the future remains unclear and depends on many variables. Furthermore, little consensus in the literature exists about how and where to site EV chargers across different use cases. Over the next decade, as jurisdictions across the State expand investment in EV infrastructure, further research could provide more in-depth analysis on these topics.
- **Disaggregated VMT forecasting.** The expected level of travel in the future is a major driver of nearly every finding in this Roadmap. Further study is needed to expand on the Roadmap's VMT forecasting, including additional sensitivity analyses around key drivers and uncertainties across the scenarios modeled, such as future population growth and household income. In particular, greater emphasis is needed on relative VMT changes between dense urban areas of New York City versus suburban and rural areas.

- **VMT impacts from EVs, ride hailing, and vehicle automation.** Relatively little is known about the potential VMT impacts from widespread use of new technologies in the transportation sector, such as EVs, ride hailing, and vehicle automation. This Roadmap did not fully explore the impacts these technologies will have on VMT due to limitations in the State-level model. This is an area of growing interest to the State and deserves further research to understand the extent of GHG emission impacts. More research is needed to understand which ride hailing applications and routes are best suited for electrification. Automation poses a separate set of challenges, and its impacts are still unclear. Research has shown that automation could halve emissions or double them, depending on how energy intensity, travel demand, fuel mix, and other factors manifest in the future.
- **Aviation decarbonization.** The mitigation cases in this Roadmap assume the aviation sector shifts dramatically toward the use of low-carbon liquid fuels and electric aircraft by 2050. Though this assumption aligns with similar assumptions in other work, greater clarity is needed about its feasibility.
- **Use of hydrogen in transportation.** Mitigation Cases 3 and 4 include considerable quantities of green hydrogen by 2050. Given the very low penetration of hydrogen and green hydrogen in transportation today and the relative immaturity of the technology and infrastructure, there are substantial uncertainties and risks around technology advancements, infrastructure deployment, and fuel availability. Additional research is needed regarding the ability for green hydrogen fuel, technology, and infrastructure to scale to meet the deployment targets in Mitigation Cases 3 and 4.
- **Grid impacts and managed charging in conjunction with building electrification.** New York State's broader climate goals include decarbonizing building energy consumption through electrification of fossil fuel end uses. This study examined grid impacts and the effectiveness of managed charging, but the interaction of increasing building electrification and load management (e.g., through pre-heating/cooling, use of thermal storage) with transportation electrification and its impacts on the grid and costs could be further analyzed.

Appendix A—Mitigation Case Details

Table A-1 summarizes policies included in each of the mitigation cases. Notably, not all high-priority policies could be modeled. The insights from this exercise must be interpreted with an understanding of the limitations of the models and tools utilized for this analysis.

Table A-1. Scenario Matrix for Four Mitigation Scenarios

Simulated Policies	Reference Case Description	Mitigation 1	Mitigation 2	Mitigation 3	Mitigation 4
		Electrification Emphasis		Mixed Electrification/H2 Emphasis	
		Moderate VMT/Mode Shift Policies	Aggressive VMT/Mode Shift Policies	Moderate VMT/Mode Shift Policies	Aggressive VMT/Mode Shift Policies
Carbon Pricing					
Carbon pricing	No policy	\$20/ton in 2030 // \$100/ton in 2050	\$10/ton in 2030 // \$50/ton in 2050	Same as M1	Same as M2
Clean Fuel Standard					
Ethanol blend within gasoline pool (2035).	No state policy; some federal policy support.	15%	10%	Same as M1	Same as M2
BD/RD blend within diesel pool (2035).	No state policy; some federal policy support.	40%	15%	Same as M1	Same as M2
Biojet blend within jet fuel pool (2050).	No state policy; some federal policy support.	75%	50%	Same as M1	Same as M2
Vehicle/Equipment Adoption Standards					
Advanced Clean Cars II, feebate, vehicle purchase incentives.	CA’s Advanced Clean Cars Rule currently in force, which expires in 2025.	LDV sales increase to 100% BEV by 2035.	Same as M1	LDV sales increase to 80% BEV, 20% FCEV% by 2035; increasing to 45% of sales FCEV in 2050.	Same as M3
Advanced Clean Truck & associated policies.	No policy	Medium-/heavy-duty vehicle sales increase to 100% BEV by 2045; (timing varies by vehicle type).	Same as M1	MHDV sales increase to 50% BEV, 50% FCEV by 2045; Heavy-duty vehicle sales increase to 100% FCEV by 2045; (timing varies by vehicle type).	Same as M3

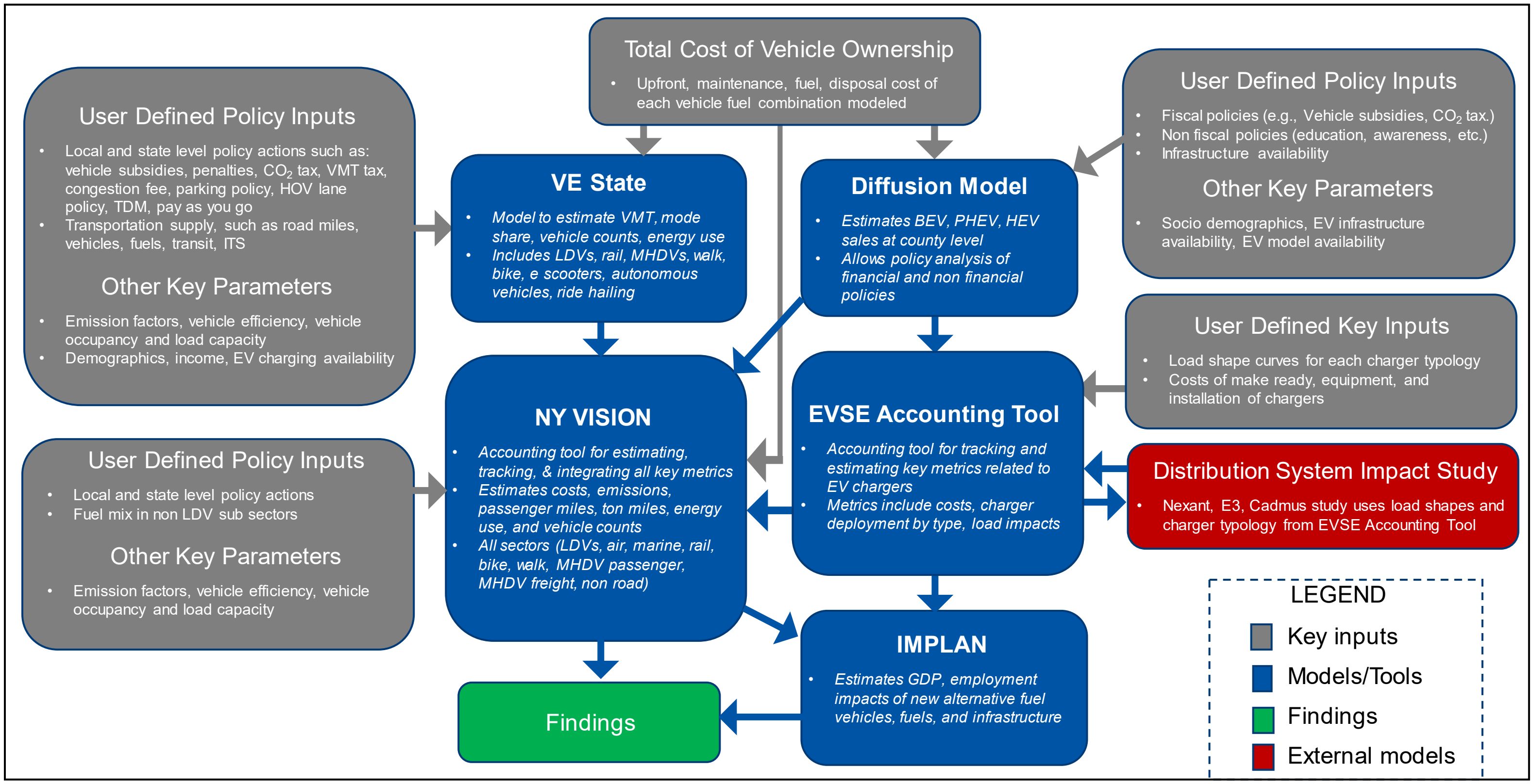
Aviation	No policy	For flights less than 1500 miles, 50% electric	Same as M1	For flights less than 1500 miles, 50% FCEV	Same as M3
Non-road petroleum phase-out.	No policy	50% electric	100% Gasoline	25% electric, 25% FCEV	100% Gasoline
Infrastructure Investment					
EVSE access expansion.	Some existing programs in place.	High public DCFC availability scenario.	Mod-High public DCFC availability scenario.	Moderate public DCFC availability scenario.	Moderate public DCFC availability scenario.
Hydrogen station access	No policy	No policy	No policy	High H2 infrastructure availability	Mod-High H2 infrastructure availability
Education/Outreach on EVs and FCEVs					
Education/Outreach	No policy currently covering sector	Marketing campaigns increase familiarity with technologies by 2x by 2030.	No change from Reference Case.	Same as M1	Same as M2
Smart Growth					
Mixed-Use Development	2050 Reference Case value for fraction of households in mixed-use neighborhoods ranges from 4 to 74% across areas.	20-25% increase in households in mixed-use neighborhoods.	25-30% increase in households in mixed-use neighborhoods.	Same as M1	Same as M2
Note		For example, in Tompkins County, where currently 1% of households are in mixed-use neighborhoods, by 2050 this proportion increases by 20% in M1, meaning that 21% of households are in mixed-use neighborhoods. In all cases, the proportional increases are 5% higher for NYC metropolitan regions than for non-NYC metropolitan regions.			
Transit Service	2050 Reference Case value for transit service level increases by 34% relative to today.	100% increase in transit service level.	200% increase in transit service level.	Same as M1	Same as M2
Note		For example, in M1 there is a 66% increase in total transit revenue miles over the level in the Reference Case in 2050.			
Complete Streets					
Complete Streets	Start value for share walking or biking to work ranges from 0.7% to 12.1% across counties.	5% of workers walk, bike, and take e-bikes by 2050 for all counties.	10% of workers walk, bike, and take e-bikes by 2050 for all counties.	Same as M1	Same as M2
Note		E-bikes include electric scooters, electric bikes, electric shared bikes, and electric skateboards.			

Employer-Run Travel Demand Management					
Employer telework & TDM measures	Start value ranges from 2 to 65% across counties.	No policy	Share of workers and households participating in TDM programs increases by 35 percentage points in each county by 2050.	Same as M1	Same as M2
Note		For example, in Nassau County the TDM participation rate among workers and households is 24% at present, so the new rate in 2050 would be 59% in that county.			

Appendix B—Tools and Models

Cadmus developed a set of inter-linked models that give the necessary resolution on geography, technology, and policy. Cadmus's integrated modeling approach includes the five models shown in blue boxes in Figure B-1. Key user inputs and other model inputs are shown in gray boxes. Note that Figure B-1 is meant to be a summary figure to orient the reader rather than an exhaustive description. The reader should refer to the following sections for more description.

Figure B-1. Summary of Roadmap Modeling Modules



B.1 Diffusion Model

B.1.1 Overview

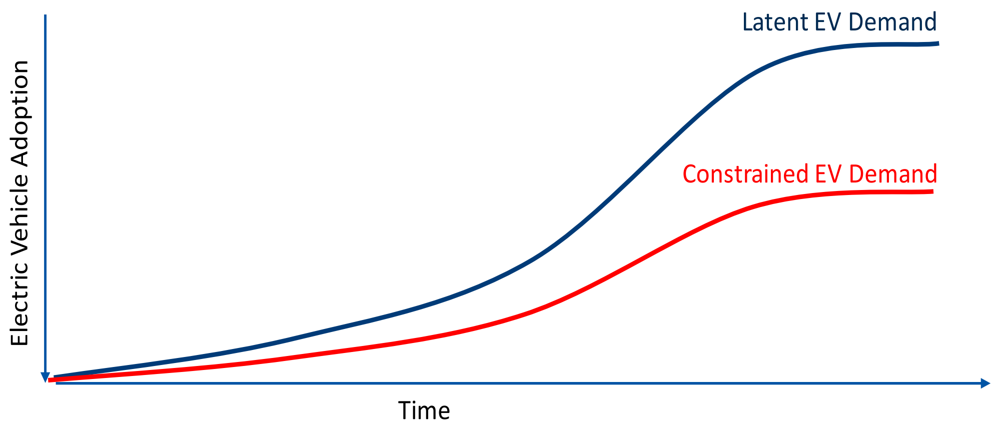
The diffusion model was used to project light-duty vehicle sales at the county level in New York State, using a hybrid discrete choice model and Bass diffusion approach. The model produces projections of market shares for five vehicle types (conventional or ICE, hybrid, plugin-hybrid, full electric, and hydrogen fuel-cell) among purchases of new passenger vehicles. S-shaped curves, as shown in below, that depict the diffusion of plug-in electric vehicles into the market. Importantly, these S-curves will capture the dynamics of technology adoption, from technology "Innovators" to "Laggards" (Figure B-5). To develop these curves, we use county-level data combined with projections of vehicle costs, model availability, and infrastructure availability.

A diffusion model is considered "inferential research" because it attempts to link cause and effect (e.g., the impact of policy incentives on the shape of the S-curve). Typically, in inferential research, revealed preference data (e.g., historical vehicle sales) is a better indicator than stated preference data (e.g., surveys of potential EV owners) because it reflects *actual* rather than *stated* choices. However, to construct models of future scenarios, revealed preference data is insufficient because it reflects only the preferences of early adopters, which may differ from preferences of later adopters.

We address this challenge by using a three-part stated preference survey of vehicle buyers (n=2123) conducted by Long et al. (2019).[111] This survey was conducted to support an implementation of the REPAC (Respondent-based Preference and Constraints) model which projects demand for various vehicle technologies.[112] This model has two sub-models explained in detail below:

1. A **Latent Demand Sub-Model** that characterizes *unconstrained* preferences of new vehicle buyers who fall into one of several customer archetypes.
2. A **Constraints Sub-Model** that prevents consumers from acting on their unconstrained or latent preferences.

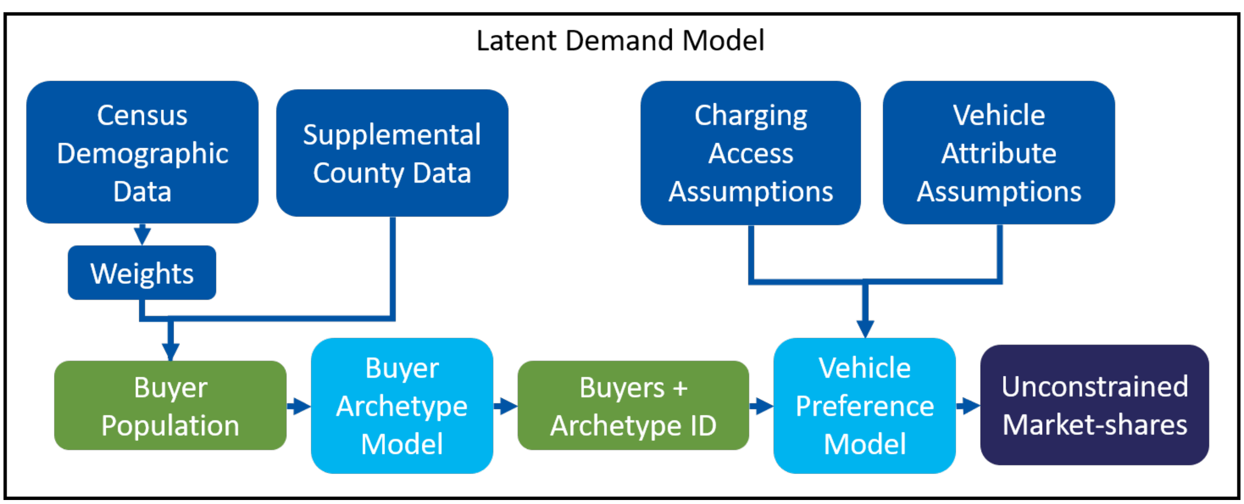
Figure B-2 Conceptual Diagram Showing Latent and Constrained EV Demand



B.1.2 Latent Demand Sub-Model

The purpose of latent demand sub-model is to estimate the market shares of new car buyers under the assumption individuals have perfect information about the vehicle choice set and have access to any vehicle-fuel combination they desire (bottom right of Figure B-3). A new car buyer's latent demand is a function of the characteristics of the buyer (top left of Figure B-3) and the attributes of the vehicles and charging infrastructure (top right of Figure B-3). The data for the Latent Demand Sub-Model includes U.S. Census demographic data on income and education, supplemental data on environmental awareness and technology orientation, charging access data, and total cost of ownership data on vehicle choices.

Figure B-3. Structure of Latent Demand Model



Using U.S. Census data, we construct an initial demographic profile for each county. This demographic profile is then re-weighted to produce a profile of potential new vehicle buyers in each county. The weights are constructed using existing research that compares the characteristics of new vehicle buyers to the general population.[113]

Each individual buyer is then assigned a set of simulated lifestyle scores that reflect environmental orientation and technology orientation.[114,115] The scores are randomly selected from a distribution that aligns with county-level data on environmental concerns and support for clean energy technology.

Each individual in the simulated population of new buyers is passed through a function that assigns them to the archetype that they have the highest probability of belonging to, based on their demographic characteristics and lifestyle scores. There are a series of possible archetypes corresponding to an individual's level of enthusiasm for electric vehicles.[116] Based on these archetypes, an individual has a unique preference function for a set of vehicle types: conventional vehicles (ICE vehicles), hybrid electric vehicles (HEVs), plug-in electric vehicles (PHEVs), and battery electric vehicles (BEVs).

Each potential buyer's latent preference for one of the four vehicle types is determined for a given set of assumptions about the attributes of the vehicles available in the market. The included vehicle attributes are sticker price of vehicle, incentive value, weekly fuel cost, and range. The preference model inputs also include several characteristics that are uniquely specified for each buyer, including access to EV charging at home, workplace, and in public, and the presence of a DC fast charging highway network availability. The relative importance of the various attributes varies for each customer archetype.[117]

Access to home charging is specified at the individual level depending on the residence type and tenure. Access to workplace and public charging vary according to a range of assumed scenarios driven by the level of public investment in charging infrastructure.[118]

B.1.3 Constraints Sub-model

In a second sub-model, we integrate the dynamics that constrain a customer from acting on their unconstrained or latent preferences for a plug-in electric drivetrain. These constraints include familiarity with plug-in electric drivetrains, dealership access, and vehicle model availability. Dealership access is determined by the percent of a county's population within a certain distance (e.g., 100 miles) of a certified dealership that offers plug-in electric vehicles.[119]

Model availability is determined at the county level according to data or assumptions on market shares for vehicles of various size classes (sedans, sport utility vehicles, light pickup trucks, vans, crossovers) and the availability of HEVs, PHEVs, and BEVs in each class**.** For example, assume a county has a size class market share of 50% light pickup trucks. In a scenario year in which no PHEV or BEV trucks are available, the county would have a 50% model availability restriction on PHEVs and BEVs**.** Further details on the constraints model approach can be found in Miele et al. (2020) and Wolinetz and Axsen (2017).[120, 121]

B.1.4 Stock Turnover Dynamics

Vehicle stock turnover dynamics including purchase and scrappage rates will be integrated into an existing turnover model.[122] For simplicity, scrappage rates will be assumed to be constant over time (e.g., 5% per year). Annual new vehicle sales are assumed to align with the scrappage rate but can be varied to allow for growth or degrowth in total vehicle ownership.

B.2 New York VISION Tool

NY-VISION serves as the central hub for all other models shown in Figure B-4

. NY-VISION is an accounting spreadsheet that estimates, tracks, and integrates data for all modes of the transportation sector. One key input to NY-VISION is LDV sales and stock, which are estimated in the Diffusion model described above. This allows tracking of LDV sales and stock over time and GHG analysis. For MHDVs, a stock-turnover model tracks annual vehicle sales and accounts for vehicle retirements. NY-VISION is based loosely on Argonne National Laboratory’s VISION Tool, which provides similar functionality for projections at the national-level. The State of California similarly has a state-level “California VISION” tool the California Air Resources Board uses for deep decarbonization planning in the transportation sector. Table B-1 shows the vehicle and fuel categories represented in NY-VISION.

Table B-1. Summary of Vehicles and Fuels Included in NY-VISION

Subsector	Vehicle Categories	Fuels/Powertrains
Light-Duty	Passenger, pickup truck, sports utility vehicle, van, crossover.	Electricity, hydrogen, E10 gasoline, renewable gasoline.
MHDV Passenger	Transit bus, intercity bus, school bus, motor home.	Electricity, hydrogen, renewable diesel, diesel, biodiesel, renewable natural gas, liquefied natural gas, compressed natural gas.
MHDV Freight	Short-haul single unit, short-haul combination, long-haul single unit, long-haul combination, refuse, light-commercial trucks.	Electricity, hydrogen, renewable diesel, diesel.
Aviation	<250 miles, 250-500 miles, 500-750 miles, 750-1000 miles, 1000-1250, 1250-1500, >1500	Electricity, jet fuel, sustainable aviation fuel.
Rail	Passenger, freight	Electricity, diesel
Marine	Passenger, freight	Electricity, diesel
Other Non-Road	All-terrain vehicles (ATVs), ground support equipment (GSE), lawn care equipment, snowmobiles.	Electricity, diesel
Walk	N/A	None
Bike and E-Scooter	Bike, e-scooter	None

In NY-VISION, the user makes manual assumptions about the evolution of all sub-sectors of New York State's transportation sector between today and 2050, including energy efficiencies, emissions, costs, energy use, electricity demand, and travel demand. NY-Vision uses emission factors from Argonne National Laboratory's GREET model to calculate GHG emissions. For electricity emissions, electricity grid emission factors are from the consulting firm E3, who are performing a parallel analysis on GHG reduction in New York State's electricity grid. Table B-2 shows the electricity grid emission factors used in the reference scenario and ZEV Mandate Extension and Advanced Clean Truck scenario.

Table B-2. Emissions Factors for the Electricity Grid Analysis ($MTCO_2$/MWh)

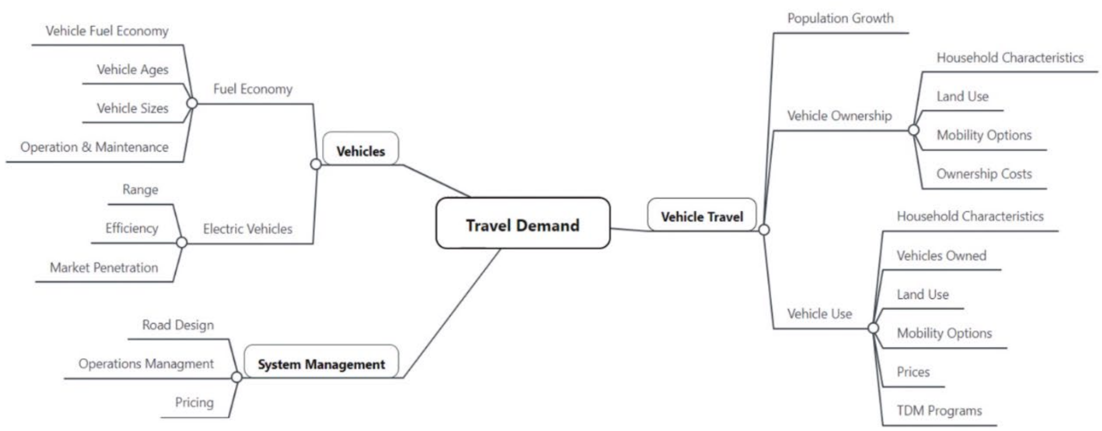
Scenario	2020	2025	2030	2035	2040	2045	2050
Reference scenario	0.17	0.18	0.17	0.15	0.13	0.14	0.15
ZEV Mandate Extension and Advanced Clean Truck scenario.	0.17	0.16	0.08	0.07	0	0	0

B.3 VE-State Tool

VE-State is a strategic model used to evaluate transportation policy impacts. It is one of three models built on the VisionEval open-source programming framework. VE-State, like the other VisionEval models, models household decision making on travel demand through "disaggregate demand/aggregate supply."

Travel demand is forecasted through the combination of rich demographic and socioeconomic detail of simulated households to capture *vehicle travel*, *vehicle* metrics, and *system management* (Figure B-4). By creating a synthetic set of individual households and its associated characteristics, like household income and vehicle ownership, VE-State models travel demand to examine equity effects and the impacts of fuel prices and other pricing policies, changes in population demographics and employment, and other factors on mode choice and travel behavior.

Figure B-4. VE-State Framework for Modeling Travel Demand



The VisionEval common framework includes a set of calculations that use data from the National Household Travel Survey and the U.S. Census that operate on the input data as well as the results of the previous calculation step. The model defines simulated household, each with unique transportation choices, while accounting for land use policies (e.g., transportation demand management measures) to characterize vehicle ownership of those households, calculate vehicle miles traveled (VMT) and emissions, and balance VMT with travel costs.

The model framework disaggregates travel demand impacts at an individual household level. Modeling at the household level makes it possible to evaluate the relationships between travel, emissions and the characteristics of households, land use, transportation systems, vehicles, and other factors. In addition, household level analysis makes it possible to evaluate the equitability of the costs and benefits of different strategies. Table B-3 illustrates the vehicle categories for which VMT was modeled in VE-State at the household, county, and statewide spatial scale.

Table B-3. Summary of Vehicle Categories for which VE-State Models VMT

Subsector	Vehicle Categories
Light-duty	Passenger car, and truck
Light Commercial Truck	Commercial service light truck
Bus	Transit bus
Heavy-duty	Combination unit short haul and long haul
Rail	Light, heavy, and commuter rail

B.3.1 Model Inputs and Parameters

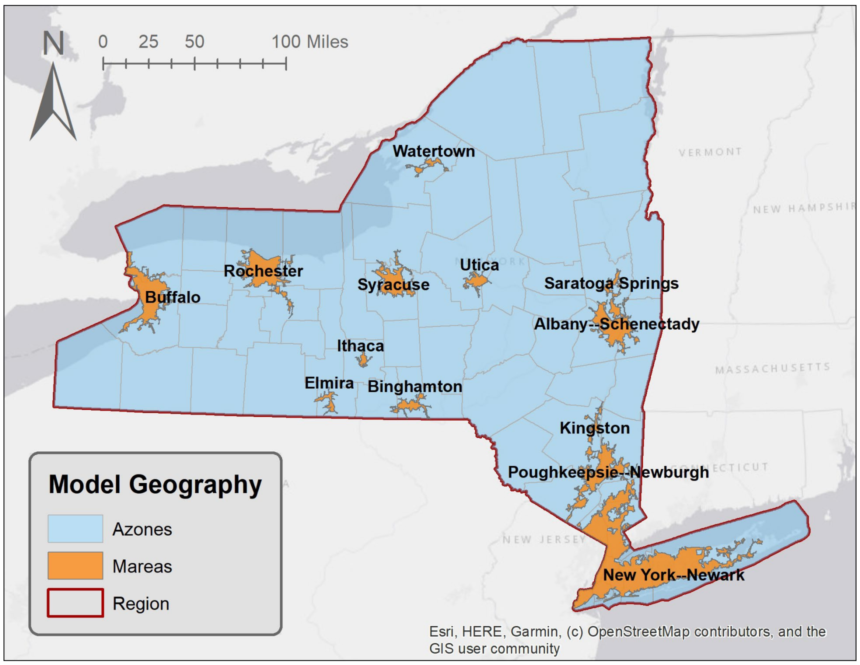
The VE-State input data is developed for the model base and future years, or 2018 and 2050. Additional detailed on VE-State input files and how they were used in the model calculations can be found in GitHub.[123]

The input data is also developed at several different geographies. The definitions of the geography levels used in VE-State are the following (Figure B-5):

- The **region** level is the entire model area—in this case, the State. Large-scale characteristics that do not vary across the State are specified at the region level. For example, the carbon intensities of vehicle fuels are defined at the region level since they tend not to vary widely across a large geographic area.
- **Azones** are large subdivisions of the region level. Counties define the Azone level in VE-State and are used in the New York VE-State model. Azones, or counties, are used to represent population and economic characteristics that vary across the region such as demographic forecasts of persons by age group and average per capita income. Azones are the only level of geography that is required to represent actual geographic areas and may not be simulated.
- **Bzones** are subdivisions of Azones. Bzones are nested within Azones (counties) and provide more granularity on the intensity and nature of development. To better understand Bzones, it helps to know that VE-State was developed as a scaled-up version of the regional VisionEval model VE-RSPM. In VE-RSPM, the Region level is the metropolitan planning region being modeled, Azones are typically municipal boundaries, and Bzones are subdivisions of Azones similar in size to Census Block Groups. Bzones in VE-RSPM represent geographical areas, referred to in the original RSPM model as "districts." Several inputs in VE-RSPM are developed at the Bzone level, for example, housing and population density. The approach to developing VE-State from VE-RSPM was to simulate the Bzone is detailed on GitHub.[124]

- **Mareas** represent Metropolitan Statistical Areas, as defined by the U.S. Census, which overlap with one or more Azones (counties). Azones can overlap with an Marea either because a portion of the urbanized area is located in the Azone or because a substantial proportion of the workers residing in the Azone work at jobs located in the urbanized area. A special Marea named 'None' is used to apply to Azones that are not associated with any urbanized area (e.g., is a town or rural area). Mareas are used to specify and model urbanized area transportation characteristics such as overall transportation supply (transit, highways) and congestion. They are also used to specify large scale land-use-related characteristics and policies in models that use Bzone synthesis.

Figure B-5. New York State VE-State Geography



Additional specification for how VE-State input and output data were characterized by geography is available on GitHub.

B.3.2 Model Calibration

The Reference Case (2018) VE-State output files that model household decision making for travel demand at the county level were validated with 2018 data:

- The U.S. Census American Community Survey at the New York State county-level was utilized as calibration data to validate the accuracy of the Reference Case (2018) VE-State output files. The following model outputs were included in calibration were: (1) demographics (population, household size, income, and workers) and (2) number of vehicles per household.

- VE-State model outputs for vehicle types (e.g., BEV, PHEV, and HEV) were validated with data from the Auto Alliance.[125]
- Values for vehicle miles travelled (VMT) for urban and rural light-duty vehicles and heavy trucks were calibrated using data from the Federal Highway Administration HPMS Table HM-71 and New York State Department of Transportation.
    - Since the model does not provide outputs for daily vehicle miles traveled (DVMT) on non-urban roadways, rural and town household and commercial service data was used as a proxy for rural DVMT. By design, the model does not provide a "total" output for VMT on State roadways but instead provides detailed VMT information for household and associated commercial service travel that can be used to analyze the impacts of various policy, demographic, and land-use scenarios.

B.3.3 Setting up Scenarios

Scenarios were created by making a small number of changes to the reference case input files. Table B-4 provides the complete list of which input files were adjusted to reflect M1/M3 and M2/M4 policy actions.

Table B-4. Modified VE-State Input Files by Scenario Policy Actions

Model Input Description	Input File Name	M1/M3	M2/M4
Suitability for bike and other personal modes of transportation.	Azone_prop_sov_dvmt_diverted.csv	Increase fraction of workers who walk and bike to 5% in 2050 for all counties.	Increase fraction of workers who walk and bike to 10% in 2050 for all counties.
Travel demand program.	Azone_travel_demand_mgmt.csv	N/A	Increase all counties by 35% in the participation rate.
Proportion of households in mixed-use areas.	Marea_mix_targets.csv	Increase fraction of households located in mixed-use neighborhoods by 20% in non-NYC MSA; 25% increase in NYC MSA.	Increase fraction of households located in mixed-use neighborhoods by 25% in non-NYC MSA; 30% in NYC MSA.
Annual revenue miles for different types of transit.	Marea_transit_service.csv	100% increase in total transit miles 100% increase in total transit miles between 2018 and 2050.	200% increase in total transit miles.
Per capita income	Azone_per_cap_inc.csv	Used BEA data from 1969–2019 to determine growth rate through 2050.	

B.3.4 Model Outputs and Analysis

The outputs of VE-State are stored in a Datastore as RDA files. Each model year, 2018 and 2050, has outputs in the following directories: Azone, Bzone, Household, Marea, Region, Vehicle, and Workers. A full list of output files can be found on GitHub.

The Azone level outputs are primarily demographic, for example the number of individuals by age. Bzone level outputs contain information on land use and population density, among other “district-level” characteristics, and they can be used in conjunction with the Household outputs to analyze the impacts of land use and development changes on travel behaviors.

Marea outputs contain most of the high-level information on travel supply and demand, such as VMT and road lane-miles. Linking these outputs back to the Azone, or county, level may require creating a factor from Household level outputs or using external data sources that include both MSA and county data.

The Household outputs represent the simulated households generated by the model. Each household has information on location (Azone and Bzone levels) ages of individuals, drivers (if any), workers, income, and travel behavior data including DVMT, transit trips, walk trips, and vehicle trips. The Vehicle and Worker level outputs can also be linked back to Household outputs using a unique household ID. Household outputs can be used in equity analyses by investigating how varying transportation and land-use scenarios affect different income groups.

Region level outputs contain statewide information. Outputs provided at this level include data on fleet powertrain proportions and travel data on freight, for example heavy truck VMT.

For analyzing results, key performance measures from VE-State outputs can be used as indicators to examine environment and energy impacts, financial and economic impacts, and community impacts of various scenarios. A full list of performance measures can be found on GitHub.[126]

Appendix C—Societal Impact Methodologies

C.1 Health Impact Methodology

While much of the discourse surrounding the electrification of transportation centers on its ability to decarbonize the sector, this focus neglects a related social benefit: reducing concentrations of criteria pollutants. Criteria pollutants including nitrogen oxides (NO_X), particulate matter, sulfur dioxide, and volatile organic compounds (VOCs) have been shown to negatively impact human health. Further descriptions of criteria pollutants and their health effects can be found in the third edition of the EPA's America's and the Environment report (2019). The Health Impacts analysis modeled the health savings (in 2020 U.S. dollars) derived through reducing the quantity of on-road (LDV and MHDV) vehicles emitting criteria pollutants in each mitigation scenario.

Prior to monetizing health damages, the authors of this study estimated the quantity of each criteria pollutant produced by each vehicle and fuel type from 2020 to 2050. The authors used grams per mile emission coefficients for a New York State run of the EPA's Motor Vehicle Emission Simulator 2021 (MOVES3). Baseline and deterioration factors were developed and used to calculate initial emissions and the increase in emissions as vehicles age, respectively. Using these baseline and deterioration (grams/mile) rates, Cadmus generated average lifetime emissions for each vehicle category and fuel type. When implemented alongside vehicle stock and sales from the New York Vision Tool, this analysis generated yearly criteria pollutant estimates from 2020 to 2050.

The study quantified health damages using the Air Pollution Emissions Experiments and Policy (APEEP) model. The APEEP model incorporates air quality and epidemiological modeling in its methods for mapping human exposure and physical impacts from air pollution to monetary costs. This model employs a marginal damage approach to quantifying health consequences as the cost of added pollutants oftentimes depends on the existing concentration. While APEEP accounts for emissions from both ground level and point sources, the model takes this breakdown a step further to provide source-specific (e.g., transportation) damages per ton of pollutant for each criteria pollutant rather than a cumulative impact for all pollutants. For this study's purposes, only ground source transportation damages were considered. As APEEP grounds its estimation in county-level emissions data from the EPA, this analysis analyzed health impacts by county.

The APEEP model converted these exposures to physical human impacts and hospital visits using concentration-response functions from 11 peer-reviewed academic studies. Finally, APEEP applied the Value of Statistical Life (VSL) approach in allocating a specific dollar amount to each of the physical effects. The VSL model monetizes the probability of premature mortality based on a fixed value of human life. For more information on APEEP's foundational studies and a technical description of the methods, matrices, and equations the APEEP model uses in quantifying health effects, refer to appendix C of "Hidden Costs of Energy, Unpriced Consequences of ENERGY Production and Use" (2010).

To estimate health damages, the authors first estimated the quantity of pollutants (in kilograms) released from transportation sources each year within a county. This quantify was then multiplied by the county-specific, pollutant-specific marginal damage coefficient to estimate a health cost. Table C-1 presents the human health costs from the transportation sector's criteria pollutants.

Table C-1. Marginal Damage Cost per Kg used in Analysis

County	FIPS Code	NOX	PM10	PM2.5	PM2.5 (TBW)	VOC
State-level non-weighted		**$1.994**	**$9.365**	**$105.229**	**$105.229**	**$16.101**
Albany	36001	$0.972	$5.586	$69.358	$69.358	$8.781
Allegany	36003	$2.904	$4.568	$56.807	$56.807	$4.843
Bronx	36005	$1.834	$26.728	$271.889	$271.889	$58.995
Broome	36007	$1.702	$4.328	$54.380	$54.380	$6.537
Cattaraugus	36009	$2.632	$8.054	$107.359	$107.359	$9.172
Cayuga	36011	$4.612	$10.194	$127.657	$127.657	$7.501
Chautauqua	36013	$2.418	$3.806	$49.816	$49.816	$4.649
Chemung	36015	$2.832	$4.154	$51.148	$51.148	$5.372
Chenango	36017	$1.549	$6.320	$79.450	$79.450	$6.180
Clinton	36019	$0.691	$1.756	$20.487	$20.487	$2.092
Columbia	36021	$1.057	$6.546	$81.509	$81.509	$7.206
Cortland	36023	$1.897	$5.153	$62.832	$62.832	$4.975
Delaware	36025	$1.608	$6.172	$75.136	$75.136	$6.603
Dutchess	36027	$1.229	$7.758	$88.685	$88.685	$10.926
Erie	36029	$3.134	$6.754	$89.715	$89.715	$10.693
Essex	36031	$0.823	$1.907	$22.347	$22.347	$2.922
Franklin	36033	$0.786	$1.833	$21.991	$21.991	$2.212
Fulton	36035	$1.166	$3.381	$42.253	$42.253	$5.149
Genesee	36037	$3.565	$7.719	$95.417	$95.417	$6.669
Greene	36039	$0.971	$6.969	$85.224	$85.224	$7.588
Hamilton	36041	$0.793	$1.280	$15.546	$15.546	$2.958

Herkimer	36043	$1.146	$3.543	$44.728	$44.728	$5.003
Jefferson	36045	$1.120	$2.295	$27.807	$27.807	$3.108
Kings	36047	$1.993	$40.886	$404.434	$404.434	$134.373
Lewis	36049	$1.143	$2.966	$36.195	$36.195	$3.484
Livingston	36051	$3.860	$8.224	$99.961	$99.961	$6.390
Madison	36053	$1.344	$6.700	$84.508	$84.508	$6.076
Monroe	36055	$2.027	$5.628	$70.830	$70.830	$8.451
Montgomery	36057	$1.295	$7.688	$97.909	$97.909	$7.680
Nassau	36059	$1.710	$58.972	$609.977	$609.977	$89.471
New York	36061	$2.889	$23.045	$216.285	$216.285	$70.902
Niagara	36063	$2.477	$5.334	$68.698	$68.698	$5.809
Oneida	36065	$1.055	$3.711	$46.622	$46.622	$4.937
Onondaga	36067	$4.533	$6.266	$77.889	$77.889	$7.505
Ontario	36069	$3.320	$6.908	$84.154	$84.154	$5.789
Orange	36071	$1.985	$14.917	$165.347	$165.347	$18.569
Orleans	36073	$2.929	$6.265	$77.602	$77.602	$4.808
Oswego	36075	$3.759	$4.852	$59.935	$59.935	$6.624
Otsego	36077	$1.152	$5.064	$62.989	$62.989	$4.999
Putnam	36079	$1.003	$18.933	$209.922	$209.922	$15.143
Queens	36081	$2.955	$61.513	$591.799	$591.799	$173.956
Rensselaer	36083	$1.450	$6.179	$75.406	$75.406	$8.279
Richmond	36085	$2.290	$13.868	$143.517	$143.517	$43.813
Rockland	36087	$2.195	$13.976	$153.747	$153.747	$32.692
Saratoga	36089	$1.637	$2.489	$30.443	$30.443	$2.975
Schenectady	36091	$0.897	$3.482	$41.875	$41.875	$6.060
Schoharie	36093	$1.051	$4.951	$62.012	$62.012	$9.131
Schuyler	36095	$1.279	$7.821	$96.974	$96.974	$7.559
Seneca	36097	$2.878	$4.866	$60.081	$60.081	$5.547
St Lawrence	36099	$2.495	$5.917	$72.904	$72.904	$4.725
Steuben	36101	$3.694	$6.824	$85.078	$85.078	$6.131
Suffolk	36103	$0.614	$10.147	$119.234	$119.234	$12.738
Sullivan	36105	$2.265	$9.009	$105.504	$105.504	$10.726
Tioga	36107	$2.743	$6.097	$74.787	$74.787	$6.205
Tompkins	36109	$2.227	$4.835	$58.384	$58.384	$5.396
Ulster	36111	$1.483	$7.349	$86.856	$86.856	$9.022
Warren	36113	$0.779	$1.745	$20.842	$20.842	$3.577
Washington	36115	$0.747	$3.820	$45.595	$45.595	$4.224
Wayne	36117	$1.764	$4.559	$55.525	$55.525	$3.906
Westchester	36119	$1.291	$23.517	$250.191	$250.191	$38.651
Wyoming	36121	$3.705	$7.371	$91.033	$91.033	$6.034
Yates	36123	$3.243	$7.147	$87.593	$87.593	$5.795

A notable weakness of this methodology was that marginal damages in Table C-1 are assumed to be static over time. In reality, the background concentration of pollution and the vulnerability of local populations will in time likely change. This implies the health impact of releasing a single kilogram of pollutant should also evolve. Accounting for these changes was beyond the scope of this project but could be considered in a future project.

C.2 Equity Impact Methodology

Unlike other societal impact analyses, the Equity Impacts study did not require any additional modeling or rigorous calculation. Rather, this study relied on graphical analyses to surface differences among household and county-level trends with a particular focus on disparities between income and race.

The equity analysis used household level outputs from the VE-State model to compare metrics such as vehicles miles traveled, vehicle expenditures, and walk, bike, vehicular, and transit trips across income or racial categories. The final graphical analysis in the equity study pulled county level LDV EV sales from Cadmus' Market Adoption (Diffusion) model. While the equity impacts analysis evaluated both household and county level trends by income level, the investigation into racial disparities occurred solely at the county level using racial makeup data from the database maintained by the U.S. Census Research Data Center at Cornell University.

All figures in the graphical analysis were developed in Microsoft Excel. The household comparison analyzed variation in mode share and vehicle ownership spending across low-, middle-, and upper-income households between the reference case and Mitigation Cases 1 and 2. Specifically, it contrasted households' mode share and vehicle expenditures today (2020) against the same metrics in 2050 for the reference case and Mitigation Cases 1 and 2. This study assumed any household generating less than $35,000 per year, between $35,000 and $85,000 per year, and above $85,000 per year fell into the low-income, middle-income, and upper-income brackets, respectively.

The county-level equity analysis focused on disparities in two measures: the change in vehicle miles traveled and LDV EV sales as a percentage of total LDV sales. The graphical analysis examined how the change (%) in 2050 vehicle miles traveled between the reference case and Mitigation Case 2 varied according to the median household income and racial makeup of counties. Trend lines in these figures revealed negative correlations between VMT and income and race. The higher the median household income or percentage of non-White individuals in a county, the greater the reduction in VMT from the reference case to Mitigation Case 2. The second portion of the county-level equity study compared

2030 LDV EV sales as a percentage of total LDV sales in Mitigation Case 1 against the median household income of counties. This study actively selected 2030 as the ICEV Ban takes effect in 2035, and, as a result, less natural variation would be observed.

C.3 Expenditure Methodology

The Total Expenditures study evaluated the costs of vehicle ownership and refueling stations as well as how these expenditures varied among the reference and mitigation cases. Expenditures in this analysis counted any spending that relates to owning and operating LDV or MHDV in New York State, but not alternative transportation expenditures such as transit ridership. In terms of refueling stations, this study accounted for only electric and hydrogen stations as expectations assume the costs associated with additional fueling stations for gasoline, diesel, and other fuels will be comparatively low. The types of spending included in this analysis are detailed in Table C-2.

Table C-2. Expenditure Categories and Examples

Expenditure Category	Description	Example in Category
Upfront vehicle expenses	Expenditures on upfront vehicle purchases of new on-road vehicles. Used vehicle sales are not tracked. Vehicle purchases in aviation, marine, rail, non-road sectors are not tracked due to lack of data.	Purchase of a new EV by a household.
Fuel expenditures	Expenditures on fuel by households and fleet operators. Expenditures include fuel purchases in on-road, LDV and MHDV subsectors.	Purchase of gasoline by a fleet operator for an ICEV.
Maintenance expenditures	Expenditures on maintenance by households and fleet operators. Expenditures include maintenance only for on-road vehicles. Aviation, marine, rail, and non-road subsectors are not included.	Maintenance payments for a privately owned ICEV.
Charging for Non LDV	Expenditures on charging stations for MHDVs. Category includes estimated cost of charging equipment, installation, land, and utility make-ready. Operational charger costs are not included.	Expenditure by multiple entities on DCFC station capital, installation, and utility make-ready.
Public charging (LDV only)	Expenditures on publicly accessible LDV charging stations by fuel providers, fleet operators, and the public sector. Category includes estimated cost of charging equipment, installation, land, and utility make-ready.	Expenditure by a city government to install public Level 2 chargers.
Private charging (LDV only)	Expenditures on privately accessible LDV charging stations by households, workplaces, multi-unit dwelling owners, fleet operators, and the public sector. Expenditures include charging for on-road vehicles only. Category includes estimated cost of charging equipment and installation.	Expenditure by a household to purchase and install a residential Level 2 charger.
Hydrogen refueling stations	Expenditures on publicly accessible hydrogen refueling stations by fuel providers, fleet operators, and the public sector. Expenditures include charging for on-road, aviation, marine, rail, and non-road subsectors. Category includes estimated cost of refueling equipment.	Expenditures by public sector to install refueling stations.

C.4 Economic Impacts

For this study, Cadmus used an IMPLAN model based on 2019 New York State data. The model is most accurate for changes in the near term. Economies evolve over time so an analysis for demand changes in 2050 will inherently be less accurate than one for 2030. In this study, the team looked at changes occurring from 2020–2050. Other limitations of the model include use of linear industry relationships, which may not hold true for marginal changes. For example, in an industry with an average employment of 10 jobs per million dollars in output, adding an additional (marginal) million dollars in output may not actually require 10 additional jobs, but the IMPLAN software would estimate the impact to be 10 direct jobs. As such, an IMPLAN analysis is intended to be order-of-magnitude in nature.

This analysis looks at direct changes in demand induced by the four mitigation scenarios, plus changes to household income from cost savings. Data from the New York VISION Tool was the starting point. Table C-3 summarizes the changes in spending for each mitigation scenario relative to the reference case.

Table C-3. 2020–2050 Net Demand Change from Reference (MM 2019$)

Direct Industry Impact	M1	M2	M3	M4
Vehicle Upfront	-290,098	-313,540	-296,608	-320,891
Electric Charging & Hydrogen	235,260	180,074	111,451	107,823
Vehicle Maintenance Expenditures	-77,581	-74,936	-65,212	-64,182
Fuel	-95,136	-92,092	-30,928	-30,108
Total Net Demand Change	**-227,555**	**-300,494**	**-281,298**	**-307,357**

As shown in the last row of Table C-3, all four mitigation scenarios represent a net decrease in total demand, driven by decreased vehicle upfront costs, maintenance, and fuel. For example, this means that from 2020–2050 under M1, New Yorkers cumulatively spend $290 billion less on vehicles, $78 billion less on maintenance, and $95 billion less on fuel while increasing spending on charging and hydrogen fuels by $235 billion compared to the reference scenario. The net savings accrue to households and business and government fleets. Cadmus modeled 90% of the decreased demand as increased household income.

Cadmus processed each mitigation scenario's direct industry impacts into IMPLAN inputs according to the approach in Figure C-1. First, Cadmus removed out-of-region demand changes since the scope of the IMPLAN modelling is New York State, and we are not able to model changes out of the study region. In this step, any changes to imports[127] were removed from the analysis since the impacts would accrue out of the region. We kept supply chain (local) impacts that support those imports, including transportation and retail and wholesale operations. The second step was identifying the appropriate IMPLAN industries to use for each of the remaining demand changes. Finally, Cadmus modeled the changes with IMPLAN and analyzed the results, checking to ensure consistency between inputs and outputs.

Figure C-1. Process of Translating NY VISION Expenditures to IMPLAN Inputs

Table C-4 shows the final IMPLAN industry demand inputs by mitigation scenario in millions of 2019 dollars. The second to last row shows the net change modeled in IMPLAN for each scenario relative to the reference case. The last row shows that the IMPLAN modeling accounts for a small fraction of the total net industry demand change (last row in Table C-4) for all mitigation scenarios. This is because vehicles and refined petroleum products are imports, and changes in import demand do not impact the NYS economy directly.

Table C-4. Final IMPLAN Industry Demand Inputs by Mitigation Scenario (MM 2019$)

IMPLAN Industry	Description	M1	M2	M3	M4
512	Automotive repair and maintenance, except car washes	(77,581)	(74,936)	(65,212)	(64,182)
419	Pipeline transportation	0	0	128,906	129,208
56	Construction of other new nonresidential structures	117,015	90,809	32,670	46,240
3286	Air and gas compressors	0	0	232	15,526
3258	Fabricated pipes and pipe fittings	0	0	232	15,526
3039	Electricity	114,203	110,709	40,513	40,599
3401	Wholesale services—Wholesale electronic markets and agents and brokers	(4,269)	(4,135)	(4,085)	(4,077)
3399	Wholesale services—Petroleum and petroleum products	(28,285)	(27,402)	(27,070)	(27,012)
3408	Retail services—Gasoline stores	(30,767)	(29,807)	(29,446)	(29,382)
3415	Rail transportation services	(2,512)	(2,715)	(2,569)	(2,779)
3417	Truck transportation services	(5,106)	(5,335)	(5,114)	(5,400)
3392	Wholesale services—Motor vehicle and motor vehicle parts and supplies	(41,446)	(44,795)	(42,376)	(45,845)
3402	Retail services—Motor vehicle and parts dealers	(71,407)	(77,177)	(73,010)	(78,987)
	Net Change from Reference	**(30,156)**	**(64,785)**	**(46,329)**	**(10,564)**
	% of Total Net Demand Change	13%	22%	16%	3%

Table C-5 shows the final household income inputs by mitigation scenario. Cost savings were allocated to each IMPLAN household group based on automobile commodity demand in the IMPLAN NYS data. Policies encouraging electrification along a different income allocation scheme will result in different economic impacts.

Table C-5. Final IMPLAN Household Income Inputs by Mitigation Scenario (MM 2019$)

IMPLAN Household	Annual Household Income Range	M1	M2	M3	M4
10001	<$15,000	5,230	6,907	6,465	7,064
10002	$15,000-29,999	13,762	18,174	17,013	18,589
10003	$30,000-39,999	12,286	16,223	15,187	16,594
10004	$40,000-49,999	7,691	10,156	9,507	10,388
10005	$50,000-69,999	22,974	30,338	28,400	31,031
10006	$70,000-99,999	25,177	33,247	31,123	34,006
10007	$100,000-149,999	53,894	71,169	66,623	72,795
10008	$150,000-199,999	34,552	45,627	42,713	46,669
10009	≥$200,000	29,233	38,603	36,137	39,485
	Total	204,799	270,445	253,168	276,621

C.5 State Fiscal Impact Methodology

The four mitigation cases simulate various policy agendas that can be implemented to achieve Climate Act-specified GHG emissions reduction goals within the transportation sector. Many of the policies are common to all scenarios but differ in their degree of required funding as well as their underlying targets. These nuanced differences arise from the design and assumptions embedded in each mitigation case, which are described above in appendix A. The high percentage of common policies among the mitigation cases point toward a clear pathway for achieving emission reduction goals.

Cadmus determined the fiscal impact to New York State for each of the mitigation cases by aggregating the estimated cost of each mitigation case policy. Table C-6 illustrates the equations used in cost estimation for each policy. When available and appropriate, calculations were based on the budgets that California, New York State, or, in some cases, Florida previously spent or allocated for similar policies.

Table C-6. Budget Calculations for Policies in Mitigation Scenarios

Policy to Administer	Calculation	Inputs	Notes
LCFS	Labor & consulting cost ($)/year * Program duration	$1,986,000/year for 30-year program life	Based on estimates from DEC of staff member quantity (10) and staff annual cost (178,600). Estimates influenced by CA LCFS and compared to CO data.
Carbon Price	Price ($)/ton CO2 emissions * CO2 emissions + (net) Admin Cost	M1/3: $/ton CO2e scales from $0 to $100 by 2050 M2/4: $/ton CO2e trends from $0 to $50 by 2050.	Dollar amounts align with other deep decarbonization studies.
ACC II	Labor cost ($)/year * Program duration	$7,144,000/year for 20-year program life	Based on staff member quantity (2) and staff annual cost (178,600) estimates from CA's ACT regulation and DEC, respectively.
ACT	Labor cost ($)/year * Program duration	$7,144,000/year for 20-year program life	Based on staff member quantity (2) and staff annual cost (178,600) estimates from CA's ACT regulation and DEC, respectively.
LDV Incentive	Incentive value ($)/year * # of eligible vehicles/year * Program duration	10-year program duration M1/2: $2000 per BEV scaled down to $0 by end of program. M3/4: $3,500 per BEV or FCEV scaled to $0 by end of program.	Based on CVRP budget and its rebate redemption rate (51% of new plug-in EVs). Calculation also influenced by B.D.H. Williams, Presentation: “Transportation Electrification: Incentives,” in: REV2019 Conf., South Burlington VT, 2019. Georgetown Climate Center reported similar findings & assumptions.

MHDV Incentive	Incentive (%)/year * (# of eligible vehicles/year) * (Retail cost/vehicle) * Program duration	35% phased down to 10% of total annual retail cost for 15-year program life. M1/2: BEV Retail Cost M3/4: BEV and FCEV Retail Costs	Based on values used to calculate NYTVIP incentives.
EVSE Installation Incentive: SFH for L2	Incentive cost ($)/plug * # of new L2 Residential plugs installed * Program duration.	10-year program duration. M1/2: $500/plug scaled down to $0/plug by end of program. M3/4: $300/plug scaled down to $0/plug by end of program.	Based on market research of plug costs.
EVSE Installation Incentive: MUD/Work/Public L2	Incentive cost ($)/plug * # of MUD/Work/Public L2 plugs installed * Program duration.	10-year program duration. M1: $5,000/plug scaled down to $2,500/plug by end of program. M2: $4,500/plug scaled down to $1,500/plug by end of program. M3/4: $2,500/plug scaled down to $0/plug by end of program.	Based on market research of plug costs.
EVSE Installation Incentive: DCFC	Incentive cost ($)/plug * # of plugs installed * Program duration.	10-year program duration. M1: $50,000/plug scaled down to $20,000/plug by program's end. M2: $40,000/plug scaled down to $15,000/plug by end of program. M3/4: $25,000/plug scaled to $10,000/plug by program's end.	Estimates based on detailed modeling conducted by Cadmus for New York State's DCFC incentive program.
EVSE Installation Incentive: MHDV	Incentive cost ($)/plug * # of plugs installed * Program duration.	15-year program duration. M1: $20,000/plug scaled down to $5,000/plug by program's end. M2: $15,000/plug scaled down to $4,000/plug by end of program. M3/4: $7,000/plug scaled to $2,000/plug by program's end.	Assumes installation for MHDV is more expensive given MHDV charging infrastructure requires more power than LDVs; however, fleets can better manage utilization to reach break-even sooner.
H2 Station Installation Incentive	Incentive value (%) * Total Fuel Cell Equipment Cost ($)/year.	Program occurs 2020 to 2050. Constant Incentive value = 10%.	Assumes NY has an H2 market similar to that of CA which is expected to be self-sufficient by late 2020s or early 2030s. Afterwards up to $300M of

		Only M3/M4 Total Equipment Cost for FCEV.	state support; The FCEV market will require 1,000 H2 stations, 100 of which CA State will support. Estimate assumes NY State will fund 10% of total H2 stations required through 2050.
Smart Growth—Mixed-Use	Program and Admin costs ($)/year * Program duration.	Program lasts for 15 years.	Costs align with CA Transformative Climate Communities and Affordable Housing & Sustainable Communities programs and annual program budgets. Also based on Austin, TX's Neighborhood Housing and Community Development program's budget which was scaled to NY according to population size.
		Annual program and administration costs assumed $504,322,274 and $35,100,000, respectively.	
		M1/3 has roughly 5% lower program funding than M2/4.	
Smart Growth—Transit Expansion	Average (program costs ($)/year * Program duration).	15-year program life	Averages the program costs from CA Low Carbon Transit, FL transit operations & capacity, and NY MTA Capital and STOA plans that have been scaled to New York State.
		$316,226,664/year program cost derived from CA program.	
		$461,660,000/year program cost based on FL transit plan.	
		$3,375,000,000/year program cost based on NY plan.	
		M2/4 specifies budgets about 1.5x higher than M1/3.	
Bike, e-bike, and pedestrian (2050)	Program costs ($)/year * Program duration.	20-year program duration.	Budget estimated according to CA's Active Transportation program annual funding.
		$127,229,547/year scaled to NY based on CA:NY budgeting ratio.	
		M2/4 include active transport budgets twice that of M1/3.	
TDM Measures (2050)	Program costs ($)/year * Program duration.	20-year program duration.	Based on the U.S. Bureau of Labor Statistics NY State workforce and State match to employer ($/person annually).
		Assumes 50% of dollar match and workforce costs.	
		M2/4 alone includes TDM.	
Outreach and Education	Marketing campaigns Increased familiarity (2030).	10-year program duration.	Directly based on CA's ZEV Investment Plan: Cycle 3's Public Education, Awareness, Access, and Marketing Activities budget as this estimate assumed equivalent EV outreach investment until price parity point is reached.
		$28,000,000/year program cost.	
		Outreach & Education campaigns only included for M1/3.	

C.6 Electric Distribution System Impact Methodology

The Transportation Electrification Distribution Impacts study, or TEDI study, examined the extent to which transitioning on-road transportation to electric vehicles could affect the distribution grid and lead to costly system upgrades. This analysis modeled system loads with and without the additional transportation electrification (TE) load to quantify the investment and electricity rate increases necessary for New York State in supporting these loads under the reference case and Mitigation Cases 1 and 4 from 2020 to 2050. The contrast between scenarios with and without the new transportation load revealed the magnitude of this TE load's impact on the distribution system.

The TEDI study also analyzed the affect that managed EV charging could have on alleviating the burden of this additional TE load on the State's grid by comparing scenarios with managed TE loads to those with unmanaged loads. The motivation for this extended analysis derives from early EV charging trends and knowledge of vehicle duty cycles that indicate unmanaged EV charging oftentimes coincides with distribution system peaks. Without intervention, this new TE load could push the electricity system toward steeper peaks that require system enhancements and upgrades. Managed charging measures offer one potential solution that can help shift EV charging activity away from these peak periods.

For this analysis, the TEDI study required the total annual kilowatt-hour usage for each study year (2020 to 2050) for three scenarios: Reference, High Distribution Impact, and Low Distribution Impact. Cadmus sourced overall system load forecasts from NYISO's Gold Book and E3's PATHWAYS analysis but substituted Cadmus-modeled TE load for NYISO's and E3's TE load. Table C-7 displays the TEDI study scenarios in which Cadmus and E3 or NYISO inputs were used as well as data on whether the TE load was managed or unmanaged.

Table C-7. TEDI Study Scenario Description

TEDI Scenario	Economy wide Parent Case	Cadmus Load Case	TE Load	Managed
Reference Scenario	NYISO Gold Book Baseline	N/A	No	N/A
Reference Scenario	NYISO Gold Book Baseline	Reference	Yes	No
Reference Scenario	NYISO Gold Book Baseline	Reference	Yes	Yes
High Distribution Impact Scenario	E3 Limited Non-Energy	N/A	No	N/A
High Distribution Impact Scenario	E3 Limited Non-Energy	Mitigation 1	Yes	No
High Distribution Impact Scenario	E3 Limited Non-Energy	Mitigation 1	Yes	Yes
Low Distribution Impact Scenario	E3 High Technology Availability	N/A	No	N/A
Low Distribution Impact Scenario	E3 High Technology Availability	Mitigation 4	Yes	No
Low Distribution Impact Scenario	E3 High Technology Availability	Mitigation 4	Yes	Yes

Table C-8. Revenue Requirement Equation

$$\mathbf{IRR = \overbrace{IO + IT + Id}^{\text{Expenses}} + r^{*}(IRB)}$$

IRR = Incremental Revenue Requirement
IO = Incremental Operating Expenses
IT = Incremental Taxes
Id = Incremental Annual Depreciation Expense
IRB = Incremental Rate Base
r = Overall Rate of Return (WACC)

Based on the formula in Table C-8, Cadmus calculated the incremental revenue requirement required by utilities in five-year increments from 2020 to 2050. For each study year, Nexant estimated and supplied Cadmus with the annual incremental Operating and Maintenance (O&M) and Capital Expenditure (CapEx) based on forecasted load increases and infrastructure upgrades (e.g., charger counts and costs). Incremental taxes were computed according to the cumulative incremental allowed return (r*IRB), using an averaged 6.5% tax rate. The TEDI study assumed a 45-year asset life for all CapEx resulting in a depreciation rate of roughly 2% per year. Incremental depreciation represented the depreciated sum of installed capital after the base year cumulative to the study end year. The study calculated the incremental rate base by summing Nexant's CapEx estimates and any prior depreciated incremental investments. Finally, the rate of return (r) comprised a statewide weighted average cost of capital (WACC) based on the WACC values reported by State utilities including Central Hudson, Con Edison, ORU, National Grid, NYSEG, and RG&E in their benefit cost analysis handbooks between 2019 and 2021. The resulting average WACC, 6.76%, was used as the rate of return in all cases.

The resulting utility incremental revenue requirements were allocated across their associated load category (i.e., managed TE load, unmanaged TE load, no TE load) to produce dollar per kilowatt estimates that quantify each scenario's impact on New York State's distribution grid. Cadmus concluded the TEDI study by conducting a sensitivity analysis that modeled the impact of these incremental rate increases on EV adoption. The sensitivity analysis found that, under the highest rate increases (i.e., an unmanaged High Distribution Impact scenario), EV sales dropped by only 103 vehicles or by 0.012% in 2033, the hardest hit year.

Appendix D—Policy Database, Details, and Analysis

D.1 Comprehensive Policy Database

Table D-1. Policy Evaluation

Intervention Name	Status and Description
Active transportation	Creating better walking and biking infrastructure to encourage active transportation, such as widening sidewalks, building bike lanes, adding lighting and signage, supporting bike and scooter sharing programs, offering secure bike parking, and providing shower facilities in workplaces.
Advanced Biofuel Feedstock Incentives	Directed at both farmer and biofuel producer, this could incentivize better farm practices such as no-till, cover crops, and double cropping as well as new feedstocks for biofuel production.
Advanced traffic management system efficiencies: Adaptive signal control, advanced signal timing strategies, active transportation demand management (ATDM), managed lanes, advanced queue warning, ramp metering, speed harmonization, etc.	Signals: Traffic signal control plans that favor mass transit services and other high occupancy vehicles in the traffic stream. The plans dynamically respond to minute-by-minute changes in traffic demands. ATDM: Dynamic freeway traffic control strategies to improve reliability and reduce total congestion. Includes extensive real-time monitoring of freeway conditions. Control response may include incident management, dynamic HOV lanes, express lanes with dynamic tolls, advanced lane closure warnings, part-time shoulder use, advanced queue warning, speed harmonization, dynamic ramp metering, dynamic reversible lanes.
Allowance for Fuel Cell Electric Vehicles to Travel through Tunnels and Bridges	Allowing fuel cell electric vehicles to travel through tunnels and bridges, including the vintage tunnels around NYC, is a critical market enabler for fuel cell electric vehicles in NYS. The states (NJ, NY, MA) need to share information on the bridge/tunnel issue, including safety studies and experiences. Risk assessments can incorporate recent research on the safety of fuel cell electric vehicles in tunnels.
Alternative Fuel and Alternative Fuel Vehicle (AFV) Fund	This could enable the State to generate funds from the sale of EPAct 1992 credits. The funds that EPAct credit sales generate could be deposited into an Alternative Fuel Revolving Fund (Fund) for State agencies to offset the incremental costs of purchasing biodiesel blends of at least 20% (B20) or ethanol blends of at least 85% (E85), developing alternative fueling infrastructure, and purchasing AFVs and hybrid electric vehicles. Funds could be distributed to State departments, institutions, and agencies in proportion to the number of EPAct credits generated by each.
Alternative fuel infrastructure financing	State and local government can offer innovative and low-cost financing options, such as property assessed clean energy (PACE) financing, for the installation of infrastructure such as H2 fueling stations. PACE financing is traditionally used in energy efficiency markets and dictates that the loan be repaid through the property tax bill. This allows upgrades to be funded by whoever owns the property, regardless of who undertook the process.
Biodiesel Requirement for Fleets (State and/or School Bus)	This could require that every school bus and/or State fleet capable of operating on diesel fuel should be operating using blends of biodiesel (B5-B20). At least 2% of the total volume of fuel purchased annually by local school districts or State fleets statewide for use in diesel school buses/State fleets could be a minimum of B20, to the extent that biodiesel blends are available and compatible with the technology of the vehicles and the equipment used.
Biofuel Infrastructure Loan Program	Fueling equipment for RNG, Renewable propane, liquefied hydrogen, electricity, E85, or diesel fuel blends containing a minimum of 20% biodiesel installed could be given a loan not to exceed $30,000. Permitting and inspection fees are not included in covered expenses. Fueling station owners who install qualified equipment at multiple sites are allowed to use the loan toward each location.

Biofuel Production Incentive Program	Could provide incentives to biofuel producers for advanced biofuel produced from sugar, starch, oil, or animal fat feedstocks and RNG. Targets for carbon intensity could be set lower over time or thresholds with price per gallons for different carbon intensities. Incentives could take the form of grants, tax credits, or loan guarantees.
Biofuel Warranty Requirement	NYS could require that all new State government diesel vehicles have a manufacturer's warranty that allows the use of biodiesel blends of 20% (B20) in the vehicle or are flex fuel vehicles and can accept E85 or CNG vehicles powered by RNG. This requirement would not apply if the State determines that there is no vehicle available that is suited for the intended use.
Biofuels and Other Low-carbon Fuels Research and Development Funding	The New York State Energy Research and Development Authority's (NYSERDA) Clean Transportation Program provides funding for projects that enhance mobility, improve efficiency, reduce congestion, and diversify transportation methods and fuels through research and development of advanced technologies. The scope of this program can be expanded to encourage advanced biofuels and/or improved techniques or processes from traditional feedstocks such as corn and soybeans. This program could also cover other low-carbon fuels.
Biofuels and Other Low-carbon Fuels Tax Exemption	By exempting sales and use taxes to biodiesel blends above a certain percent (for example 10% for biodiesel or ethanol), the State could incentivize B11/E85. This could also be applied to other low-carbon alternative fuels.
Biofuels PACE Program	Biofuels PACE Program provides interest buydown on loans to biodiesel, ethanol or green diesel production facilities and livestock operations.
Carbon Pricing	Carbon Pricing places a cost on GHG emissions. Carbon pricing, either a carbon tax, cap-and-trade system, or similar, can serve to provide a long-term signal to consumers and investors to move away from fossil fuels by properly pricing the externalities of carbon emissions. New York State participates in the Regional Greenhouse Gas Initiative (RGGI), a cap-and-trade program covering electric power sector. California's cap and trade program has included a declining cap on transportation sector emissions since 2015, which are regulated at the point of fuel distributors.
Carpooling	Carpooling policies and programs reduce VMT through shared rides. The state can encourage carpooling through the use of carpool lanes and preferential tolls, promotion of apps that facilitate carpooling, providing locations for casual carpool pick-ups and drop-offs, and adoption of workplace and school carpooling programs.
Clean Fuels Program (LCFS)	A policy to reduce the carbon intensity of transportation fuels compared to current usage trends. Emissions intensity targets are set by a governing jurisdiction. Each "obligated party" (i.e., fuel distributor) must meet the average emission intensity targets through the sale of lower carbon intensity fuels such as biodiesel and renewable natural gas or through the purchase of credits that are generated by low-carbon fuel sales. This incentivizes lower CI biofuels and EV adoption.
Commercial and Medium- and Heavy-Duty EV Incentive	EV rebate programs provide a financial incentive that covers a portion of the purchase price of an EV. The New York Truck Voucher Incentive Program (NYTVIP), administered by the New York State Energy Research and Development Authority (NYSERDA), provides a voucher for the incremental costs of alternative fuel vehicles. The voucher amount depends on the vehicle technology and the vehicle weight class. New York State could expand the rebate by increasing the number of rebates available or increasing the level of the incentive.
Congestion pricing	Congestion pricing (or value pricing) uses pricing to shift discretionary rush-hour highway travel to other transportation modes or to off-peak periods to enable the roadway system to flow more efficiently. Pricing strategies include: variably priced lanes (e.g., express toll lanes or high-occupancy toll lanes, HOT lanes), variable tolls on entire roadways, cordon charges (fixed or variable charges to driving into or within a congested city during rush hours), or area-wide charges (per-mile charges on all roads within an area that may vary by level of congestion). Might include higher tolls for single-occupant vehicles, or single-occupant AVs.

Consumption tied to production mandate of biofuel	Many states have embraced low blend biodiesel mandates that increased over time from as low as 2% biodiesel (B2) to B5, B10, and B20. In this policy, mandates of consumption are benchmarked based on In-State production capacity.
Conventional advertising and information campaigns	State agencies, cities, and utilities have employed a variety of advertising campaigns to increase EV awareness, such as partnerships with dealerships, social media campaigns, major employer partnerships, and online cost calculators. NYSERDA currently contributes to the "Drive Change. Drive Electric." EV marketing campaign, which could be expanded through additional funding and partners.
Dealer incentives	This intervention includes incentive programs that provide incentives to both consumers and dealers for each EV sale, to encourage dealers to prioritize EV sales. New York State does not currently offer incentives for dealers but could expand their current EV incentive programs.
Demand Charge Relief	Demand charges have been a major cost for medium- and heavy-duty fleets and DCFCs. This intervention would waive or lessen demand charges for EVSE, at least in the near term. California's PUC has granted demand charge waivers, and approved rates that shifted demand charges to higher per kWh fees during peak periods.
Development incentives for transit-oriented, high-density, mixed-use (re)development	Public agency land development regulations, fees, and development bonuses for meeting the desired mixed-use or housing/jobs balance, for infill developments near major transit stations and in EJ areas, or for brownfield redevelopment.
Electrification of shared mobility and mobility-as-a-service	New York State could enact policies that drive ride hailing towards electrification. California's Clean Miles Standard and Incentive Program, established by CARB in response to SB 1014, includes annually increasing targets for the number of passenger-miles traveled using zero-emission means.
Employer policies to promote telework/virtual meetings or alternative commute modes	Agencies can lead by example and can promote local employers to adopt similar policies. Public agencies might consider promoting virtual or telework strategies through targeted regulations, promotions, tax incentives, and subsidies. Employers offering free or subsidized parking to employees can implement parking cash outs. Under a parking cash out program, an employer gives employees a choice to keep a parking space at work, or to accept a cash payment and give up the parking space. Parking cash out programs are one of the most effective means to encourage employees not to drive alone to work. Cash out programs are an effective means of allocating scarce parking or managing a growing demand for more parking. Parking cash out programs benefit employees because they allow employees choose whether or not to continue driving alone. Employees perceive these programs as fair since nobody is forced to stop driving or give up free parking, but those who do are rewarded financially.
EV-Ready Building Codes	This intervention would mandate that new buildings are constructed to allow for the future installation of EV charging stations. EV infrastructure is much less expensive to install during new construction than as a retrofit. Several U.S. cities, including New York City, have introduced EV-Ready building codes. The state of California has mandated that new buildings be made EV-capable.
EVSE financing	State and local government can offer innovative and low-cost financing options, such as property assessed clean energy (PACE) financing, for the installation of EVSE at homes. PACE financing is traditionally used in energy efficiency markets and dictates that the loan be repaid through the property tax bill. This allows upgrades to be funded by whoever owns the property, regardless of who undertook the process.
EVSE Open Access Requirements	EVSE open access requirements include standards for EVSE providers that prohibit them from levying a subscription fee or requiring membership to use their stations. They can additionally include requirements that providers accept at least two forms of payment and clearly disclose information about their rates at the point-of-sale. New York State has not adopted such a standard yet.

EVSE Parking Requirements	EV-ready and EVSE parking requirements set minimum standards for the percentage of parking spots in parking lots that are either equipped with EVSE or the electric infrastructure necessary to support EVSE.
Expansion of Private Light-duty EV Rebate Program	EV rebate programs provide a financial incentive that covers a portion of the purchase price of an EV. New York State currently offers the Drive Clean Rebate program, which offers up to $2,000 per EV. New York State could choose to expand the rebate by increasing the number of rebates available or raising the amount of the incentive.
Extend and Strengthen Light-duty ZEV Mandate	The current LDV ZEV Mandate, managed by California's Air Resources Board (CARB), requires automakers to sell a certain number of zero emission vehicles or to buy ZEV credits from other manufactures if they do not produce enough of their own. NY, along with 10 other states have adopted California's Air Resources Board (CARB) ZEV Mandate. This could be strengthened through extension of the target year and increase in targeted sales penetration.
Feebate	Feebates create a fee for vehicles with high CO_2 emissions and provide a rebate for vehicles with low or no CO_2 emissions. An advantage of a feebate Program is that it can be designed in such a way that it is revenue neutral. New York State does currently not have a feebate program.
Fiber optic communications (Broadband internet) network expansion policies	To enable more telework and less commuting, a public agency might encourage private sector investment in high-speed broadband internet infrastructure in communities through regulations, tax incentives, and subsidies. Policies may be more focused on building rural infrastructure or subsidizing internet connections and computers for communities in “transit deserts.” Installation of publicly accessible, free, internet terminals in libraries, schools, and government buildings. Might consider building code regulations for new apartment buildings that require an Internet access room in addition to the usual foyer, mailboxes, and laundry room.
Incentivize infrastructure plans that maximize freight movement efficiency	Generally public agency regulations, permitting, tax incentives and subsidies to encourage the desired activities by logistics services. Could include rail service upgrades, elimination of at-grade rail crossings, safety, and schedule improvements.
Incentivize private industry ridehail service use of shared, electric, and automated vehicles	Encourage TNC's and other providers of taxi-like services to increase deployment of shared and, ideally, electric vehicles. May include a mix of regulations, permits, fee discounts, infrastructure (taxi holding areas) and subsidies to encourage the desired deployment. May incentivize automated vehicles in the future.
Incentivize use of alternative last-mile delivery modes	Agency through regulations, tax incentives encourage delivery companies to use alternative modes such as cargo e-bikes, electric UAVs, ground drones, electric vans, and AV delivery vans. Regulations may include building code requirements for UAV landing pads and public storage lockers for deliveries.
Increased parking rates, reduced parking supply, parking management, curb management	Various parking management implementations that raise the cost of parking ICE vehicles, and/or make parking for all motor vehicles scarcer or more costly. Might include dynamic pricing of parking or dynamic curbside management to manage curb use by TNCs, buses, taxis, shared e-scooters, shared e-bikes, residents, workers, and delivery vehicles. Could also include reducing parking requirements for new buildings or renovations, especially near transit.
Increasing awareness of EVSE availability through signage or apps	Adding signage that helps send the message that corridors are feasible to drive with EVs, such as a US DOE program that provides a designation to corridors that have EV infrastructure. New York State currently participates in the alternative fuel program and has designated several of their highways as alternative fuel corridors. Could also create or ensure accuracy of apps like Plugshare that show the location of EV chargers.
Increasing awareness of hydrogen fueling availability through signage or apps	Adding signage that helps send the message that corridors are feasible to drive with FCEVs, such as a US DOE/US DOT program that has designated corridors with hydrogen infrastructure. New York State currently participates in the alternative fuel program and has designated several of their highways as alternative fuel corridors. I-84, I-87, I-90, and I-95 are designated as "corridor-pending" for hydrogen. To be designated "corridor-ready" for hydrogen, the

	corridors must have no more than 100 miles between publicly available hydrogen dispensing stations within 5 miles of the highway. Could also create apps that show the location of hydrogen fueling stations.
Installation of DCFC for use by TNC EVs	Provide funding for the installation and operation of DCFC that are specifically designated for use by TNC EV drivers. New York State does not currently offer this program.
Internal Combustion Engine (ICE) Ban	This might include a ban on the sale of ICE vehicles or a ban on the entry of an ICE vehicle into a specific jurisdiction. Fourteen countries and 20 cities have introduced some sort of ICE vehicle phase-out. Norway has an ambitious timeline to ban all ICE vehicles sales by 2025, and Norway's capital city, Oslo, plans to make its city center "fossil-free" by 2024.
Invest in transit system improvements and expansion to increase access, reliability, and resiliency	Targeted infrastructure investments to increase access, reliability, and resiliency of public transportation, including expanding walking/biking connections to transit, and facilitating multi-modal transportation (e.g., through the implementation of coordinated schedules and fares and the use of a common payment system between operators).
Investment in public transit	New York State could increase funding to improve, expand, and/or optimize public transit.
Land use and curb management planning policy to promote staging areas for ridehail vehicles to disincentivize circulating trips	Dynamic curbside management to manage the sharing of curb space by TNC's, buses, taxis, shared e-scooters, shared e-bikes, residents, workers, and delivery vehicles.
Low Carbon Fuel Standard	A policy to reduce the carbon intensity of transportation fuels compared to current usage trends. Emissions intensity targets are set by a governing jurisdiction. Each fuel distributor must meet the average emissions intensity targets through the sale of lower carbon intensity fuels such as biodiesel and natural gas or through the purchase of credits that are generated by low carbon fuel sales. NY Senate Bill S4003A, which is in Committee, would reduce carbon intensities from the on-road transportation sector by 20% by 2030. NY Senate Bill S4003A is in Committee. This bill would reduce carbon intensities from the on-road transportation sector by 20% by 2030."
Mandating E15	E15 instead of E10 would displace an additional 290 million gallons of gasoline (not discounted for lower energy content). Currently NYS consumes about 590 million gallons so the total would be ~980 million gallons, immediately and significantly displacing petroleum. Only ICE vehicle made before 2001 are not compliant. Ethanol can be made from some in-state and 100% U.S. regional resources.
Medium- and Heavy-Duty ZEV Mandate (i.e. California's Advanced Clean Trucks)	A ZEV Mandate requires automakers to sell a certain number of zero emission vehicles or to buy ZEV credits from other manufactures if they do not produce enough of their own. New York State, along with 14 other states and the District of Columbia, has agreed to a target of 30% ZEV sales of MHDV trucks by 2030 and 100% by 2050.
Pay-per-mile auto insurance	Auto insurance policies consisting of a daily base rate and a variable rate (cost per mile). These programs incentivize low-mileage vehicle ownership.
Private EVSE Incentive	Private EVSE incentives provide financial support for non-public EVSE installation. New York State currently offers a few different EVSE incentive programs, some of which cover workplace and MUD EVSE installations. The state could increase the level of the rebate or extend the program to cover residential EVSE installation. A multi-state survey of people who had purchased EVs found that 22% would not have purchased their PEV without a home EVSE subsidy, and another 39% said it was a very important part of the decision. Additionally, a survey of EV owners said that 40% would like for utilities to install home EVSEs.
Private Hydrogen Infrastructure Incentives and Grants	Private hydrogen infrastructure incentives provide financial support for hydrogen infrastructure installation by non-public entities. California provides direct funding for hydrogen infrastructure under Assembly Bill 8 for at least the first 100 public-

	access hydrogen stations for light-duty vehicles in the state. New York State currently offers an Alternative Fuels and Electric Vehicle Recharging Property Credit. The credit for each installation of property is equal to the lesser of $5,000 or 50% of the cost of property less any cost paid from the proceeds of grants. Key decisions will include to what extent current programs should be expanded or extended. For example, the level of the tax credit could be increased.
Promote complete streets	New York state could provide incentives for local governments to implement complete streets in their jurisdictions.
Promote information sharing between public and private industry partners	For pilot programs, agencies can specify the data or the summary statistics that are valuable measures of effectiveness to monitor the impacts and track performance of pilot programs with new technologies.
Promote private sector initiatives to develop automated trucks capable of platooning	AV trucks can follow each other close enough to achieve fuel savings by reducing air drag.
Promote reorganization, relocation, and establishment of new warehouses, distribution centers, and delivery centers in and near high-demand urban areas; and expedite review of new and upgraded intermodal terminals	Generally public agency regulations, permitting, tax incentives and subsidies to encourage the desired activities by the logistics services.
Public and Heavy-duty EVSE Make-ready Rebates	Utilities propose to invest in make-ready infrastructure for public charging and/or MHDV charging. New York State DPS recently approved a $700 million make-ready program, which mandates New York's six IOUs to install over 53,00 level 2 chargers and 1,500 DCFC by 2025, including $200 million directed to environmental justice communities.
Public EVSE Installation Mandates	This intervention would create requirements for EV charging station deployment in New York State. Where the private market does not achieve goals, the state would develop state-funded charging stations. New York State does not currently have a public EVSE installation mandate. The Illinois Department of Transportation was required to install at least one charging station per interstate rest stop by January of 2016.
Public Fleet EV Mandates	This intervention would create requirements for public fleets to achieve a certain number or percentage of EVs in their fleets. One example is Massachusetts' Chapter 169, Section 1 of “An Act Relative to Green Communities”, which set a goal of 50% of vehicles owned and operated by the Commonwealth to be alternative fuel vehicles or hybrids by 2018. The NYC Clean Fleet Plan has replaced 2,200 gas- powered on-road fleet vehicles, with a plan to reach 4,000 by 2025.
Public Fleet Light-duty EV Rebates and Grants	A state-level intervention to provide EV purchase incentives to assist local governments in purchasing EVs. Massachusetts, Connecticut, California, and Maryland also have incentives to help cover the incremental costs of clean vehicles for public fleets. Massachusetts' program, known as EVIP, offers $7,500 per vehicle and is primarily targeted to municipal fleets.
Public Hydrogen Infrastructure Incentives and Grants	"Public hydrogen infrastructure incentives provide financial support for hydrogen infrastructure installation by municipal authorities, school districts, and other public entities. California provides direct funding for hydrogen infrastructure under Assembly Bill 8 for at least the first 100 public-access hydrogen stations for light-duty vehicles in the state. Pennsylvania's Alternative Fuels Incentive Grant program provides grants to school districts, municipal authorities, political subdivisions, and others to support the cost to purchase and install the necessary fleet refueling or home refueling equipment for bi-fuel, dual-fuel, hybrid, or dedicated alternative fuel vehicles.

Public/ Workplace EVSE Incentive	Public and workplace EVSE incentives provide financial support for public and workplace EVSE installation. NYSERDA's Charge Ready Program currently offers a $4,000 per new charging port installed and $1,500 per charging port replaced incentive. The incentive is eligible for public and workplace parking lots with at least 10 parking spots, and for MUDs with at least 8 parking spots. The level of the rebate could be increased, or the program could be extended to small parking lots.
Rail subsidies for freight movement	General public agency regulations, permitting, tax incentives and subsidies to encourage the desired activities by the logistics services.
Rate-Based Utility Investment in Transportation Electrification	This intervention instructs utilities to add grid upgrades aimed at increasing transportation electrification to their rate base. New York State DPS' recently approved make-ready program is funded through rate-based utility investment. CA took a similar approach with SB 350, which determined transportation electrification to be in the public interest and directed investor-owned utilities to invest ratepayer funds in advancing transportation electrification.
Registration Fee and Excise Tax Reduction for EVs	Some states and localities have reduced or eliminated registration fees and/or excise taxes levied on EVs and other alternatively fueled vehicles as a method of incentivizing their purchase.
Remote Work Policies	As demonstrated in the COVID-19 pandemic, remote work can reduce VMT. Remote work can be supported through policies that enable remote work for certain employees, as well as by increasing internet access.
Require certain vintage on-road trucks and/or Tier 3 or 4 for off-road equipment.	These could be by project (see NY Port Authority) or by state regulation that all diesel and ICE vehicles must meet certain vintage thresholds by certain dates. This should be a technology neutral approach with the focus on the latest post-combustion equipment. By removing the oldest, most polluting and least efficient vehicles from NYS roadways, NYS can make dramatic improvements in air quality as the oldest vehicle classes are responsible for an excessive amount of pollution and waste. For example, diesel vehicles made after 2010 have SCR, DOC and PM devises for post-combustion. Also, ICE vehicles made after 2001 can accept E15 rather than E10. Moving to more efficient less polluting vehicles faster will reduce both GHGs and pollutants.
Ride-and-drive events, educational sessions for fleet operators	There have been several ride-and-drive events in New York State, but these could be expanded to more locations and/or occur more frequently.
Setting Statewide Targets for Hydrogen Refueling Stations	California set statewide targets for hydrogen refueling stations, provided assistance in siting the stations, and committed $20 million per year to funding the first 100 stations. Assembly Bill 8 requires an annual report on station development. Targets, coordination of station siting, and reporting on progress help in documenting and applying lessons learned to maximize the efficiency of statewide infrastructure development.
Streamlined Permitting for Hydrogen Dispensing	Streamlined permitting processes for hydrogen dispensing reduce the time and cost associated with installing a hydrogen fueling station. Permits are issued at the local level, but states can take actions to support municipalities in streamlining the hydrogen dispensing permit process, such as identifying a single point of contact at the state level for questions and requests regarding hydrogen. Municipalities can streamline permitting by providing one-stop regulatory approval. California directly adopted NFPA 2 to facilitate station permitting along with extensive AHJ outreach. California also developed a hydrogen station permitting guide.
Support online platforms to offer municipal services (e.g., licenses, permits, tax filings, payments, etc.)	Public agencies could offer online, multi-lingual websites or apps for state or municipal services to reduce the need for in-person trips to government offices. Through regulations, agencies can encourage private sector to improve security of internet transactions, reduce spam, reduce spyware, and reduce cyberattacks.
Taxes on private individual-owned AVs	Vehicle ownership tax to discourage private individuals from purchasing an AV for their exclusive use (In essence discouraging low-cost private chauffer option.)

Time of Use Rates for Hydrogen Production	The cost of electricity has a large impact on the economic competitiveness of hydrogen production via electrolysis. Time of use electricity rates can help to lower the cost of electrolysis, thereby reducing the cost of green hydrogen.
Time-of-use Rates	Time-of-use (TOU) rates introduce time-differentiated electricity prices, with higher prices at times when there is high demand on the electric grid relative to supply and low prices when there is low demand on the electric grid relative to supply. TOU rates incentivize EV drivers to charge at times that are beneficial to load balancing on the grid and can lower the overall cost of charging EVs. TOU rates are becoming more available across the country.
Transit and School Bus EV Rebates and Grants	A state level intervention to provide EV purchase incentives to assist local governments in purchasing EVs. The New York Truck Voucher Incentive Program (NYTVIP) provides funds for a percentage of the incremental cost of the vehicle, up to a per-vehicle cap. Many states offer such rebates for transit and school bus electrification.
VMT Tax	An annual tax on the number of miles driven by a vehicle. May be applied to all vehicles, to specific vehicle types (such as trucks or privately owned AVs), or to specific vehicle usage (such as inefficient trips made by an empty AV or empty ridehail vehicle in urban or high-demand areas). A truck VMT tax could be applied to all travel by all trucks, or trucks could be taxed at different rates on the basis of one or more factors: vehicle type or configuration (such as single unit versus combination truck), vehicle weight or weight per axle, and location or location and time of travel.

D.2 Details on High-Priority Policies

Table D-2 summarizes the attractiveness of each transportation electrification policy along the key dimensions, where the effectiveness dimension is defined as the demonstrated effectiveness of the policy to increase EV sales. A rating of High implies a policy increases EV sales (Effectiveness), does not pose a financial burden to the State (Fiscal Impact), and promotes equity and public health (Equity/Public Health). A Low rating implies the opposite. Medium implies somewhere in the middle.

Table D-2. High-Priority Policy Suitability Matrix—Electrification

Policy	EV Sales Impact	Fiscal Impact	Equity/Health Impact
CA ACC II Revised ZEV Mandate Extension	High	High	Medium
CA Advanced Clean Trucks Rule	High	High	High
Vehicle Purchase Incentives	Medium	Low	Medium
Feebates	Medium	High	Low
Carbon Pricing	Medium	High	Low
Low Carbon Fuel Standard	Medium	Medium	Medium
Outreach and Education	Medium	Medium	Low
Charging Infrastructure Investment	Medium	Low	Low
Utility rate designs	Low	Medium	Low

Note: High is more desirable

Table D-3. presents the same characterizations for VMT management and system efficiency improvement policies, where the effectiveness dimension is defined as the demonstrated effectiveness of the policy to manage VMT, increase system efficiency, or foster mode shift.

Table D-3. High-Priority Policy Suitability Matrix—VMT Management and System Efficiency Improvement

Policy	Mode Shift	Fiscal Impact	Equity/Health Impact
Smart Growth Incentives	High	Medium	High
Complete Street Policies	Medium	Medium	High
Shared Mobility Services (mass transit and micro-mobility)	High	High	High
Vehicle-Miles Traveled (VMT) fee	Low-High*	Med-High	Medium
Employer Telework	High	Low	Medium

* Impacts depend on fee amount

Similarly, Table D-4 provides the assessment of policies that advance hydrogen and biofuels adoption, where effectiveness is defined as demonstrated effectiveness of the policy to foster fuel-switching, technology adoption, and GHG emissions reductions.

Table D-4. High-Priority Policy Suitability Matrix—Hydrogen and Biofuels

Policy	Effectiveness		Fiscal Impact		Equity & Public Health	
	Biofuels	Hydrogen FCEVs	Biofuels	Hydrogen FCEVs	Biofuels	Hydrogen FCEVs
Incentives for Distrib. and Fueling Infrastructure	Low	Medium	High[a]	Low[b]	Low[c]	High[d]
Low Carbon Fuel Standard	Medium		High		Mixed Benefit	
Advanced Clean Cars II	N/A	Medium	N/A	High	N/A	High
Advanced Clean Trucks Rule	N/A	High	N/A	High	N/A	High

[a] Liquid biofuels.

[b] Hydrogen and renewable natural gas.

[c] Similar to petroleum-based fuels.

[d] Hydrogen for MHD fuel cell vehicles.

The high-priority policies summarized in this section are the components that are modeled in various combinations and to various degrees in each mitigation scenario.

D.2.1 Zero-Emission Vehicle (ZEV) Mandates

Vehicle mandates are part of a broader policy category that includes requirements for binding and non-binding vehicle sales and are useful in providing policy certainty and setting expectations on vehicle sales for all stakeholders involved in vehicle markets and transportation infrastructure.[128] Mandates have long been used to regulate transportation emissions at both federal and state levels, such as the mandated phaseout of leaded gasoline that began in the 1970s.[129] The U.S. EPA has authority over air quality and vehicle efficiency standards, but Section 177 of the Clean Air Act permits California to set its own standards that other states may adopt.

Advanced Clean Cars II	
New York State could adopt the proposed CA ZEV mandate (ACC II) that would likely increase ZEV sales percentages beginning in 2026 to require that by 2035, 100% of applicable passenger car and light truck sales are zero-emission.	
Scope	LDVs from classes 1-2a, all fuels
Jurisdiction	State, local
Timing	Mid- to long-term (6-11+ years)
Barriers Addressed	Up-front cost, insufficient model availability, awareness, and education
Effectiveness	High (for EVs and FCEVs)
State Fiscal Impact	High
Equity & Public Health	High

Through the Section 177 provision, in 1993 New York State adopted the California ZEV Program.[130] Since 2018, New York State has implemented the multi-state ZEV Implementation Plan, which requires that automakers of a given size sell increasingly larger shares of light-duty EVs and FCEVs beginning with the 2018 model year, with increasing percentages for required sales through 2025. California is now in the early stages of the regulatory process of considering a post-2025 Advanced Clean Cars (ACC II) ZEV Mandate Extension that would target 100% ZEV sales for passenger cars and light trucks by 2035.

Advanced Clean Truck & Associated Policies	
This ZEV mandate would require that by 2035, zero-emission truck sales would be 55% of Class 2b – 3 truck sales, 75% of Class 4 – 8 straight truck sales, and 40% of truck tractor sales. Further, by Governor Hochul's September 2021 announcement requires that by 2045, 100% of new sales would be zero-emission. If adopted in New York State, the MHD ZEV sale requirements could begin with the 2025 model year.	
Scope	MHDVs from class 2b to class 8, all fuels
Jurisdiction	State, local
Timing	Mid- to long-term (5-11+ years)
Barriers Addressed	Up-front cost, insufficient model availability, awareness and education
Effectiveness (Biofuels)	N/A
Effectiveness (Hydrogen FCEVs)	High
State Fiscal Impact	High
Equity & Public Health	High

Additionally, in July 2020, New York State signed a joint memorandum of understanding with 14 other states and Washington, D.C., committing to 30% ZEV sales in the medium- and heavy-duty vehicle (MHDV) subsector by 2030, and 100% by 2050.[131] The signatories have agreed to consider the adoption of the Advanced Clean Trucks Rule promulgated by the California Air Resources Board (CARB), which requires 55% of Class 2b – 3 truck sales, 75% of Class 4 – 8 straight truck sales, and 40% of truck tractor sales be ZEVs by 2035.[132] This policy is also responsive to 2020 Executive Order N-79-20 that directed CARB to promulgate regulations that would achieve 100% zero-emission in the MHDV subsector by 2045.[133]

D.2.2 Vehicle Purchase Incentives

Vehicle Purchase Incentives	
EV purchase incentive programs, generally in the form of a purchase rebate, provide financial support that covers a portion of the purchase price of an EV.	
Scope	All sizes, electric
Jurisdiction	State, local
Timing	Near-term (1-3 years)
Barriers addressed	Up-front cost
Effectiveness	Medium
State Fiscal Impact	Low
Equity/Public Health	Medium

Policies that send price signals to the consumer align private and societal costs and address cost barriers associated with EVs relative to ICE vehicles. New York State implements such policies on a state-wide basis under the Charge NY initiative, which includes NYSERDA's existing Drive Clean Rebate program, which offers a vehicle purchase incentive of up to $2,000 per vehicle, and the New York Truck Voucher Incentive Program, which offers a vehicle purchase incentive for electric trucks and buses that varies by weight class and vehicle type. There are at least 300 pricing-based programs offered across the U.S., including grants and rebates, registration and licensing fees or exemptions, and tax incentives.[134] Typologies include incentives and disincentives affecting both up-front and on-going vehicle costs. The highest EV purchase incentive programs in the United States are currently in Colorado, which offers up to $5,000 per EV and California, which offers a mix of rebates worth up to $5,850 for certain household types and regions.

D.2.3 Feebates

Feebates	
Feebates institute a penalty for vehicles with high CO_2 emissions and provide a rebate for vehicles with low or no CO_2 emissions.	
Scope	All sizes and fuel-types
Jurisdiction	Regional, State
Timing	Near- to Long-term (can phase in/out over a decade)
Barriers addressed	Up-front cost
Effectiveness	Medium
State Fiscal Impact	High
Equity/Public Health	Low

Feebates are another price-based policy that helps align private and social costs. The format of a feebate policy can change over time to accommodate changing market dynamics—in early years, a small fee on the many higher-emission vehicles in the market can fund a relatively substantial benefit for the few lower-/no-emission vehicles in the market; later, as the market evolves, the policy might levy heavier penalties on higher-emission vehicles, which can fund a small benefit to the larger population of lower-/no-emission vehicles. Jurisdictions at the state and local levels have the authority and administrative capacity to establish a feebate program. Feebates have been discussed widely for nearly two decades within the Unites States. Currently, no state implements a feebate program.

D.2.4 Carbon Price

Carbon Price	
Carbon pricing encourages switching to less carbon-intensive fuels, modes, and vehicles. Over the long-term, it can spur new innovation.	
Scope	All sizes and fuel-types
Jurisdiction	Regional, State
Timing	Near- to Long-term (can phase in/out over a decade)
Barriers addressed	Total cost of ownership
Effectiveness	Medium
State Fiscal Impact	High
Equity/Public Health	Low

A carbon price places a cost on GHG emissions, either in the form of a tax or a cap-and-trade or cap-and-invest system. This price can serve as a long-term signal to consumers and investors to shift away from fossil fuels by properly pricing the externalities of carbon emissions. An important benefit of a carbon price is that it can be applied broadly across a variety of technologies, economic sectors, or geographies, which allows for emission reductions to be achieved wherever the least-cost opportunities exist.

New York State already participates in the Regional Greenhouse Gas Initiative (RGGI) along with Northeast and Mid-Atlantic states. RGGI is a cap-and-trade program covering the electric power sector that establishes an auction through which electric power generators must purchase pollution allowances. California's cap-and-trade program has included a declining cap on transportation sector emissions since 2015, which are regulated at the point of fuel distributors. California's program not only provides certainty about emissions reductions year over year, but also raises substantial revenues that are reinvested in programs that further EV deployment and other sustainable transportation initiatives. Since 2015, California has invested more than $3.5 billion of its cap-and-trade revenue in sustainable transportation programs.[135] In December 2020 Massachusetts, Connecticut, Rhode Island, and the District of Columbia agreed to move forward with a cap-and-invest program covering GHG emissions from the transportation sector, the Transportation and Climate Initiative Program (TCI-P). New York State continues to monitor the TCI-P and collaborate with these states and other Northeast and Mid-Atlantic states on the development of the framework behind the TCI-P.

D.2.5 Low-Carbon Fuel Standard

Low Carbon Fuel Standard (LCFS)	
The New York State LCFS could require a reduction in average carbon intensity of fuels that would entail compliance through the sale of low-carbon fuels or the exchange of credits.	
Scope	All sizes and fuel-types
Jurisdiction	Regional, State
Timing	Near- to Long-term (can phase in/out over a decade)
Barriers addressed	Total cost of ownership
Effectiveness	Medium
State Fiscal Impact	Medium
Equity/Public Health	Medium

An LCFS would increase the unit cost of fossil fuels relative to lower carbon alternatives. The standard regulates the carbon emission intensity of transportation fuels, setting a target that declines over time compared to current levels. Each fuel distributor must meet the average emissions intensity target through the sale of less carbon-intensive fuels such as electricity, advanced biofuels, renewable natural gas, and hydrogen, or through the purchase of credits from other entities that have generated these credits through their own sales of low carbon fuels.

The New York State Senate considered establishing an LCFS during the 2019–2020 Legislative Session. S4003A, which is in Committee as of January 2021, would reduce carbon intensities from the on-road transportation sector by 20% by 2030.[136] If adopted, New York State would join Oregon and California as one of the few U.S. states with an LCFS. California's LCFS has been in place since 2011 and targets the same reductions as proposed in New York State, while since 2016 Oregon's Clean Fuels Program has targeted reductions of 25% by 2035.[137,138]

The principal barrier to greater EV adoption that on-going policies like a carbon price, gasoline tax, or LCFS address is the higher total cost of ownership of EVs compared to ICE vehicles. The policies can help reduce the differential between the TCOs by making it less expensive to fuel an EV compared to an ICE vehicle per mile of travel. For example, a $10 per metric ton carbon price increases the cost of driving an average gasoline-powered car by 46 cents per 100 miles compared to 6 cents per 100 miles for a BEV that receives power from the NYS grid.[139]

D.2.6 Outreach and Education

Outreach and Education	
Aimed at increasing EV and FCEV awareness and familiarity, activities can include partnerships with dealerships, social media campaigns, ride-and-drive events, major employer partnerships, and online cost calculators.	
Scope	All sizes and fuel-types
Jurisdiction	Regional, State
Timing	Near- to Long-term (can phase in/out over a decade)
Barriers addressed	Awareness
Effectiveness	Medium
State Fiscal Impact	Medium
Equity/Public Health	Low

Research indicates that the car-buying public lacks awareness and understanding of EV technologies. Insufficient familiarity with EVs can be inhibit adoption as unfamiliar buyers are intimidated by unfamiliar technology or view only sticker prices without considering potential available incentives, TCO savings, and other benefits of EV ownership.[140] Outreach and education can address these challenges. State agencies, cities, and utilities have used different types of advertising campaigns to increase EV awareness, such as partnerships with dealerships, social media campaigns, major employer partnerships, and online cost calculators. The "Drive Change. Drive Electric." EV marketing campaign, which NYSERDA supports, is one such program.

Improved signage for EV-ready corridors can also raise awareness of EVs and EV charging availability among potential EV drivers. There are eight corridors within New York State that have been designated EV Ready through the Federal Highway Administration's Alternative Fuel Corridor program.[141] Ride-and-drive events, where consumers and fleet managers have the opportunity to test drive the vehicles, can give New Yorkers hands-on experience with the technology and function of EVs.

D.2.7 Infrastructure Investment

EVSE Investment	
Investment in EV charging infrastructure can support the viability of EVs. These can be public funds or utility-funded upgrades aimed at increasing transportation electrification and growing the utility rate base.	
Scope	All sizes and fuel-types
Jurisdiction	Regional, State
Timing	Near- to Long-term (can phase in/out over a decade)
Barriers addressed	Charging access
Effectiveness	High
State Fiscal Impact	Medium
Equity/Public Health	Medium

Charging infrastructure investments provide financial support for residential, workplace, public, or commercial EVSE installations. This support most often comes in the form of incentives, rebates, and financing, but could also entail direct installation by governments or utilities. Investment can support any number of EVSE-related costs, but a common variation is to cover the cost of the electrical infrastructure required up to but excluding the charger itself, called make-ready infrastructure. Investment in EVSE supports EV adoption by reducing range anxiety, increasing charger availability, and enabling infrastructure in locations and for market segments not reached by the private EVSE industry.

Several charging infrastructure investment programs are available in New York State, spanning the LDV and MHDV sectors and backed by both government and utilities. NYSERDA's Charge Ready NY Program currently offers $4,000 per new charging port installed and $1,500 per charging port replaced in parking lots at eligible public sites, workplaces, and multi-unit dwellings. New York State’s Department of Public Service recently approved a $700 million Make-Ready program, which mandates New York State's six IOUs to invest $200 million into environmental justice communities and install over 53,000 level 2 chargers and 1,500 DCFC by 2025.[142] NYPA’s Evolve NY program will invest up to $250 million statewide, primarily by building a network of DCFCs across the state. Additionally, $19.2 million from New York State’s portion of the Volkswagen Settlement will fund light-duty EVSE.[143]

D.2.9 Incentives and/or Financing for Distribution and Fueling Infrastructure

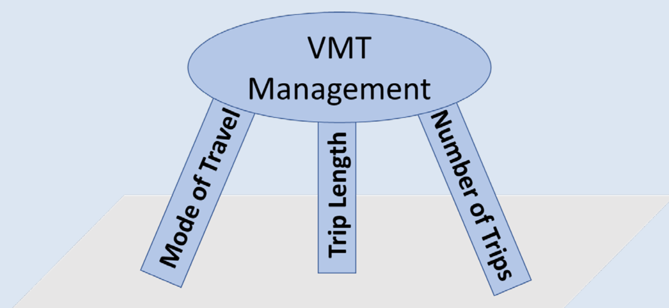
Incentives for Distribution and Fueling Infrastructure	
Investment in fueling infrastructure can support petroleum reduction. These can be public funds or utility-funded upgrades aimed at increasing transportation decarbonization.	
Scope	All sizes and fuel-types
Jurisdiction	Regional, state
Timing	Near- to long-term
Barriers addressed	Insufficient fueling access, lack of market opportunity for suppliers
Effectiveness	Low (biofuels) / Medium (hydrogen FCEVs)
State Fiscal Impact	High (liquid biofuels) / Low (hydrogen and renewable natural gas)
Equity/Public Health	Low (biofuels) / High (hydrogen for MHD fuel cell vehicles)

Infrastructure investments provide financial support for the infrastructure needed to supply hydrogen, liquid biofuels, and renewable natural gas to vehicles. This financial support most often comes in the form of incentives, rebates, and financing but could also entail direct installation by governments or utilities.

VMT Management in Perspective

Vehicle Miles Traveled (VMT) management is a three-legged stool. Any policy for managing VMT focuses on strategies that shift the mode of travel to more VMT-efficient modes, reduce trip lengths, and/or reduce the need to travel. Better transit service and higher parking costs are examples of strategies designed to shift the mode of travel to more VMT-efficient modes. Mixed-use development and other land development policies typical of Smart Growth are examples of strategies designed to shorten trip lengths. Teleworking and other policies that use technology to replace physical travel are examples of strategies that reduce the need to travel. The most effective VMT management policies address all three aspects of VMT: mode of travel (mode choice), trip length (trip distribution), and forgone trips (trip generation).

Mode of travel is the easiest leg to change and the benefits for VMT management are immediate. Trip length and number of trips take longer to change but are most effective for management of VMT.



Investment can address a variety of cost barriers such as fuel delivery infrastructure costs, fuel blending costs, fuel dispensing infrastructure costs, and fuel storage costs at the fueling station.

D.2.10 Smart Growth Incentives

Smart Growth policies attempt to manage VMT by reducing trip lengths (through higher-density, mixed-use development) and encouraging shifting of travel to more VMT-efficient modes of travel through improved transit and active transportation (bike and pedestrian) infrastructure.

The fundamental concept behind Smart Growth is that one can reduce the amount of vehicle travel (and achieve other environmental goals) by providing the right intensity and mix of residential and commercial development along with a robust transit infrastructure. Placing residences and jobs closer together reduces the distance needed to travel to work or to shop and increases the proportion of trips made by walking. Higher density developments reduce the walking distances needed to access transit and provide the higher levels of ridership needed to support efficient transit service.

Smart Growth Incentives	
Smart growth incentives enacted by municipalities or regional planning agencies provide fee waivers, density bonuses, and expedited review processes in exchange for high-density, mixed-use, affordable, and transit-oriented developments.	
Scope	Housing, land use/zoning, infrastructure development
Jurisdiction	State, local
Implementation Timing	Near- to mid-term (1-5 years)
Barriers addressed	Vehicle-oriented development patterns and land uses that obviate more efficient modes
Effectiveness	High
Economic/Financial	Medium
Equity/Public Health	High

Some states, including New York and Virginia, have established a statewide transportation project prioritization system to support the relationship between transportation project scoring and Smart Growth goals.[144, 145]

New York State adopted the Smart Growth Public Infrastructure Policy Act (SGPIPA) in 2010 as an amendment to the Environmental Conservation Law (Article 6).[146] To comply with the law, New York State Department of Transportation (NYSDOT) established:

- A Smart Growth Policy (2012)[147] to define organizational responsibilities and policy objectives.
- Smart Growth Procedures (2012)[148] to guide employees in complying with SGPIPA; a central tool is the Smart Growth Screening Tool.
- A Smart Growth Advisory Committee to direct multi-agency, multi-region projects.[149]

While SGPIPA requires state infrastructure agencies to adhere to eleven Smart Growth criteria, widespread success of Smart Growth ultimately requires local governments to implement Smart Growth policies. As part of the EPA's Smart Growth Implementation Assistance project in Madison County, NY, the Smart Growth Self-Assessment for Rural Communities was developed in 2015.[150]

Another notable approach is the City of Austin's Safe, Mixed-Income, Accessible, Reasonably Priced, and Transit-Oriented (S.M.A.R.T.) Housing program. This program shifted from a regulatory approach to an incentive-based model by offering a variety of incentives such as fee waivers, density bonuses, tax incentives, and development agreements to build and to provide affordable housing options.

D.2.11 Complete Streets

A Complete Streets policy attempts to manage VMT by encouraging travelers to use bicycle, pedestrian, and transit modes, thus reducing VMT per capita. Unlike Smart Growth policies that influence both mode choice and trip length, Complete Streets policies and strategies focus on mode choice. Complete Streets strategies consequently can have a more immediate effect on VMT (by shifting modes of travel) than Smart Growth. But over the long term, Smart Growth combining both mode choice and trip length effects will have a greater effect on VMT than Complete Streets alone.

The goal of a Complete Streets policy is to design and operate city streets so that they better serve all users of the street, especially pedestrians, bicyclists, and transit passengers, who are often underserved by traditional street designs. Accessibility and the safety of all users of the street are paramount concerns. Complete Streets is a high-priority VMT management policy because it encourages travelers to switch to more efficient modes (bike, walk, transit), thereby reducing VMT per capita.

Complete Streets	
A complete streets policy is achieved through planning, providing design guidance, and providing dedicated funding.	
Scope	Roadway infrastructure
Jurisdiction	State, regional, local
Implementation Timing	Near- to mid-term (1-5 years)
Barriers addressed	Prioritizing non-auto trips through supporting transit or active transportation infrastructure
Effectiveness	Medium
State Fiscal Impact	Medium
Equity/Public Health	High

New York State adopted a Complete Streets Act in 2011,[151] which amended the Highway Consolidated Laws of New York (Article 11, Section 331)[152] to define requirements and exceptions for the application of complete street design features. A state report issued in 2014 noted five main areas for further improvement:[153]

- Greater coordination with local jurisdictions about Complete Streets processes and guidance for local implementation.
- Increased education for the public and stakeholders about best practices.
- Revisions to the NYSDOT Complete Street Planning Checklist.[154]
- Greater clarity about Complete Streets processes, project development, and design best practices.
- Addressing a disconnect between the Complete Streets Act and a lack of dedicated funding.

While revisions have since been made to the NYSDOT Complete Street Planning Checklist, there are still opportunities for improving the implementation of the Complete Streets policy by improving local jurisdiction coordination, education, and developing increased funding for Complete Streets projects.

D.2.12 Shared Mobility Services (Transit and Micro-mobility)

Shared Mobility Services (Transit and Micromobility)	
A suite of policy approaches to support and invest in energy-efficient mobility: public transit, automated/connected/shared micro-mobility, and micro-transit services.	
Scope	Multiple modes: rail, bus, van, bike, scooter, etc.
Jurisdiction	State, regional, local
Implementation Timing	Near- to mid-term (1-5 years)
Barriers addressed	Common platform to link multimodal on-demand trips
Effectiveness	High
Economic/Financial	High
Equity/Public Health	High

Like the Complete Streets strategy, this Shared Mobility Services strategy focuses on changing the mode choice of travelers. As such, it is quickly implemented and has immediate effects on VMT. However, since it focuses on only one leg of the VMT management stool (mode choice), it is not as effective as Smart Growth in managing VMT per capita.

The Shared Mobility strategy involves supporting and investing in energy-efficient mobility: public transit, automated/connected/shared micro-mobility and micro-transit services. These services enable and encourage travelers to choose more VMT-efficient modes of travel.

Encouraging widespread use of shared modes of travel such as mass transit, micro-transit (i.e., small-scale, on-demand services), and micro-mobility devices (i.e., bikeshare and e-scooters) requires making these modes affordable, convenient, reliable, fast, and connected both digitally and physically.

A paradigm shift is starting to take hold in the U.S.—and is gaining steam rapidly abroad—as transportation agencies and transit operators recognize the need to evolve into *mobility managers* by implementing the Mobility-as-a-Service (MaaS) concept. MaaS integrates multiple transportation options through on-demand service and an integrated payment platform. For example, a rural or suburban resident might use an app to call a ridehail pickup from their home to take them to a transit station, board a train into a downtown, and then use a bikeshare to get to their final destination. Full implementation of the MaaS concept entails one app providing the information, request, ticketing, and payment for this entire trip.

Today's transportation services tend to be operated as separate systems, with the exception of paratransit. Policies that support and invest in integrating multiple operators and modes under a single digital platform serving customers across a region will enhance transportation system efficiency.

While New York City is a national leader in terms of transit mode share, the rural, suburban, and smaller urban areas in New York State will require a large injection of investment and innovation to significantly increase transit and micro-mobility mode share. Effective shared mobility services will require:

- Developing partnerships and new service models that create connected networks of rail, bus, van, bike, scooter, and other modal options.
- Developing integrated fare payment and passenger information platforms.
- Reimagining governance so that public transportation agencies, cities, counties, and regional organizations can collaborate based on aligned policies and consistent rules.[155]
- Constructing the infrastructure needed to run successful service, including bus lanes, mobility hubs, enhanced bus stops and stations, and bike and scooter lanes.

New York State is taking steps to explore mobility management. In Upstate New York, the Shared Mobility Network project educated stakeholders, conducted feasibility studies, and coordinated between private mobility companies, transit agencies, cities, and MPOs from 2015 to 2018, leading to $7 million in capital and operating investments primarily into bikeshare and carsharing programs. Though existing transit agencies were not the managing entities for these programs, the project resulted in awareness of and receptivity to the idea of forming Mobility Development Corporations as a potential next step.[156]

There are numerous pilot projects of MaaS currently being deployed in the United States. Two representative examples are the San Francisco Bay Area's integrated transit payment system, Clipper Card, and the City of Arlington, Texas' on-demand micro-transit service. The Bay Area's Clipper Card integrates payments for 24 transit services across a 9-county region, the Bay Wheels bikesharing system, and Bay Area Rapid Transit (BART) daily parking.[157] Similar innovations are being advanced in rural and suburban areas of California, with the San Joaquin Council of Governments (SJCOG) recently launching its EZhub mobile ticketing app that integrates cashless payments for seven transit services.[158] New York City's OMNY program integrates subway and bus fare payment, which is a starting point for the integrated MaaS payment programs that the Clipper Card builds on. The city of Arlington, Texas has become the first city in the U.S. to run a 100% on-demand micro-transit service, overcoming years of opposition to more traditional mass transit investments.[159]

On top of the need to prepare for new technologies, agencies across all regions of New York State have already identified and requested transit service and infrastructure improvements but lack the funding to implement. A statewide transit plan would allow New York State to assess the level of funding needed, prioritize investment decisions across the state, and identify steps needed to harness shared mobility technologies.

D.2.13 Road User Charges and Other Pricing Strategies

RUCs and Other Pricing Strategies	
RUCs can incentivize lower driving mileage by pricing road use on a per-mile basis.	
Scope	Passenger vehicles and/or trucks
Jurisdiction	State, national
Implementation Timing	Mid- to long-term (5-11+ years) with some NYC congestion pricing strategies sooner
Barriers addressed	Current lack of price-based signals to drivers that represent the full societal costs of driving
Effectiveness	Low to High (depends on fee amount)
Economic/Financial	Medium to High (depends on fee amount)
Equity/Public Health	Medium

An annual vehicle tax or fee that is proportional to the vehicle-miles traveled by the vehicle is a tool for directly managing VMT. It is potentially among the most effective strategies for managing VMT because it affects all three legs of the VMT management stool (mode choice, trip length, and number of trips). Its effectiveness is immediate and long term (as long as the VMT fees remain in effect). It is readily and easily adjustable for changing conditions. The income raised can be used to address equity impacts and other agency goals.

A VMT fee, also called a road user charge, is a tax on the number of miles traveled by a vehicle. RUCs may be applied to all vehicles or may be applied in different ways to certain vehicle types (like trucks) or to certain operating conditions (like an automated vehicle or ridehail vehicle not carrying any passengers). They may be administered annually, quarterly, or on a pay-as-you-go basis. RUCs are being explored in several states to address the issue of declining revenue from fuel taxes as fuel economy increases. They are marketed as a simple switch from a "pay-per-gallon" to a "pay-per-mile" option that follows a "user pays" principle for infrastructure funding—thus allowing the state to receive revenue from hybrid and electric vehicles that contribute less or no gas taxes but still cause wear and tear on the road. RUCs incentivize a reduction in the number of unnecessary vehicle trips and the length of trips taken, thus reducing GHG emissions. However, the primary motivation to use RUCs as a source of revenue is at odds with using them to disincentivize personal vehicle travel.

Other road-pricing strategies such as congestion pricing, roadway tolls, and parking fees can also reduce VMT per capita. These other strategies can be very effective at achieving their localized VMT reduction objectives for the areas and roadways where they are applied. However, they usually affect only one or two legs of the VMT management stool for limited localities and facilities within the region and therefore would be less effective at managing regional VMT than a regional or statewide RUC.

The National Cooperative Highway Research Program (NCHRP) Project 19-08 measured the administrative, collection, and enforcement costs of alternative revenue-generation systems: motor fuel taxes, tolling, RUCs, cordon/congestion pricing, and parking fees.[160] The study found that "though VMT fee systems have been tested and proposed, no such systems are currently in use that levy fees for all vehicle types. Consequently, there is no hard cost data available except information developed for pilot tests or submitted by companies competing to build and operate the proposed VMT fee system in the Netherlands." The 2011 final report provides guidance for revenue-generation system policy development.

Truck VMT taxes are in place at the state level in New York, Kentucky, New Mexico, and Oregon. New York State has heavy weight impact tax that charges vehicles based on the number of VMT under heavy weight use. The tax is relatively low, weight-based graduated tax rate for trucks that ranges between 0.8-5.5 cents per mile (compared to Oregon's 6.2-28.8 cents per mile VMT tax range).

Several states are exploring VMT fees through pilot or volunteer-based programs. The state of Oregon's OReGO program, launched in 2015, enrolls light-duty passenger vehicles. The OReGO program was created by Senate Bill 810 in 2013, making Oregon the first state to establish a VMT fee program after conducting several pilot studies between 2005 and 2012. Volunteer participants pay 1.8 cents per mile and receive a fuel tax credit when applicable. Revenue is directed to the State Highway Fund. The first phase was limited to 5,000 vehicles, and the program was opened to an unlimited number of personal vehicles in 2019 (still on a voluntary basis), with electric or fuel-efficient (40+ mpg) vehicles exempt for mpg-based registration fees. The program allows both GPS and non-GPS options (such as odometer reading) for reporting, and the Oregon Legislature set up privacy protections for participant data, including non-disclosure by account managers and destruction of data after 30 days of payment processing.[161] A statewide survey found that while 32% of respondents thought a road usage charge is a fair way to fund transportation improvements, 46% of respondents felt the program unfairly penalizes people in rural areas.[162]

The OReGO program has inspired other states to explore VMT fees. The California Road Charge Pilot Program was launched in 2016 and ran for nine months, with over 5,000 vehicles across the state participating. The pilot program was enabled by Senate Bill 1077 passed by the California State Legislature in 2014 and administered by the California Department of Transportation (Caltrans). Like in Oregon, the fee was set at 1.8 cents per mile to be revenue neutral compared to a gas tax (the rate was established by taking a five-year average of the gas tax and dividing by average miles per gallon of the statewide fleet). After the pilot, 73% of pilot participants felt that the VMT fee was fairer than a gas tax. However, the pilot participant sample was not demographically representative of Californians, with rural, low-income, and certain races and ethnicities underrepresented. At the time of the post-pilot evaluation in 2017, it was determined that it would be challenging to implement a broad program before 2025.[163]

In addition to Oregon and California, VMT fee pilot programs have launched in Washington, Hawaii, Minnesota, Nevada, and Colorado. Despite the momentum, a mandatory VMT fee may be challenging for several reasons:

- Out of state driving would require multiple states to cooperate on transfers between states.
- The fee collection method currently requires the mandatory use of GPS devices, which may generate privacy concerns, even if data deletion measures are required.
- The VMT fee program should be carefully designed, perhaps with off-setting subsidies to eligible households, to ensure that it does not negatively impact inequities in the transportation system.[164,165,166]

As an alternative to directly taxing the vehicle owner, a state agency might apply the approach taken in California of designating VMT as an environmental impact of new land development that must be mitigated (e.g., California's Senate Bill 743—Steinberg 2013). The onus is then on the local agency and the land developer to jointly identify, fund, and implement strategies for managing VMT per capita by the proposed land development.

D.2.14 Employer Telework and Other Employer-Based Travel Demand Management Measures

Employer Telework and other employer based travel demand management measures	
A teleworking policy creates flexibility for workers and should be accompanied by a program to fully support remote workers' needs.	
Scope	Public and private employees
Jurisdiction	State, local
Implementation Timing	Near- to mid-term (1-5 years)
Barriers addressed	Long commutes
Effectiveness	High
State Fiscal Impact	Low
Equity/Public Health	Medium

Teleworking is a Transportation Demand Management (TDM) measure that encourages employers to allow (or encourage) employees to work from home, reducing the need to commute to and from work and thereby reducing VMT and GHGs.

Telework focuses on the trip reduction leg of the VMT management stool. Of the three legs of the VMT stool, trip reduction is the most effective way to reduce VMT by reducing the need for the trip in the first place.

Employer based travel demand management (TDM) measures focus on encouraging employees to switch to more VMT efficient modes and times of day for their commute trips. A variety of TDM measures may be employed including ride sharing programs, subsidized transit passes, bike lockers, showers, marketing of TDM services to employees, preferential parking, subsidized vanpools, etc.

Various New York State departments including the Department of Transportation and the Department of Homeland Security and Emergency Services encourage private employers to allow teleworking. The New York Department of Civil Service allows teleworking for certain positions, provided that the employee and manager sign a Memorandum of Agreement.[167] In response to the COVID-19 pandemic, the State created a Pilot Statewide Telecommuting Program.[168] Originally a two-month pilot, the program has been extended multiple times and allows state employees to work from home up to five days per week.[169]

A comprehensive telework policy for state employees with supportive programs and technologies would enable New York State to lead by example. The selection, adoption, and installation of a uniform web meeting software package for state employees could be a significant part of such a policy. Additional measures might include an agency policy statement identifying employee positions and number of days a week that are eligible for telecommuting.

While many states are developing pilots in response to COVID-19, Utah's Governor's Office of Management and Budget had already created a teleworking initiative in 2018 to achieve four goals:

- Creating State jobs for rural residents.
- Using State buildings efficiently.
- Recruiting and retaining high-performing employees.
- Reducing air pollution.[170]

Utah's initial pilot enrolled 136 employees across four state agencies, resulting in the reduction of 273 pounds of vehicle emissions, among other savings.[171] Following the successful pilot, the state now plans to implement telework across all state agencies. Utah initially set a target of a 30% adoption rate among eligible employees, or 2,555 employees, by the end of 2020. As a result of the pandemic, the state was able to quickly ramp up to having 8,500 state employees teleworking. Utah modeled its program after a successful program in Tennessee.[172,173]

High-speed internet access is a barrier to teleworking. This continues to be a challenge in many rural areas across New York and the U.S., as well as in underserved urban and suburban communities. In New York State, 7.38% of the rural population has no access to high-speed Broadband communications (≥100/10 Mbps speed), compared to only 0.79% in urban areas, as of December 2019.[174] Expanding the fiber optic network to enable Broadband internet access or 5G access is a vital utility expansion that is needed to provide equitable access to remote working, remote learning, and remote health care options to rural and underserved communities.

D.2.15 Utility Rate Designs

Utility rate designs	
Changes to utility rates to better reflect system costs and encourage transportation load is managed cost-effectively. Interventions include TOU rates, subscription-style demand charges, or demand charge holidays.	
Scope	All sizes and fuel-types
Jurisdiction	Regional, State
Timing	Near- to Long-term (can phase in/out over a decade)
Barriers addressed	Total cost of ownership
Effectiveness	Low
State Fiscal Impact	High
Equity/Public Health	Low

investment can be supplemented by utility rate designs that encourage vehicle charging during periods when there are lower wholesale energy prices and less strain on the grid. To the degree that grid carbon intensity is correlated with the time-differentiated factors underlying these utility rates, bill cost management should be correlated with carbon reductions. Designs might entail introduction of TOU rates, variable or critical peak pricing, or peak day pricing, all of which aim to better align retail prices with real-time grid prices.[175] New York State utilities already offer TOU rates across their customer classes, however uptake of these rates instead of the default flat rate is very low, as shown in Table D-5.[176]

Table D-5. Uptake of Opt-in Residential TOU Rates in New York State

Utility	Residential TOU Customers	Total Residential Customers	% TOU
National Grid	5,624	1,475,271	0.4%
Con Edison	1,720	2,896,029	0.1%
Central Hudson	1,000	266,061	0.4%
RG&E	1,273	334,750	0.4%
NYSEG	4,016	766,954	0.5%
O&R	3,399	198,331	1.7%

Additionally, utility rate designs like the demand subscription embedded in Pacific Gas and Electric Company's Business EV rate or subsidies such as the demand charge deferral Southern California Edison offers to Commercial and Industrial customers, can improve the economics for high-power EVSE installations that would otherwise incur high demand charges, such as those at fast-charging stations or serving MHDV fleets.[177,178] Such designs are aimed at mitigating the potential imbalance between demand and energy charges when charging station utilization is low. When utilization increases and stations deliver more energy, fixed costs can be spread across these kilowatt-hours in an economically viable way.

It should be noted that demand charges support critical policy objectives of reducing utility system costs and protecting utility customers, including low-income customers, from cost shifts and bill increases, and these objectives should be considered alongside benefits of potential utility rate designs. One example of a utility rate design currently underway in New York is the re-examination of the Standby Rate through a series of Department of Public Service Staff whitepaper proposals which will allow customers, including those with commercial and residential EV charging loads, an increased ability to manage their bills to more accurately reflect the impacts of their usage on the system.

D.3 Analyses of Selected Individual Policies

D.3.1 Effectiveness of Policies on Electric Vehicle Sales

One stream of academic literature focuses on estimating the impacts of transportation electrification policies on EV sales. These papers are useful for decisionmakers who prioritize limited budgets to advance EV sales. Broadly, this research stream compares EV adoption across multiple jurisdictions and controls for important socio-economic, attitudinal, and lifestyle factors.[179,180] In a paper by Narassimhan and Johnson (2018), the authors isolate causal impacts of several policy types on BEV and PHEV adoption using a quasi-experimental design with panel data from across the United States. As shown in Table D-6, policy impacts in this paper vary between policy types and between BEV and PHEV buyers. Some estimates are likely inaccurate. For example, the researchers show adding one additional public charger per 100,000 people results in 7.2% increase in BEV sales and 2.55% increase in PHEV sales.

It is noteworthy that the estimates in Table D-6 generally align with other research. For example, Sierzchula et al. (2014) analyzed country-level EV data from 2012 in a similar regression and reported that a $1,000 vehicle incentive is related to a 0.6% percentage point in EV sales, holding all other factors constant. The authors report a stronger relationship than Narassimhan and Johnson (2018) for the impact of charging infrastructure on EV sales: for every additional public charger per 100,000 people, the authors report a 13% percentage point increase in EV sales (compared to 7.2% and 2.6% in Narassimhan and Johnson [2018]).

Table D-6. Policy Impact on BEV and PHEV Adoption

Policy (Description)	Percentage Change in BEV Adoption	Percentage Change in PHEV Adoption
Vehicle Purchase Incentives		
Tax credit: 1% increase in tax credit relative to the MSRP value of vehicle	1.8%	NS
Rebate: 1% *increase in rebate value relative to the MSRP value of vehicle*	2.1%	NS
Charging Infrastructure Investment *1 additional public charger per 100,000 people*	7.23%	2.55%
Utility Rate Designs *Existence of EV-specific electricity rate for residential charging*	NS	NS
Carbon Price/LCFS *1% increase in gasoline price*	0.84%	0.5%
Outreach and Education *Proxied by League of Conservation Voters' score for U.S. House representatives from different states.*	0.22%	NS

Note: Effects deemed not significant noted with "NS."

Using the relationships described above, the project team conducted an analysis to present these disparate policies in a consistent format. Note that policies for which a cost metric was not available (HOV lane access and environmental awareness) and those that were not associated with a statistically significant effect on EV adoption (residential EV rate) are not included in this analysis. Most importantly, although the measure of impact is standardized in terms of dollars-per-avoided GHG tonne, the estimated effect *only* represents the avoided emissions associated with increased EV adoption. For example, an increase in gasoline price would also be expected to drive reductions in ICE vehicle VMT and resulting GHGs, but these ICE-related avoided GHGs are not encompassed in the tonnes denominator in Table D-7.

Table D-7. Illustrative Standardized Impact of Policies on Avoided GHGs from Increased EV Adoption

Policy	Illustrative Cost	Illustrative Effect (# EVs adopted)	Standardized Impact ($/tonne avoided GHGs)[a]
Vehicle Purchase Incentives			
Tax credit Impact on BEV adoption *1% increase in tax credit relative to the MSRP value of the vehicle* [b]	$350 increase in tax credit	525	$187
BEV Rebate Impact on BEV adoption *1% increase in rebate value relative to the MSRP value of the vehicle* [c]	$350 increase in rebate value	613	$241
Charging Infrastructure Investment *1 additional public charger per 100,000 people* [d] **…on BEV adoption**	$4000 per public charger	2109	$5
1 additional public charger per 100,000 people d **…on PHEV adoption**	$4000 per public charger	782	$20
Carbon Price/LCFS *1% increase in gasoline price* [e] **…on BEV adoption** *1% increase in gasoline price* [e] **…on PHEV adoption**	$0.02/gallon increase	245 153	$8,043f $17,707f

a Applies lifetime avoided emissions of 53 tonnes per BEV and 38 tonnes per PHEV.

b Assumes 50% uptake of tax credit, drawing on Borenstein and Davis 2016.

c Assumes 75% uptake of rebate, per CSE 2020a.

d Effect is estimated per 100,000 people above the age of 16.

e Price increase applied to 4.8 billion gallons of LDV gasoline consumed annually in NYS.

f ICE-related avoided GHGs are not encompassed in estimates of avoided emissions.

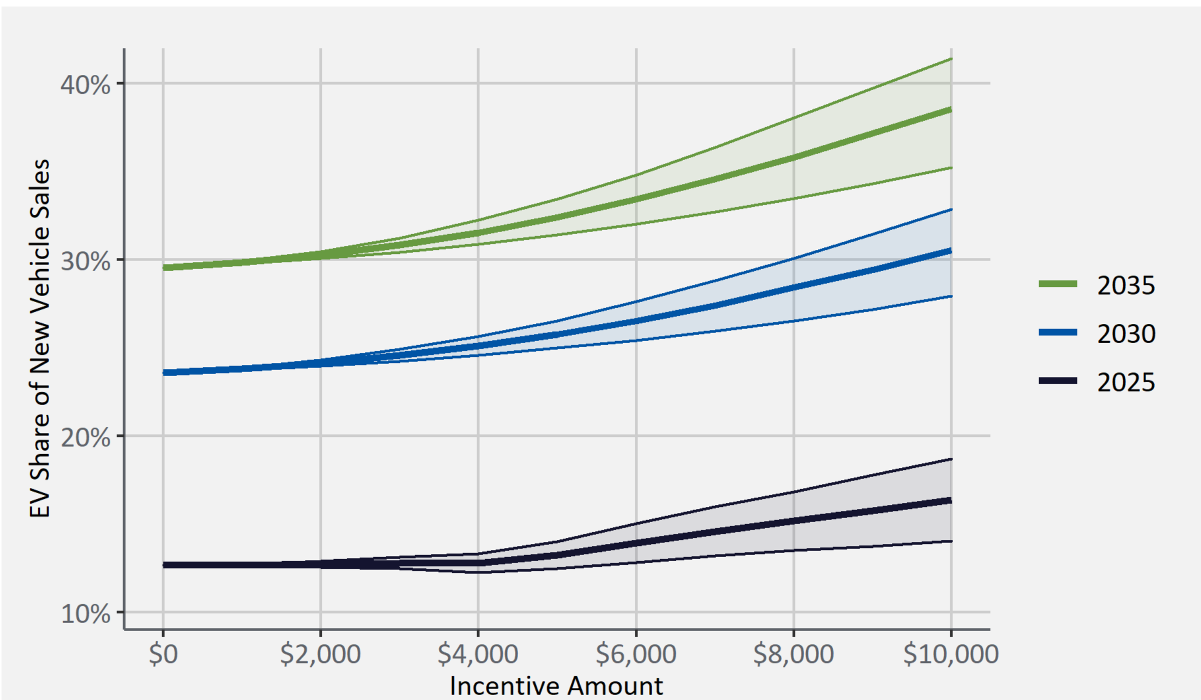
According to this analysis, of the policy types examined, the most cost-effective policy to achieve emissions reductions through induced EV adoption is investment in public charging. This observation holds for BEVs even as the assumed average charger cost is increased to $100,000 per charger, representative of a DC fast charger installed at a high-cost site. The measured effect may be because investments address several key barriers to electrification, including vehicle range anxiety and charging access for renters, residents of MUDs, and others that are unable to install a home charger.

Notably, although Table D-6 indicates that a tax credit is less effective at inducing BEV adoption than an on-the-hood rebate, a tax credit is deemed more cost-effective in terms of cost per tonne of avoided emissions because the uptake of tax credits is assumed to be lower than uptake of rebates. A lower uptake, or adoption, of the benefit means lower costs to implement the policy, reducing the numerator of the standardized impact. This may indicate the policy is a relatively more efficient tool to achieve emissions reductions from increased LDV electrification, but the result should be interpreted carefully as it is quite sensitive to the assumed uptake.

Figure D-1 shows a sensitivity analysis of EV sales versus incentive, using the Diffusion Model described above. The three years modeled in the figure have a different starting point due to the assumptions around total cost of ownership in those years (see section above on TCO assumptions). Overall, the figure shows the relative insensitivity of consumers to higher incentives, even in later years.

Figure D-1. EV Sales Shares Increase with Increasing Vehicle Purchase Incentive Amounts

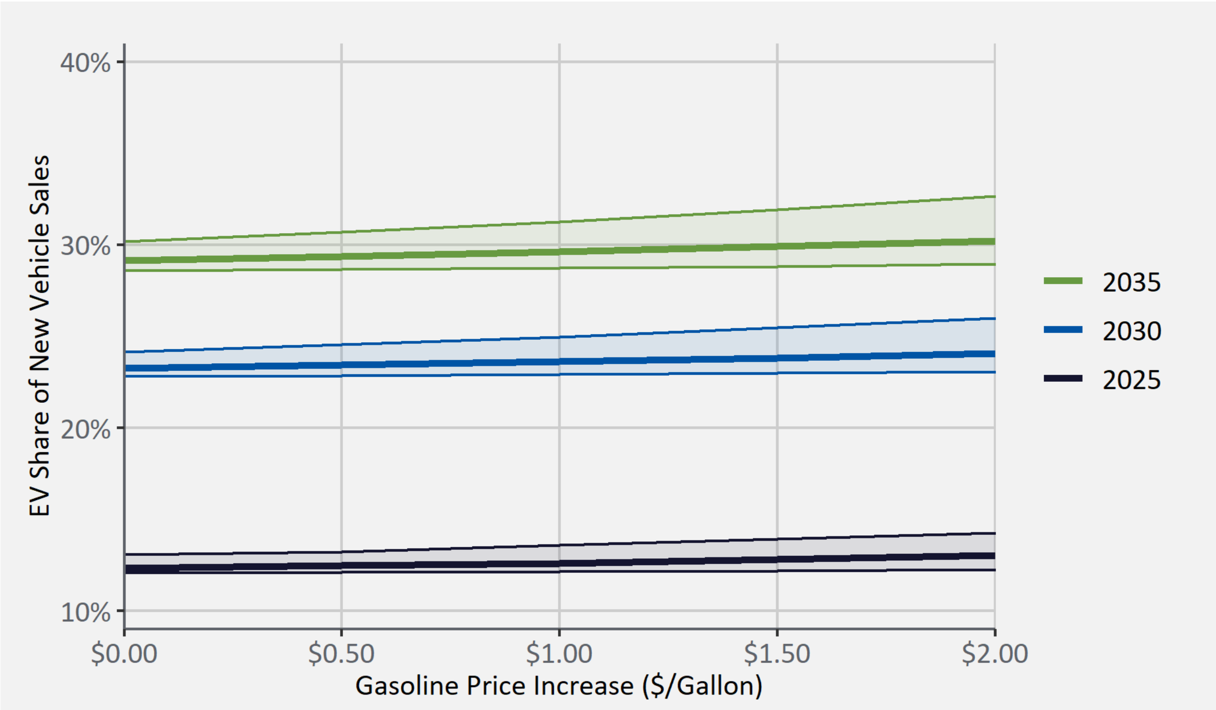
Source: Cadmus 2020. Incentive amount reflects hypothetical combined state and federal incentives.



While fuel cost savings from switching to an EV are not understood to affect consumer activity in the near-term, in the longer run, consumption is elastic: when fuel prices rise—such as from a carbon price or LCFS—individuals respond by changing consumption patterns, such as by driving fewer miles or purchasing more fuel-efficient vehicles.[181] This is illustrated in the EV market shares estimated under various scenarios of increased gasoline prices. If gasoline prices in New York State were $0.50 higher than expected starting in 2025, it is projected to drive increases in the EV market share of 0.15 (±0.1) percentage points relative to the Reference Scenario. The impact of higher gasoline prices is larger in later years. In 2035, an equivalent price increase is projected to cause an increase in EV market share of 0.25 (±0.2) percentage points or 1,560 additional electric vehicle sales per year. Figure D-2 depicts the projected impact of higher gasoline prices on EV market share in 2025, 2030, and 2035.

Figure D-2. Impact of Increased Gasoline Prices on EV Market Share

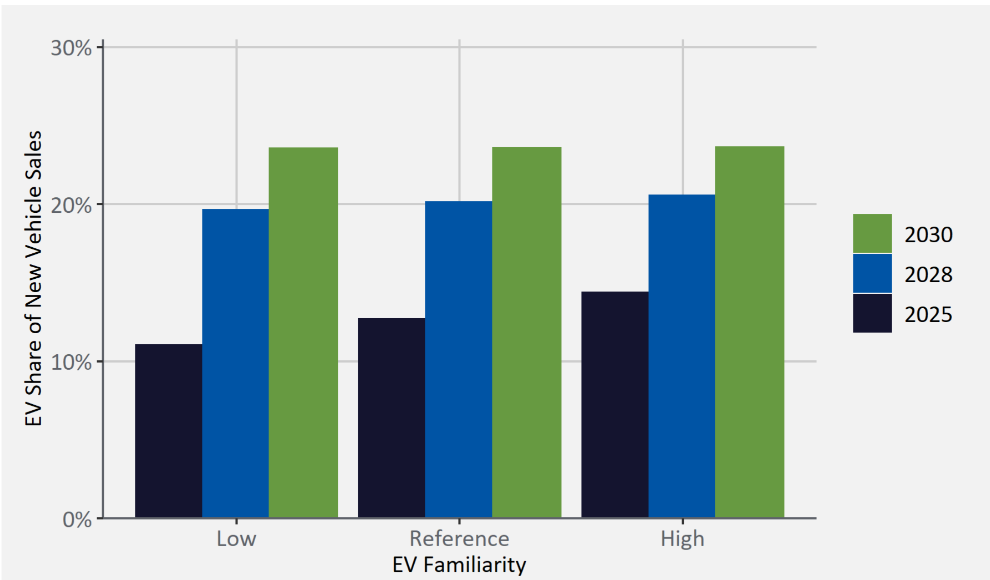
Source: Cadmus 2020.



Another factor associated with EV adoption is environmental awareness.[182] Research has shown that in states where consumer awareness of EVs is high, there is a corresponding response seen in vehicle sales.[183] EV outreach and education programs can raise visibility and the public's understanding of the technology to capture this adoption effect. In a survey covering almost 20,000 EV rebate recipients in California, respondents identified a variety of information channels, including manufacturer websites, family, friends, and colleagues, online discussion forums and blogs, ride and drive events, and media coverage as important to their decision to acquire an EV.[184]

Outreach and education efforts are likely to have the greatest impact in the short term, while EV market share remains relatively low. As EV penetration increases, potential buyers are more likely to become familiar with EV technology through general exposure. Figure D-3 depicts EV market share projections under central assumptions of EV familiarity used in the Reference Scenario and illustrates how higher and lower levels of familiarity might shift these projected shares. Outreach and education efforts that change public familiarity with EVs are expected to have the greatest impact in 2025 or earlier. After 2025, the effect of these efforts on adoption levels diminishes.

Figure D-3. Familiarity Effect on EV Market Share



In theory, to the extent that utility rate designs further reduce the TCO for EVs relative to ICE vehicles, they could also spur EV adoption. However, the availability of EV-specific residential utility rates has not been shown to have a measurable effect on EV adoption in LDV markets.[185] This is not surprising, as consumers tend to emphasize upfront costs over lifetime costs of vehicle ownership in their purchase decisions. It would follow that the availability of EV-specific rates and the incremental savings they might generate would not significantly affect rates of EV adoption.

Furthermore, the power of the default, which is documented throughout behavioral science literature, and specifically in the context of consumer responses to electricity choices, may undermine the potential effect of utility rate designs on EV adoption.[186,187] Because all ratepayers are defaulted into standard rates, it takes concerted action to switch to a TOU or EV-specific rate option. In both California and Minnesota, utilities report that the vast majority of EV owners in their territories remain on the default tariff, rather than switching to a whole-house TOU or EV-specific tariff that is designed to be more cost-effective for EV owners.[188,189] These rates may be important for reducing the cost of electric grid upgrades, so may be important to pursue for other reasons, but are unlikely to have a significant direct impact on EV adoption.

Appendix E—Sensitivity Analyses

E.1 Reference Scenario Sensitivity Analysis

This appendix presents a sensitivity analysis on the electric LDV projections described in Chapter 3. Two additional potential trajectories of electric LDV adoption in New York State are described below and named High Barriers Scenario and Low Barriers Scenario. These two additional cases represent the upper and lower bound on what the project team sees as a reasonable set of input assumptions for the Diffusion Model.

E.1.1 High Barriers Scenario

In the High Barriers Scenario, people slowly move from cities to more rural and suburban areas. They continue to rely on home-delivery of goods, even as they are asked to return to physical office locations.[190] The federal government fails to take meaningful action on climate change and New York State struggles through an economic recovery. The High Barriers Scenario, detailed in Table E-1, illustrates a pessimistic scenario with high VMT, weak federal government action, and risk averse consumer behavior. The "scenario descriptors" contained in this table are assumptions used to create this scenario, not statements of fact.

Table E-1. High-Barriers Scenario Characteristics

Factor	Scenario Descriptors
Socioeconomic and Lifestyle	
Urbanization/ De-urbanization	• There is flight from the city as a result of COVID-19 (de-urbanization) • Even as effects of COVID-19 fade and people stop teleworking, urban cores are not as vibrant as they once were, leading people to live outside the city and commute via personal vehicles.
Economic Activity	• The global economy grows at less than historic rates.
Equity	• As people become more concerned with their personal economic situation, their appetite to address social inequities decreases.
Consumer, Corporate and Institutional Behavior	• As effects of COVID-19 fade, people stop teleworking and resume commuting via personal vehicles. • Lower urbanization results in less use of public transit. • Use of ride hailing remains about the same, while public transit ridership decreases and personal car ownership increases. • E-commerce continues to increase from today as people have become accustomed to the convenience of home delivery.
Population	• A weak economy leads to a declining population in New York State.

Factor	Scenario Descriptors
Policy and Institutions	
Federal Action	• Weak federal action on transportation climate policy, California waiver is overturned by Supreme Court (dissolving ZEV mandate and California fuel economy standards), no extension of EV tax credits.
Technological Change	
Mobility Options	• Shared autonomous vehicles never quite gain traction in a de-urbanized world, perpetuating personal vehicle ownership as the norm. • However, non-shared autonomous vehicles are prevalent, further enabling dispersed living and longer commutes. • Micro-mobility doesn't take off as a result of de-urbanization. • A weakening economy means automakers lower investment in new makes/models of EVs. Model availability of EVs decreases relative to the Reference Scenario.
Energy Supply and Delivery	• EV battery costs decline slower than anticipated as less electrification research is conducted due to weak federal standards and low funding levels. • The weak global economy means oil price decline from today's levels, even as VMT rises in New York State.

E.1.2 Low-Barriers Scenario

In the Low-Barriers Scenario, New York State emerges from the COVID-induced recession quickly. People return to cities as soon as they can and support local business by shopping in person. Getting around involves a comprehensive network of public transit, micro-mobility, and shared autonomous electric vehicles. The federal government gets serious about aggressively addresses climate policy, improving emissions standards and funding the EV transition. The Low Barriers scenario, detailed in Table E-2, illustrates an optimistic scenario with low VMT, strong federal government action, an expansion of mobility options, and confident consumer behavior. The "scenario descriptors" contained in this table are assumptions used to create this scenario, not statements of fact.

Table E-2. Low-Barriers Scenario Characteristics

Factor	Scenario Descriptors
Socioeconomic and Lifestyle	
Urbanization/ De-urbanization	• After an initial flight from the city as a result of COVID-19, there is a reliable vaccine and people are eager to get back to urban cores (urbanization).
Economic Activity	• The global economy grows at faster than historic rates.
Equity	• As people become more secure in their personal economic situation, their appetite to address social inequities increases.
Consumer, Corporate and Institutional Behavior	• As people get back to the urban core, public transit ridership increases. • Those who have longer commutes continue to telework, recognizing the convenience and cost savings. • To aide in local economic recovery, people make a conscious effort to buy from local stores, slowing e-commerce's continued rise.

Factor	Scenario Descriptors
Population	• The strong economy leads to a boom in population across all demographics in New York State.
Policy and Institutions	
Federal Action	• Strong federal action on transportation climate policy including a national ZEV requirement in 2040, California waiver is upheld by Supreme Court, extension of EV tax credits.
Technological Change	
Mobility Options	• Autonomous electric vehicles become safe, reliable, and convenient and are developed for shared-use, often carrying four or more passengers. They are rarely individually-owned and instead used primarily in first-mile, last-mile, and ride hailing applications. • Micro-mobility proliferates and is also used in first- and last-mile applications. • Ride hailing is replaced by shared autonomous EVs, micro-mobility, and public transit.
Energy Supply and Delivery	• EV battery costs decline faster than anticipated as more electrification research is conducted due to strong federal standards and an increase in dedicated federal funds. • Oil prices increase relative to today's prices.

E.1.3 Sensitivity Scenario Results

The following figures, Figure E-1 and Figure E-2, depict the results of sensitivity scenarios. The assumptions underlying the two scenarios reflect High Barriers and Low Barriers to EV adoption, respectively. Both scenarios align with the Reference Scenario through 2025 reflecting the expected impact of the NY 2025 ZEV mandate. After 2025 the scenarios diverge.

Figure E-1 depicts the results of the high barriers sensitivity scenario. The assumptions underlying this scenario reflect potential trajectories for the auto industry and EV technology that would be relatively unfavorable for EV adoption. In this scenario, EV market share falls in 2026 following the sunset of the 2025 ZEV mandate. EV market share is projected to be 12% of new vehicles purchased in 2025, rising to 16% in 2035, and 20% in 2045. As in the Reference Scenario, EV market share is relatively evenly divided between BEV and PHEV.

Figure E-1. Light Duty EV Adoption—High Barriers Sensitivity Scenario

Source: Cadmus 2020.

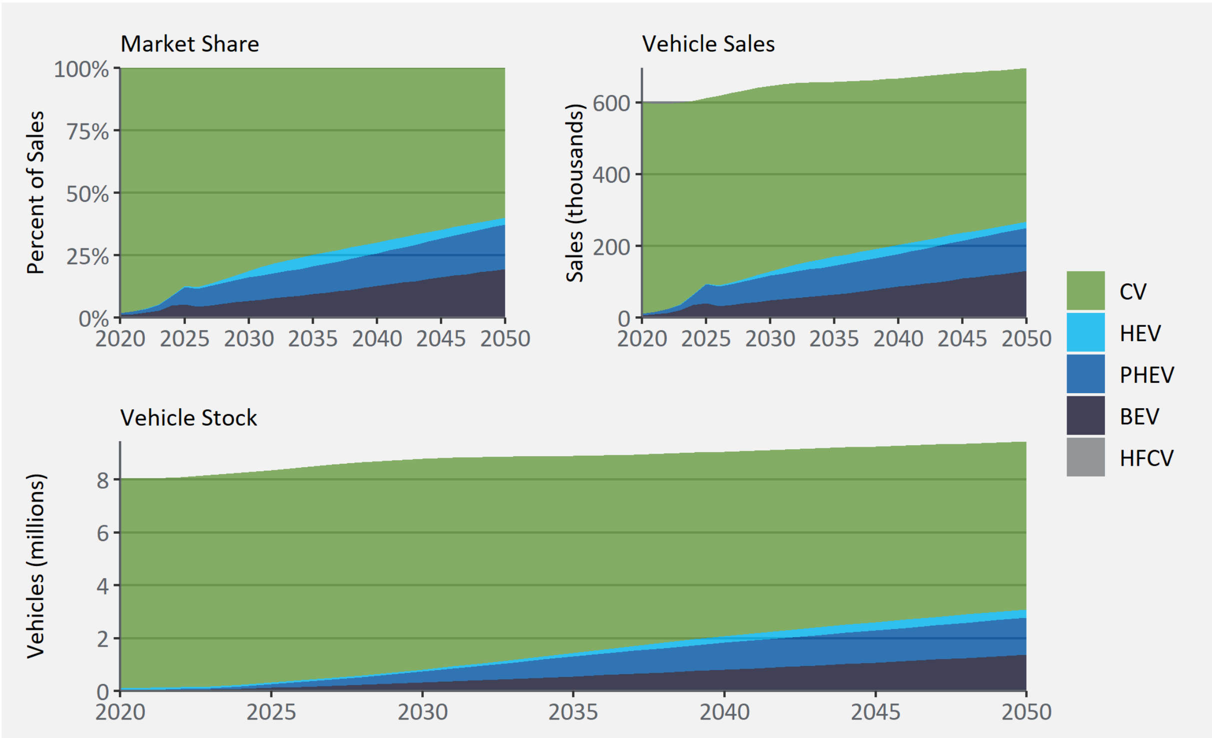


Figure E-2 depicts the results of the low barriers sensitivity scenario. The assumptions underlying this scenario reflect potential trajectories for the auto industry and EV technology that would be relatively favorable for EV adoption. In this scenario, EV market share rises sharply between 2020 and 2030 as the availability of EV models and familiarity with EVs increases. EV market share is projected to be 12% of new vehicles purchased in 2025, rising to 51% in 2035, and 65% in 2045. As in the Reference Scenario, EV market share is relatively evenly divided between BEV and PHEV.

Figure E-2. Light Duty EV Adoption—Low Barriers Sensitivity Scenario

Source: Cadmus 2020.

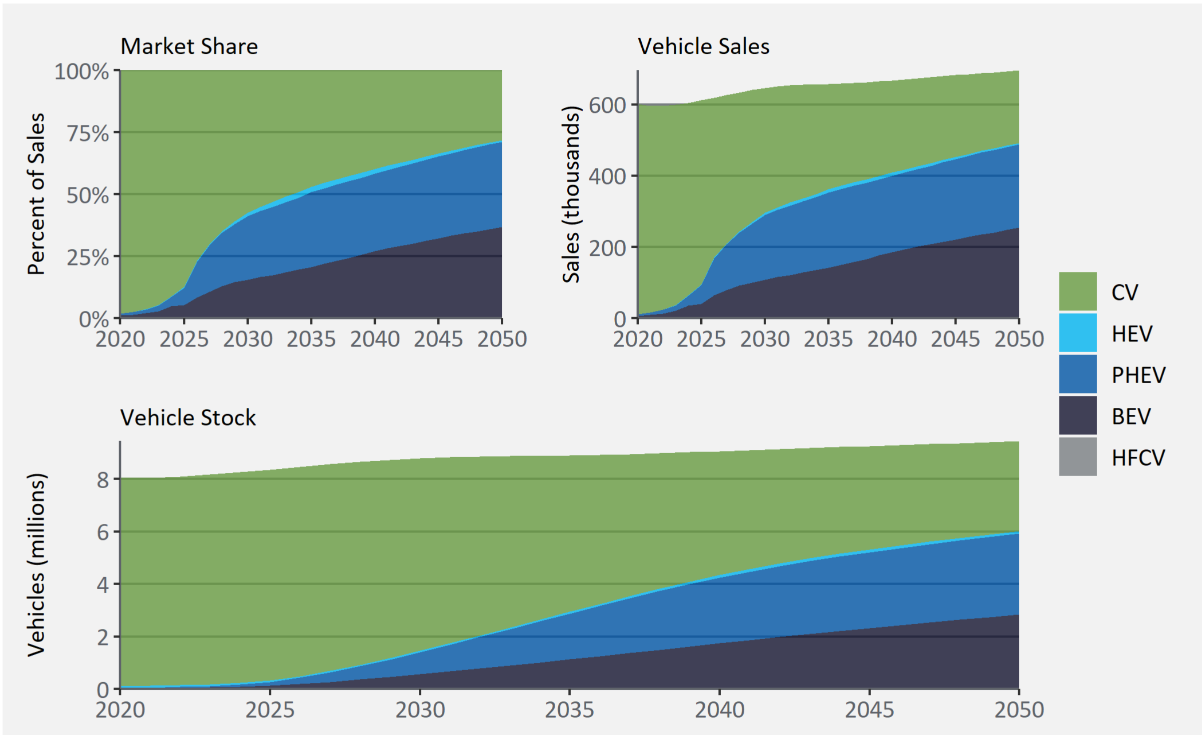


Table E-3 contains a selection of market share and vehicle stock results for the Reference Scenario and sensitivity scenarios. EV stock is projected to reach 947,000 in 2030 or 11% of the total LDV stock with sensitivity scenario estimates of 754,000 and 1.4 million. EV stock is projected to increase to 1.8 million in 2035 (20% of total stock) and 3.1 million in 2045 (34% of total stock).

Table E-3. Reference and Sensitivity Scenario Light Duty EV Market Share and Vehicle Stock

Year	EV Market Share			Total LDV Stock (1,000s)
	High Barriers	Reference	Low Barriers	
2020	2%			8,055
2025	12%			8,367
2030	16%	24%	42%	8,802
2035	20%	29%	51%	8,898
2040	26%	35%	58%	9,066
2045	32%	42%	65%	9,261
2050	37%	48%	71%	9,440

E.1.4 EVSE Public Charger Availability Sensitivities

Due to uncertainty around DCFC technology, public charging infrastructure projections are sensitive to expectations about the relative utilization of DCFC and L2 chargers. To characterize the expected range of DCFC infrastructure outcomes, two additional sensitivity analyses are presented below. These cases are characterized by low and high availability and utilization of DCFC. Under the low DCFC case, the relative utilization of various charger typologies in future years is assumed to remain near current utilization levels. The high DCFC case reflects an assumption that improvements in battery and charging technology allow for a significant increase in the utilization of DCFC. Figure E-3 depicts the projected numbers of public and workplace L2 and DCFC chargers under the low and high DCFC cases. Under the high DCFC case, the number of DCFC chargers increases at a faster rate, reaching 118,000 in 2045.

Figure E-3. Public, Workplace, and DCFC EV Charger Counts by DCFC Utilization Case[191]

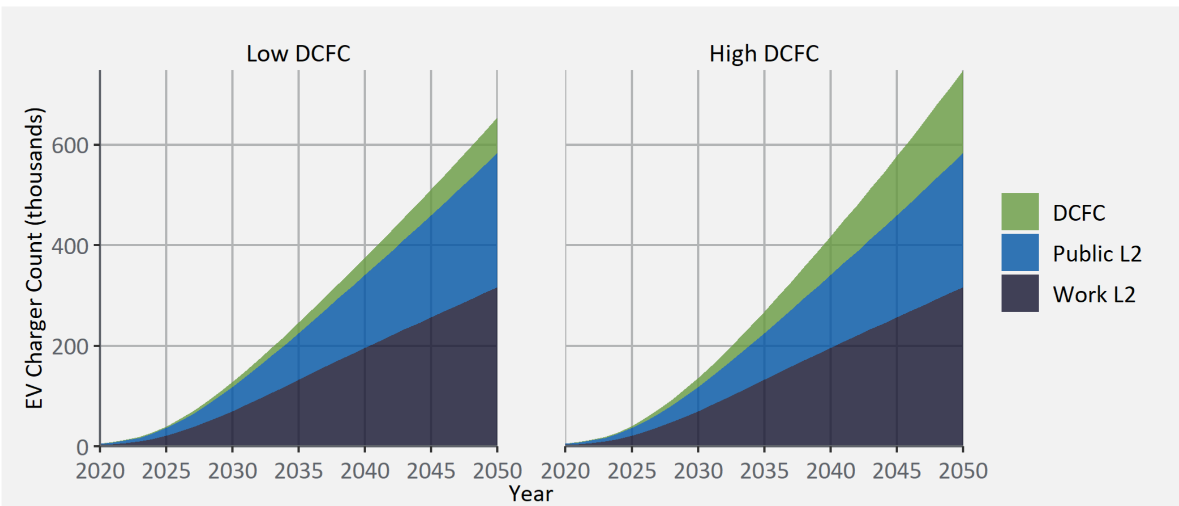


Table E-4 contains the projected charger counts by type. DCFC projections vary across the three scenarios.

Table E-4. Projected Charger Counts (Thousands)

Year	Home L1	Home L2	Public L2	Workplace L2	DCFC		
					Low Scenario	Reference Scenario	High Scenario
2020	26	17	2	3	0	0	0
2025	133	115	15	22	3	4	4
2030	410	460	48	71	10	14	18
2035	643	944	93	133	21	32	43
2040	742	1,454	145	197	35	56	77
2045	703	1,905	203	257	52	85	118
2050	583	2,333	267	317	71	118	164

Figure E-4 depicts the projected number of public chargers per EV for the low DCFC and high DCFC cases. There are two primary factors that drive changes in the ratio of public chargers to EVs over time. First, as the number of EVs increases, the expected number of charging sessions on each charger is expected to increase. This allows fewer chargers to support a greater number of vehicles. The second factor is growth in EV ownership among households without access to home charging. Households in this category rely on public and workplace charging and require a higher rate of public chargers per EV. These two factors have conflicting effects on the overall rate of chargers per EV. However, under both the Low and High DCFC case, the second factor dominates, leading to an increase in the ratio of public chargers to EVs over time.

Figure E-4. Public, Workplace, and DCFC EV Charger Counts per EV by DCFC Utilization Case

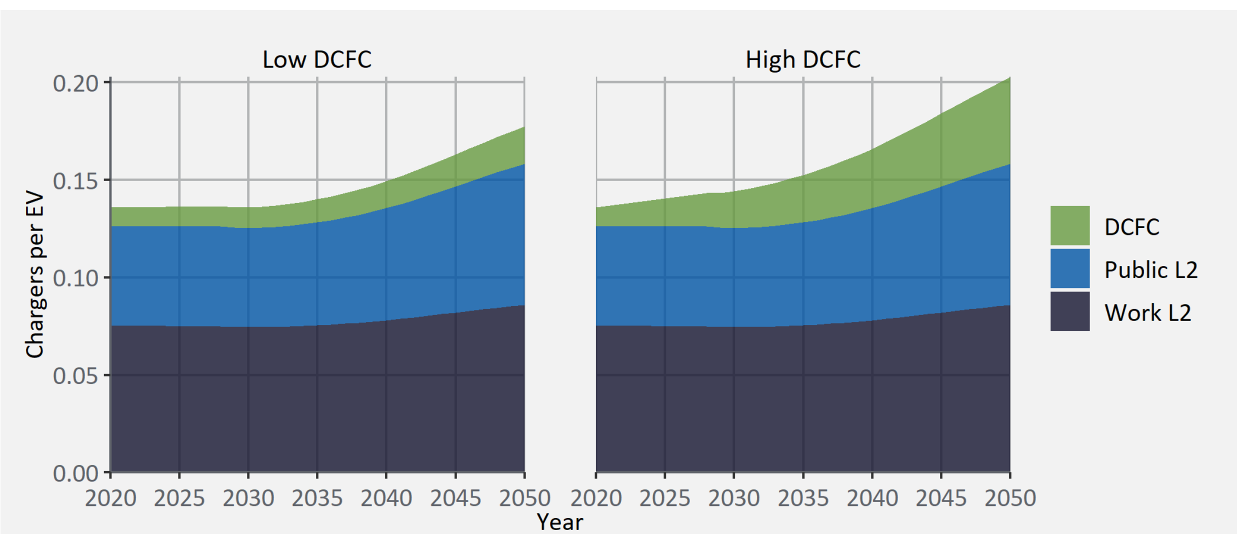
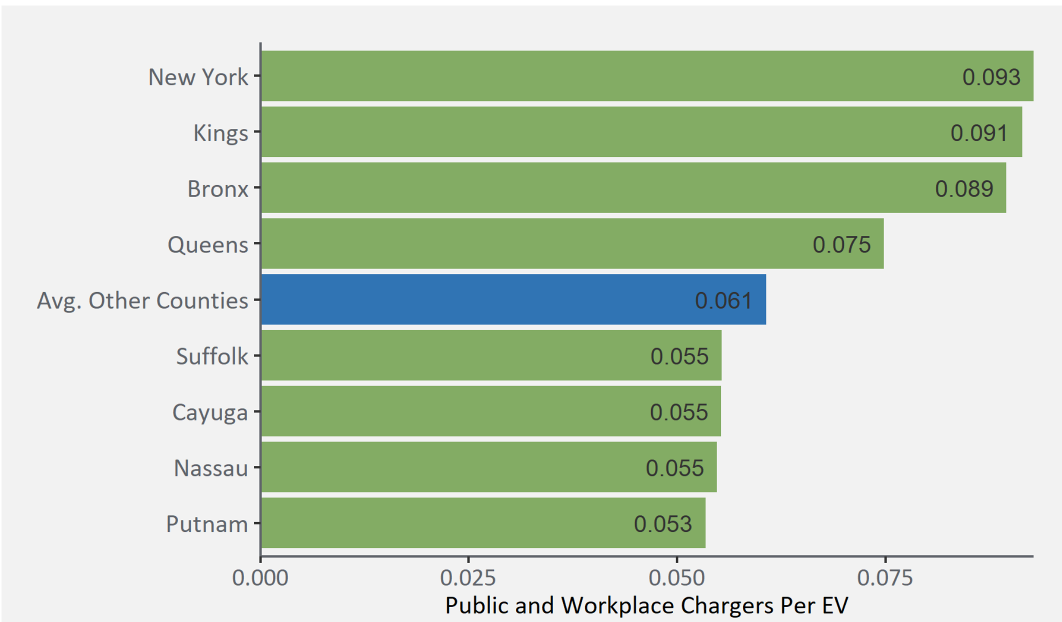


Figure E-5 depicts the projected number of public and workplace chargers per EV by county under moderate to high EV market share (20%-50% depending upon the county) at midcentury. Differences in the expected numbers of chargers per EV are driven primarily by differences in the share of vehicle buyers with access to home charging. In counties with higher population density (e.g., New York, Kings, Bronx, and Queens Counties), the projected number of public chargers per EV is higher to serve the relatively large share of EV owners without home charging access. For most counties, depicted by the blue bar, the projected rate was between 5.6 and 6.6 public chargers per 100 EVs.

Figure E-5. Projected Public and Workplace Chargers Per EV by County[192]



Note: Public and workplace chargers include public L2, workplace L2, and public DCFC. The figure includes the counties with public charger per EV rates in the upper and lower extremes. The blue bar reflects the average among the remaining counties which had little variation in projected rates of public chargers per EV.

Endnotes

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