Transportation Investment Strategy Tool Documentation, 2023

prepared for

Georgetown Climate Center

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February 2023

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Overview of Tool

This document describes the key methods and assumptions embedded in the Transportation Investment Strategy Tool (the Tool). This tool is a Microsoft Excel workbook developed to illustrate the potential changes in vehicle-miles of travel (VMT), greenhouse gas (GHG) emissions, and other outcomes that could result from investments in a wide range of – primarily low-carbon – transportation strategies, including electric and alternative fuel vehicles, vehicle travel reduction, transportation system efficiency, and investments and services to encourage the use of more efficient modes of travel. This documentation is current as of version 4.25 (August 2022 release). This version of the tool was used by the Georgetown Climate Center (GCC) for state-specific analysis conducted in collaboration with RMI.

The tool takes inputs in the form of investments (expressed in dollar values) in transportation strategies, and provides a variety of outputs, including:

- Changes in VMT, travel delay, and petroleum use.
- Economic changes (monetary flows) for businesses, consumers, and government.
- Changes in GHG emissions, air pollution, safety, physical activity, and related health benefits.

The Transportation Investment Strategy Tool is intended for state, multi-state, or national program-level analysis of investment across various transportation strategies. This tool is an evolution of a tool developed to support regional policy discussions among northeast and mid-Atlantic states and the District of Columbia. Most of the strategies in the tool are ones that tend to reduce emissions; however, the tool also includes highway expansion, a strategy that leads to increased emissions. The Tool is not intended for detailed, project-level analysis.

Interface with Other Tools

The Transportation Investment Strategy Tool may be used as part of a suite of tools applied to obtain a comprehensive understanding of the benefits and impacts of transportation investment programs for the transportation sector. For example, the U.S. Department of Energy's (DOE) National Energy Modeling System (NEMS) provides the baseline national forecasts of VMT, vehicle stock, fuel prices, fuel efficiency, and vehicle technology shares that are used in the Tool. NEMS is an integrated energy system model on which the U.S. Department of Energy's Annual Energy Outlook (AEO) is based, and the forecasts in the Tool are consistent with the AEO 2020 Reference Case travel and energy projections for the U.S. NEMS is also used to supplement the Tool with more detailed modeling of the effects of light-duty vehicle electrification incentives.

While it is possible to use the Tool for a stand-alone analysis of a one-time input of NEMS data, it is also possible to use the Tool interactively with NEMS to shed light on how strategies to reduce emissions in the transportation sector can affect other energy sectors. For example, under a scenario in which electric vehicles (EVs) represent a rapidly growing share of vehicles, NEMS provides information about increases in electricity demand and other changes in the electric sector. NEMS also models how travel demand and energy prices interact.

The Tool can also be used to process data for input into economic, health, and incidence models to assess macroeconomic benefits, public health benefits, and equity implications of a proposed clean transportation investment program.

For example, the Regional Economics Models, Inc. (REMI) model uses capital expenditures, fuel expenditures, and other types of outputs from NEMS and the Tool as inputs to estimate estimates of changes in jobs, income, and gross domestic product (GDP) that could result from different investment scenarios.

Reducing carbon emissions and investing in low-carbon transportation strategies is also expected to result in public health benefits by improving air quality and providing greater access to public transportation, enhancing safe spaces for biking and walking, and encouraging alternatives to traveling in private motor vehicles. Therefore, the Tool generates estimated changes in premature deaths from air pollution and the value of air pollution reduction, in addition to deaths prevented from physical activity associated with walking, biking and transit ridership.

Baseline Data

The Tool includes baseline projections for population, VMT, vehicle fleet and fuel characteristics, and other factors for health and economic impact analysis.

- Population estimates from the Census, and jurisdiction forecasts, are used to consider the effects of strategies that may vary by area type (e.g., as a function of population density or metro area size).
- VMT projections by state, for five vehicle types, were developed based on VMT forecasts from NEMS and state population forecasts. The five vehicle types include light-duty automobiles and motorcycles, light-duty trucks, medium-duty trucks, heavy-duty trucks, and buses.
- Data on factors including fuel prices, fuel efficiency, fuel carbon content, and vehicle sales and stock are taken from the NEMS model as run by OnLocation, based on AEO 2020 Reference Case data.
- Fuel use and emissions data only reflect on-road diesel and motor gasoline and do not include other transportation fuel types, such as aviation fuel, fuel for waterborne vessels, ethanol, biodiesel, or non-road diesel applications.

Key Strategy Assumptions

The tool takes an overall dollar value of investment by year and a distribution of this investment across a portfolio of transportation investment strategies to develop a program of investment (billions of dollars) by strategy and year. In the Tool, an overall investment level and a percent allocation of investment by strategy can be provided for each year between 2022 and 2040. Those investment dollars are applied to various cost-effectiveness or impact assumptions for each strategy to estimate the GHG reductions and other benefits associated with the investment.

- The Tool applies different GHG reduction cost-effectiveness by area type where possible and logical. For example, bicycle investments may be more cost effective in high-density neighborhoods, and transit investments may be more cost-effective in larger urban areas. The Tool allocates investment to each area type based on the amount of population within each area type.

- **Electric and alternative fuel vehicle incentives** include light-duty vehicles, medium and heavy-duty trucks, transit and school buses, and rail.
  - The effects of light-duty EV consumer incentives can be independently modeled using NEMS, which includes models of consumer adoption of EVs. EV sales, stock, and VMT results from NEMS are passed back to the Tool.
  - For electric medium and heavy trucks, hydrogen fuel cell heavy trucks, electric buses, and rail electrification, a variety of assumptions are made to estimate benefits and cost-effectiveness. These include assumptions about fuel/energy efficiency; incremental capital, operating, and maintenance costs; fuel and electricity costs; charging or refueling station costs; and annual miles driven per vehicle. Sources include the AEO/NEMS; Alternative Fuels Data Center; National Renewable Energy Laboratory; U.S. Environmental Protection Agency (EPA); California Air Resources Board; Transit Cooperative Research Program (TCRP); data state agencies; and other studies performed by researchers and practitioners.
- **Vehicle travel reduction** strategies include shared ride incentives, land use/smart growth, bicycle investment, pedestrian investment, micromobility, and travel demand management.
  - A variety of data and methods are used to estimate the benefits and impacts of these strategies per dollar spent.
  - Examples of key assumptions include capital, operating, and maintenance costs per new mile of facility or revenue-mile of service; traveler response in terms of ridership per revenue-mile, facility use per mile, or mode shift per dollar spent; and the prior mode of travel of people switching to biking, walking, or transit.
  - Land use benefits are estimated based on number of households shifted into “smart growth” areas, as observed from incentive program data from around the U.S., and observed differences in travel for households in different area types.
- **System efficiency strategies** reduce fuel consumption and GHG emissions by reducing vehicle emissions per mile rather than reducing overall miles of travel. System efficiency strategies in the Tool include highway system operations (e.g., traffic flow improvements), freight intermodal investment (shifting goods movement from truck to rail), highway preservation, and highway expansion. When the Tool and NEMS model are run together, the estimated fuel savings from these strategies are passed into the NEMS model.
  - The benefits of these strategies are generally estimated based on national or regional-scale modeling studies that looked at traveler delay and fuel savings. Data from sample projects with evaluation results are also considered. Benefits per dollar are applied to total levels of investment. Freight investments also consider mode-shifting from truck to rail per dollar spent, based on modeling studies.
  - Fuel consumption savings from highway preservation are assumed to result from reduced vehicle delay, as well as smoother pavements. These benefits are estimated based on data from the Federal Highway Administration Highway Economic Requirements System model.

  - The evaluation of highway expansion strategies considers the offsetting effects of induced demand as well as the benefits of congestion relief. Under the default assumptions included in the model, highway expansion projects tend to lead to net increases in GHG emissions due to induced demand effects.

- **Urban and intercity transit strategies** include fixed-guideway investment (bus rapid transit, light/heavy rail, commuter rail, and intercity rail); bus operating improvements (service expansion, efficiency measures such as transit signal priority, and fare reductions); and "state of good repair" investments to maintain capacity and reliability.

  - Fixed-guideway investments are evaluated based on capital and operating costs per mile, and annual VMT reduced per dollar of capital investment, based on data from recent planning studies of projects in the Northeast and Mid-Atlantic region.[1] VMT from new transit service is considered as well as reductions in automobile VMT.

  - Bus operating improvements are evaluated based on elasticities of ridership with respect to travel time and cost, as well as empirical data on the time savings of efficiency measures. TCRP reports serve as key sources.

  - The National Transit Database is used as a general source for baseline data (e.g., average passengers per vehicle, operating cost per vehicle revenue-mile by mode).

  - State of good repair benefits are based on a review of Northeast and Mid-Atlantic region transit agencies' state of good repair requirements studies to identify costs, and assumptions about ridership loss if a state of good repair is not maintained.

Emissions, Health, and Safety

Emissions, health, and safety benefits are estimated based on changes in VMT by vehicle type and change in person-miles of travel (PMT). These are monetized as well as translated into mortality and morbidity health outcomes.

- To estimate safety benefits, fatality and injury motor vehicle crashes are assumed to be reduced in proportion to VMT reduced, using average rates million vehicle-miles from national crash data. Crash benefits are monetized based on U.S. Department of Transportation (DOT) guidance and Federal Transit Administration assumptions.

- Health benefits of physical activity are estimated as a result of increases in walking and bicycling from transit, bicycle, and pedestrian investment. Reduced mortality is estimated based on the World Health Organization (WHO) Health Economic Assessment Toolkit (HEAT) and monetized based on U.S. DOT guidance on value of a statistical life.

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[1] While some of the strategy effectiveness estimates are based at least in part on studies from the 13-state TCI region, these benefits are believed to be generally representative of the scale of benefits that would be observed from a similar level of investment in similar projects elsewhere in the U.S.

(Footnote continued on next page...)

- Reductions in emissions of air pollutants from motor vehicles are assumed to be proportional to reductions in VMT by vehicle type. Emission factors from the U.S. EPA Motor Vehicle Emission Simulator (MOVES) model are applied to VMT reductions. Emission reductions are translated into health and monetary outcomes based on modeling conducted by Harvard C-CHANGE.[2]

[2] https://www.hsph.harvard.edu/c-change/news/trechstudy/

1.0 Overview of Tool

1.1 Tool Purpose

The Tool is a Microsoft Excel workbook developed to help understand the changes to greenhouse gas (GHG) emissions, vehicle-miles of travel (VMT), and other outcomes that could result from investments in a wide range of – primarily low-carbon – transportation strategies. Examples of these strategies include:

- Transit expansion, such as bus rapid transit, light rail, and heavy rail;
- Promotion of urban infill and other compact land use;
- Pedestrian and bicycle infrastructure in urban areas;
- Travel demand management;
- System operations efficiency technologies; and
- Electric and alternative fuel vehicles.

The Tool takes inputs in the form of investments (expressed in dollar values) allocated across a portfolio of transportation investment strategies and provides a variety of outputs, including:

- Changes in VMT and travel delay;
- Changes in petroleum use;
- Economic changes (monetary flows) for businesses, consumers, and government; and
- Changes in GHG emissions, air pollution, safety, physical activity, and related health benefits.

Summary estimates of these factors are provided for years 2032 and 2040, based on a program of investments starting in 2022 or later. The Tool also calculates these factors for every year from 2022 through 2040.

The Tool is intended for state, multi-state, or national scale program-level analysis of investment across various transportation investment strategies. While nearly all of the strategies in the Tool are typically intended to reduce emissions, highway expansion is also included. The Tool is not intended for detailed, project-level analysis. The assumptions in the Tool consider average effectiveness levels for a given strategy; actual impacts of a given investment may vary considerably, depending on how and where the investments are made. This documentation is current as of version 4.25 (August 2022 release). This version of the tool was used by the Georgetown Climate Center (GCC) for state-specific analysis conducted in collaboration with RMI.

1.2 Interface with Other Analysis Tools

The Tool may be used with other tools applied to obtain a comprehensive understanding of the benefits and impacts of transportation investment programs for the transportation sector.

- The U.S. Department of Energy's (DOE) **National Energy Modeling System** (NEMS) provides baseline national forecasts of VMT, vehicle stock, fuel prices, fuel efficiency, and vehicle technology shares that are used in the Tool. NEMS is an integrated energy system model on which the U.S. Department of Energy's Annual Energy Outlook (AEO) is based, and the forecasts in the Tool are consistent with the AEO 2020 Reference Case travel and energy projections for the U.S. NEMS has also been used to supplement the Tool with more detailed modeling of the effects of light-duty vehicle electrification incentives.

- While it is possible to use the Tool as a stand-alone model based on a one-time input of NEMS data, it is also possible to use the Tool interactively with NEMS to shed light on how strategies to reduce emissions in the transportation sector can affect other energy sectors. For example, under a scenario in which electric vehicles (EVs) represent a rapidly growing share of vehicles, NEMS provides information about increases in electricity demand and other changes in the electric sector. NEMS also models how travel demand and energy prices interact.

- The **Regional Economic Models, Inc. (REMI)** model is a dynamic economic simulation model that can be run to estimate the macroeconomic implications of investment scenarios analyzed using THE TOOL. REMI measures the flow of money throughout the economy. Inputs from the Tool include costs incurred and cost savings by user group (businesses, consumers, and government). Outputs include changes in jobs, income, and gross domestic product (GDP) that could result from different investment scenarios. The Tool has the capability to provide state-level outputs to REMI for national economic analysis. The economic analysis methods are described in more detail in Section 5.0 of this document.

2.0 Description of Strategies

Table 2-1 provides a brief description of the clean transportation investment strategies modeled in the Transportation Investment Strategy Tool.

Table 2-1 Clean Transportation Strategies

Strategy	Description
EV/alternative fuel incentives	
Light-duty EVs: vehicle incentives	Consumer incentives to purchase full battery electric (BEV) and plug-in hybrid electric (PHEV) light-duty vehicles.
Light-duty EVs: infrastructure incentives	Incentives or subsidies to deploy public EV charging infrastructure.
Electric transit buses	Direct purchase of public agency electric transit buses and/or support infrastructure.
Electric school buses	Direct purchase or reimbursements to school districts to purchase electric school buses and/or support infrastructure.
Electric trucks – medium-duty/urban	Incentives (rebates, cost discounts, tax credits, etc.) for medium-duty truck (MDT) fleet operators or owner/operators to purchase new battery-electric trucks and/or support infrastructure. May also include direct purchase of electric trucks and/or support infrastructure for public fleets.
Electric trucks – heavy-duty/short-haul	Incentives (rebates, cost discounts, tax credits, etc.) for heavy-duty truck (HDT) fleet operators or owner/operators to purchase new battery-electric trucks and/or support infrastructure. May also include direct purchase of electric trucks and/or support infrastructure for short-haul applications.
Hydrogen trucks - long-haul	Incentives (rebates, cost discounts, tax credits, etc.) for HDT fleet operators or owner/operators to purchase new trucks powered by hydrogen fuel cells or retrofit existing trucks. Incentives may include rebates for the vehicle itself and/or subsidies for needed refueling infrastructure.
Passenger rail electrification	Purchase of electric locomotives for public commuter or intercity passenger rail fleets, and construction of necessary infrastructure including catenary, substations, maintenance equipment, etc.
Vehicle travel reduction	
Shared ride incentives	Monetary incentives to encourage travelers to use shared-ride services, e.g., subsidies for shared rides taken using transportation network company (TNC) services.
Micromobility: shared e-scooters & e-bikes	Subsidies for shared electric scooter and/or electric bicycle programs (capital, operating, user-side subsidies).
Micromobility: e-bike ownership subsidies	Discounts or rebates for purchase of an electric bicycle.

Land use/smart growth	Policies and investments that support infill, compact development, and transit-oriented development to reduce vehicle travel. Expenditures may be used for land use planning, funding incentives to municipalities (e.g., increased local aid per new housing unit developed in smart growth districts), funding incentives for private development (e.g., tax credits), or infrastructure investment (e.g., complete streets projects, public amenities) to attract new private development in “smart growth” areas.
Bicycle investment	Investment in bicycle infrastructure, including bike lanes, separated bike lanes, shared-use paths, and bike boulevards.
Pedestrian investment	Investment in bicycle infrastructure, such as sidewalks, traffic calming, and complete streets projects.
Travel demand management	Programs, such as employer outreach, rideshare and vanpool programs, subsidized transit passes, development requirements, and neighborhood trip reduction programs, to encourage alternatives to automobile travel for commuting and potentially other purposes. Includes a mix of outreach and direct transit subsidies.
System efficiency	
System operations	Intelligent Transportation Systems (ITS) strategies, such as signal timing and coordination, adaptive signal control, ramp metering, incident response, traveler information, advanced traffic management systems, and integrated corridor management to reduce congestion and improve traffic flow.
Freight/intermodal	Investments to encourage freight modal shift from truck to rail. Examples include relieving capacity constraints at critical freight rail bottlenecks; addressing rail infrastructure constraints, such as low clearance bridges and low railcar weight limits; and improving accessibility to intermodal facilities.
Highway preservation	Investments to keep roadways functioning safely, reliably, and at expected levels of service. Examples include pavement preservation to minimize increased user costs associated with rough pavement; bridge preservation to avoid the need for unplanned closures or weight restrictions; and resiliency enhancements to withstand extreme weather events.
Highway capacity expansion	
Highway expansion	Projects to reduce bottlenecks and congestion by expanding roadway capacity.
Urban & intercity transit	
Bus rapid transit	Construction and operation of new bus rapid transit services, including infrastructure, vehicles (all electric), and operating expenses.
Urban rail	Construction and operation of new urban rail services (light rail, heavy rail, streetcar), including infrastructure, vehicles, and operating expenses.
Commuter rail	Construction and operation of new commuter services, including infrastructure, vehicles, and operating expenses.
Intercity rail	Construction and operation of new intercity passenger rail services, including infrastructure, vehicles, and operating expenses.

Bus service: expansion	Service expansion that adds vehicle revenue-hours (VRH) through extension of service-hours, more frequent service, or new routes.
Bus service: efficiency	Operational improvements that reduce run times and reduce emissions per mile, including transit signal priority, queue jump lanes, curb extensions at stops, and stop consolidation.
Electric microtransit	Subsidies or incentives for microtransit (app-enabled, flexible-route services using smaller vehicles than standard buses).
Transit fare reduction	Reduced public transit fares.
Transit state of good repair	
Bus	Investment in bus systems (e.g., new bus purchase, maintenance) to keep buses running in a state of good repair, minimize delays due to mechanical problems or lack of equipment, and maintain expected comfort levels (e.g., air conditioning, sufficient service to avoid overcrowding).
Urban rail	Investment in urban rail systems (e.g., new rail car purchase; railcar, track, and station maintenance) to keep trains running in a state of good repair, minimize delays due to mechanical problems or lack of equipment, and maintain expected comfort levels.
Commuter/intercity rail	Investment in commuter rail systems (e.g., new rail car purchase; railcar, track, and station maintenance) to keep trains running in a state of good repair, minimize delays due to mechanical problems or lack of equipment, and maintain expected comfort levels.
Other, or Indirect (non-GHG reducing)	Money that is spent in ways that do not directly reduce transportation GHG emissions.

3.0 Baseline Data

Baseline data, and in some cases forecasts for the time period 2017 – 2040, are included in the Tool for every state for population, VMT, transit service by mode, vehicle fuel efficiency and technology shares, and fuel-based emission factors. These baseline data are included in the Tool at the state level and either added or weighted by state population to obtain national data for use in national analysis. The Tool also provides the capability to select custom aggregations of states to support multi-state/regional analysis.

The Tool's baseline data related to fuel use and emissions only reflect on-road diesel and motor gasoline and do not include other transportation fuel types, such as aviation fuel, fuel for waterborne vessels, ethanol, biodiesel, or non-road diesel applications.

3.1 Population

Population forecasts are used in the land use/smart growth strategy to assist in determining an appropriate shift in population among area types.

State level population forecasts for 2020, 2030, and 2040 are taken from state-specific forecasts compiled by the Weldon Cooper Center for Public Service, Demographics Research Group, as of June 2020.[3] For states missing 2040 data, 2040 population was extrapolated from the 2020 and 2030 forecasts. Population for any intermediate years needed (e.g., 2032) was interpolated.

Population density and population by **urbanized area size** and **metropolitan area size** were used to develop state-specific population distributions by area type. The default area type distributions by state were developed from the 2018 American Community Survey (ACS) five-year population estimates at the census tract level (2014-2018).[4] Land area by state by area type was calculated from 2018 Census Bureau TIGER files.

3.2 Vehicle-Miles of Travel and Vehicle Stock

The Tool includes five vehicle types for the purpose of projecting VMT:

- Light-duty automobiles (including motorcycles) (LDA).
- Light-duty trucks (passenger and commercial) (LDT).
- Medium-duty trucks (MDT).
- Heavy-duty trucks (HDT).
- Buses.

[3] https://demographics.coopercenter.org/sites/demographics/files/2019-01/NationalProjections_ProjectedTotalPopulation_2020-2040_Updated12-2018.xls

[4] 2018 American Community Survey: 5-Year Data [2014-2018, Block Groups & Larger Areas]. IPUMS NHGIS, University of Minnesota, www.nhgis.org

Base year (2017) VMT by state and vehicle type were obtained from the Federal Highway Administration (FHWA) Highway Performance Monitoring System (HPMS) as reported in the Highway Statistics Series. NEMS produces forecasts of VMT for three vehicle types (light-duty vehicles, medium trucks, and heavy trucks) for the U.S. as a whole and nine U.S. Census regions. VMT forecasts by vehicle type were apportioned by state based on state population growth forecasts and the overall NEMS regional VMT forecast. Light duty vehicle VMT was proportioned into automobiles vs. light duty trucks based on the base-year proportions of light-duty auto vs. truck VMT by state from HPMS. Bus VMT was projected using the base-year bus VMT proportion by state from HPMS.

Projections of vehicle stock for the five vehicle types were based on the national VMT projections divided by the average annual miles per vehicle as documented in Section 4.2.

Transit vehicle-revenue miles (VRM) by mode and urbanized area (UZA) size were used to apportion transit investments based on the volume of service, since the Tool considers different effectiveness levels by UZA size for some transit strategies. Transit VRMs for fixed-route bus, light and heavy rail, and commuter rail were obtained by state from the 2014 National Transit Database. Reporting in the NTD is by three UZA sizes – small (less than 200,000 population), medium (200,000 – 1 million population), and large (greater than 1 million population). Transit service was also reported specifically for the New York City metropolitan area given the unique scale and role of transit service in this region.

3.3 Fuel Efficiency, Technology Shares, and Emission Factors

Annual forecasts of vehicle fuel efficiency by vehicle type, technology shares by vehicle type, and emission factors by fuel type were used to develop estimates of GHG emissions based on changes in VMT by vehicle type.

Fuel efficiency, expressed in miles per gallon of gasoline-equivalent (MPGGE) for light-duty vehicles and miles per gallon of diesel-equivalent (MPGDE) for medium and heavy trucks, was taken from NEMS, with reference case/ baseline data provided by OnLocation in August 2021 that is consistent with the 2020 AEO Reference Case. Fuel efficiencies for buses were estimated to be 3.1 MPG in 2017 for transit buses, based on Porter et al (2019), and 6.3 MPG for school buses, based on U.S. DOE Alternative Fuels Data Center data. Values were increased in future years in proportion to the change in heavy truck MPG forecast in the U.S. DOE AEO 2020 Reference Case, since buses are regulated by the same heavy-duty vehicle standards as trucks.

Fuel prices (dollars per gallon gasoline and diesel and cents per kilowatt-hour of electricity) were also taken from NEMS and expressed in 2020 dollars.

Shares of technology by vehicle type were also taken from the August 2021 runs (for light-duty vehicles) or from the AEO 2020 Reference Case for medium and heavy trucks and buses. The technology (fuel) types in the Tool include gasoline/ethanol, diesel/biodiesel, electric, and a combined “other” category. Other fuel types such as compressed natural gas (CNG), propane, and hydrogen, generally represent a small fraction of fuel shares and the gasoline emissions factor was used for all other fuel types for simplicity.

Carbon dioxide (CO_2) emission factors for gasoline and diesel were taken from August 2021 NEMS output provided by OnLocation. These emission factors exclude emissions from ethanol and biodiesel.[5] The 2022 factors are 66.1 kg per million British thermal units (BTU) for gasoline and 68.4 kg/million BTU for diesel, which were converted to 7.94 kg per gallon of gasoline-equivalent (GGE)[6] for gasoline and 9.41 kg/GGE for diesel based on a conversion rate of 120,238 BTU/GGE from NEMS.

For electricity generation, carbon dioxide equivalent (CO_2e) factors expressed in grams per megajoule (g/MJ) were taken by state from the U.S. EPA eGrid database for 2018 and weighted to produce a national average factor. The factor in 2018 is 113.5 g/MJ. This factor is assumed to decline at a rate of 2.5 percent per year, to 79.6 g/MJ in 2032 and 65.0 g/MJ in 2040, based on short-term targets set for the Regional Greenhouse Gas Initiative (RGGI) program adopted by the northeast and mid-Atlantic states.

[5] Biofuels were excluded because the NEMS application was developed to support the TCI initiative which was intended to place an emissions cap only on the fossil portions of finished gasoline and diesel.

[6] GGE is a unit of energy. One GGE of any fuel contains the same amount of energy as a gallon of gasoline. For example, one gallon of diesel fuel contains about 11 percent more energy than a gallon of gasoline and is therefore equivalent to 1.11 GGE.

4.0 Key Strategy Assumptions

Section 4.1 describes the area type methodology used to differentiate cost effectiveness of strategies in different geographies. Sections 4.2 through 4.5 describe key assumptions for each strategy, for electric and alternative fuel vehicles, travel reduction, system efficiency, and transit investment, respectively.

4.1 Area Type

The Tool applies different GHG reduction cost-effectiveness by area type where possible and logical. For example, bicycle investments may be more cost effective in high-density neighborhoods, and transit investments may be more cost-effective in larger urban areas.

The area types differ by strategy depending upon the underlying data and what area type definition is most suited to the strategy. The area types are described below.

Density-based Area Types: Area types based on census tract-level population density are defined for the following land use and for bicycle and pedestrian investments. The density-based area types include:

- Rural = population density of less than 500 persons per square mile;
- Suburban = population density of 500 to 4,000 persons per square mile;
- Urban = population density of 4,000 to 10,000 persons per square mile;
- Core = population density of at least 10,000 persons per square mile; and
- New York City = a category allowing entry of parameters specific to the population of New York City.

Transit Area Types: For transit strategies, three area types are defined consistent with the urbanized area types used for classifying systems in the National Transit Database. The analysis is built on NTD data for Northeast and Mid-Atlantic region systems, so these area types are used for consistency:

- Large UZA = population greater than 1 million;
- Medium UZA = population of 200,000 to 2 million; and
- Small UZA = population less than 1 million.

Metropolitan Area Types: For system efficiency and Travel Demand Management (TDM) strategies, three area types are defined based on consolidated metropolitan statistical area (MSA) size. These area types are consistent with the metro area size categories in the Texas Transportation Institute Urban Mobility Report, from which data are used to scale the system efficiency benefits. They are also close to the metro area size categories used in the Moving Cooler report (CS, 2009) which are used to scale the TDM strategy benefits. The area types are:

- Very large metro = population greater than 3 million;

- Large metro = population of 1 to 3 million; and
- Medium/small metro = population less than 1 million.

As a default assumption, the Tool allocates funding for each strategy by area type *in proportion to the amount of population in each area type in the state.* For example, if 50 percent of a state's population is in large UZAs, 50 percent of the funding for each transit strategy will be assigned the cost-effectiveness value for the large UZA area type. This procedure is illustrated in Table 4-1 for the TDM strategy. Line B shows the breakdown of an example state's 2014 population by area type. Line C allocates $10 million in annual funding for TDM across the three area types in proportion to the population in each area type. Line D shows the cost-effectiveness of TDM strategies by area type, as measured in metric tons (tonnes) of GHG emissions in 2032 per million dollars spent annually between the analysis start year and 2032. Line E shows the resulting GHG reductions for each area type and the resulting statewide total.

Table 4-1 Example of Application of Cost-Effectiveness by Area Type

	Area Type:	State Total	Very Large Metro	Large Metro	Medium/ Small Metro
A	2014 Population:	6,657,291	4,202,767	563,918	1,890,606
B	2014 Population (%):	100%	63%	8%	28%
C	Funding for TDM Strategy ($millions per year):	$ 10.0	$ 6.3	$ 0.8	$ 2.8
D	TDM cost-effectiveness by area type (2032 annual tonnes GHG per annual $million):		5,336	2,372	1,368
E	Tonnes GHG reduction in 2032 from TDM strategies:	39,345	33,617	1,898	3,830

Note: Sample data; cost-effectiveness may vary depending on input parameters.

4.2 Electric and Alternative Fuel Vehicle Incentives

4.2.1 Electric Light-Duty Vehicle Incentives

The effects of light-duty electric vehicle consumer incentives for vehicle purchase are modeled using NEMS. NEMS output was obtained in August 2021 for a Reference Case and for a case representing extension of the federal EV tax credit through 2040 and a lifting of the cap on EV tax credits per vehicle manufacturer. This output included:

- Light-duty vehicle sales for EV and PHEV.
- Light-duty vehicle stock for EV and PHEV.
- Light-duty VMT for EV and PHEV.
- Cumulative light-duty EV subsidy provided.

The difference in EV sales, stock, and VMT between the two scenarios was used to estimate an impact factor in terms of new EV sales, stock, or VMT per dollar of incentive. To allow the Tool to test different levels of EV incentives without re-running NEMS, it was assumed that the impact in terms of new EVs per dollar would scale linearly with the degree of incentive in any given year. This is believed to be a reasonable assumption as long as the number of additional new vehicles incentivized is a relatively small fraction of total vehicle sales in any given year.

4.2.2 Public Charging Infrastructure

The effects of light-duty electric vehicle infrastructure incentives are estimated based on recent studies estimating charging infrastructure costs and evaluating effectiveness, as measured in terms of number of new EVs supported per unit of new public charging.

Costs

Costs were estimated from two studies, by the Rocky Mountain Institute (RMI) (Nelder and Rogers, 2020) and the International Council for Clean Transportation (ICCT, 2019). An estimated range of costs and the source of each estimate is shown for various DCFC cost components in Table 4-2. The user of the tool can select whether to use the lower or higher cost estimate. There may be additional costs associated with local utility grid connections and upgrades, such as connections to 3-phase power lines, not included in these estimates. These costs can be highly variable and site-specific.

Table 4-2 Cost Estimates for DCFC Public Charging

Cost Element (per port)	Lowest Cost	Highest Cost	Source
DCFC (150 kW)	$20,000	$35,800	RMI
Transformer (150-750 kVA) Average	$39,500	$61,300	RMI
Data contracts	$84	$240	RMI
Network contracts	$200	$250	RMI
Credit card reader	$325	$1,000	RMI
Cable costs	$1,500	$3,500	RMI
Labor	$11,760	$20,160	ICCT
Materials	$16,380	$27,300	ICCT
Permits	$105	$210	ICCT
Taxes	$67	$111	ICCT
Total per DCFC port	**$89,921**	**$149,871**	

For public Level 2 charging, ICCT (2019) estimates an average cost of $5,440 per charger based on a total nationwide cost and charger deployment for the 2019 – 2025 timeframe. Nelder and Rogers (2020) provide a range of costs from $2,500 to $4,900. The ICCT value was used in the tool.

For studies that estimated EV sales increases based on the increase in charge ports or locations, without looking specifically at DCFC vs. Level 2 impacts, an average cost per port was estimated based on the current distribution of DCFC and Level 1 and 2 ports. AFDC identifies a total of 864 Level 1 ports, 98,031

Level 2 ports, and 26,210 DCFC ports publicly available in the U.S.[7] This represents a Level 1+2 share of just under 80 percent. The average cost per port, considering the "high" cost per DCFC port, is $35,800

Effects

Effectiveness of new public infrastructure at incentivizing EV sales and use was estimated based on four studies.

Li, et al (2017) use U.S. data from 2011 to 2013 for 353 metropolitan statistical areas (MSAs). They estimate that a 10 percent increase in the number of public charging stations (where a station typically includes three or four charging units, also known as ports) would increase EV sales by about 8 percent, for an elasticity of 0.8.

When applying an elasticity value, the number of new EVs per new charging station depends upon the ratio of the existing number of EVs to charging stations. This elasticity was applied to U.S. data on the number of charging stations, points, and sales for 2021, as shown in Table 4-3. A 10 percent increase in charge points and ports would mean 3,174 new points with 10,681 new ports. An 8 percent increase in annual sales would mean an additional 48,640 vehicles sold. This results in 15.3 new vehicles per new charge point, or **4.6 new vehicles per new port**. At the average cost of about $36,000 per port, this results in an incentive cost of **$7,800** per new vehicle assuming the port is fully funded with public investment.

Table 4-3 Estimated U.S. EV Charge Points, Locations, Registrations, and Sales (2021)

Item	Value	Source
Public and private EV charge stations (ports)	106,814	AFDC, 11/21/2022
Public and private EV charge points (locations)	31,738	AFDC, 11/21/2022
LD-EV registrations	1,109,000	AFDC, 11/21/2022
EVs per station (port)	10.4	Calculated
EVs per charge point (location)	34.9	Calculated
LD-EV sales	608,000	https://www.energy.gov/energysaver/articles/new-plug-electric-vehicle-sales-united-states-nearly-doubled-2020-2021

Delacrétaz, Lanz, and van Dijk (2021) evaluate 2014 – 2017 data from Norway to look at relationships between EV adoption and both charging stations and charging points. They find an elasticity of 0.091 with respect to the number of charging points, at the mean value of charging point availability, and an elasticity of 0.14 with respect to the number of charging stations (ports). Elasticity increases as the number of points or stations increases.

Applying the port elasticity to U.S. data, a 10 percent increase in the number of ports as of 2021 would be 10,681 new ports, compared to a 1.4 percent increase in registrations = 15,526 new registrations, for a ratio

[7] https://afdc.energy.gov/stations/states, accessed November 23, 2022

of **1.5 new EV registrations per new port**. At the same average cost as used above, the incentive cost is about **$24,600** per new EV.

Burra, Sommer, and Vance (2023) examine data from Germany for the 2016 to 2021 period. This study looks at differences in impacts of subsidies for both vehicle purchase and stations, with subsidy levels increasing over time across three subsidy phases. The study found that a 10 percent increase in capacity would increase the uptake of EVs by 1.44 percent in the short run, and 3.75 percent in the long run at lower subsidy levels (compared to a vehicle purchase subsidy at the equivalent of 4,000 Euros), with both elasticities higher at higher subsidy levels (4.74 and 12.34 percent, respectively, at a subsidy equivalent to 9,000 Euros per vehicle). Applying these values to the current number of U.S. ports as shown above would result in an increase of between **1.5 and 12.8 new EVs per new port**, or a subsidy cost of **$2,800 to $24,000 per new EV** if ports were fully subsidized.

Sommer and Vance (2021) also publish another paper based on data from Germany. This research looks at the relative effect of Level 2 ("normal") vs. fast-charge (DCFC) infrastructure. They find that a 10 percent increase in normal charging points is associated with a 5.4 percent increase in battery-electric vehicles (BEV). Fast chargers have an influence of about 4.5 times that level (10 percent increase in DCFC = 24.3 percent increase in BEVs), but the point estimate has a wide confidence interval. Using a weighted average market share of Level 2 and DCFC per above, a 10 percent increase in DCFC yields a 9.4 percent increase in BEVs, or **9.7 new EVs per new port** at a subsidy of **$3,700 per new EV**.

Overall Assessment

It is not clear that any one of the above studies are preferable to others. The only study using U.S. data is based on old data (2013 and earlier). Other studies consider more recent data from European countries. Elasticities have been found to vary depending upon the level of existing deployment and other contextual factors.

Version 4.25 of the tool (August 2022) used initial estimate values (based on a much more limited review than described above) of **10.2 new EVs per new charge port**, and cost ranges only for DCFC based on the costs shown in Table 4-2. The resulting subsidy was estimated to be **$14,700 per new EV** for infrastructure investment. The estimates provided by version 4.25 of the tool are therefore likely to be conservative compared to updated estimates based on the range of studies described above.

Using a straight average of all the values estimated above provides an average value of **5.6 new EVs per new charge port**, at a subsidy of **$6,400 per new EV**. This value may be considered for use in future tool updates as typical for DCFC infrastructure. Given the limited number of recent studies to draw from, this approach is not directly in line with investments expected to take place as a result of the recently-established National Electric Vehicle Infrastructure (NEVI) Program. NEVI-compliant stations, which must be capable of providing charge at a power level of at least 150 kW, are likely to be more expensive on average than those considered in the above-referenced studies, which may include DCFC with power levels as low as 50 kW, which may be another reason to use a more conservative value.

4.2.3 Alternative Fuel Medium- and Heavy-Duty Vehicles

Six classes of alternative fuel vehicles are included in the Tool: (1) electric transit buses; (2) electric school buses; (3) electric medium-duty trucks; (4) electric heavy-duty short-haul trucks; (5) hydrogen fuel cell electric vehicle (H2 FCEV) long-haul heavy-duty trucks; and (6) commuter rail electrification. Truck electrification was limited to the medium-duty and short-haul sectors because of the range limitations of battery electric technology. Hydrogen fuel cell is considered a more viable option for long-haul trucks.

Similar methods were used for all categories. Key assumptions are shown below by type of assumption. For some parameters, multiple data sources are shown for comparison, and the assumptions selected are shown in bold.

Base year efficiency is shown in Table 4-4, measured in MPGGE. Future year efficiencies are increased in proportion to AEO MPG forecast for trucks.

Table 4-4 Base (Gasoline or Diesel) Vehicle Efficiency

Vehicle Type	MPGGE (2017)	Source/Notes
Transit diesel buses	3.1	Alternative Fuels Data Center
School buses	6.3	Alternative Fuels Data Center
Trucks - MDT/urban	7.8	AEO – 2019 Reference Case
Trucks – Class 8 short-haul and long-haul	5.6	AEO – 2019 Reference Case
Passenger rail (per rail vehicle)	1.8	CS (2019), based on previous analysis of National Transit Database energy consumption for commuter rail systems.

Table 4-5 shows the assumed energy efficiency ratio (EER) for each vehicle type. The EER represents the relative efficiency of the vehicle using the energy input into the vehicle (fuel tank or plug). It does not account for lifecycle emissions (e.g., electricity generating and transmission losses).

Table 4-5 Energy Efficiency Ratio vs. Base Vehicle

Vehicle Type	EER	Source/Notes
Electric transit bus	3.5	Giuliano et al. (2018) reproduce data from California Air Resources Board (CARB) (2017) showing observed EER for MD/HD electric trucks vs. diesel ranges from ~3.5 – 4.0 at speeds above 20 mph, 4.0 – 5.0 for 10 – 20 mph, up to 7.0 for speeds below 10 mph. (Note – AEO shows somewhat lower ratios.) E.g., for Foothill Transit, “the BEB [battery electric bus] fuel economy was almost four times higher than that of CNG buses” (Hanlin, 2018). Cold climate would likely impact efficiencies. Gao et al. (2017) modeling suggests EERs in the 3.0 – 3.5 range for short haul class 7 delivery and utility bucket trucks in Knoxville, TN..
Electric school bus	3.5	
Electric truck - MDT/urban and HDT/short-haul	3.5	
H2 FCEV truck – Class 8 long-haul	1.5	Hunter (2018) shows H2-FCEV MPGGE of 10 v. 7 for diesel.
Passenger rail	2.3	CS (2019), based on previous analysis of National Transit Database energy consumption for diesel and electric commuter rail systems.

Table 4-6 shows the incremental vehicle cost, which is the incremental cost of the alternative fuel vehicle compared to the base vehicle. For the Tool, intermediate year values for 2025 are also estimated. Year 2030 values are used for all future years through 2040.

Table 4-6 Incremental Vehicle Cost vs. Base Vehicle

Vehicle Type	Incremental Cost – 2017[a]	Incremental Cost – 2022	Incremental Cost – 2030	Source/Notes
Electric transit bus	**$ 315,000**	**$241,000**	**$ 172,000**	Appears to be general agreement on current range; using CARB numbers.
	$ 315,000		$ 171,818	Giuliano et al. (2018) citing CARB (2015b).
	$ 300,000 - $ 400,000			New York State Energy Research and Development Authority (NYSERDA).
Electric school bus	**$ 200,000**	**$153,000**	**$110,000**	NYSERDA and MassDOT correlate on 2017 costs. Factored to 2030 based on Wood et al incremental cost for MDT.
	$ 120,000			Casale and Mahoney (2018).
	$ 215,000			VEIC (2018) bus cost of $325k from MA pilot compared to $110k diesel bus cost cited in Casale and Mahoney (2018).
	$ 200,000			NYSERDA.
Electric truck - MDT/urban	**$ 110,000**	**$84,000**	**$ 60,000**	Wood et al. (2017).
Electric truck - HDT/short-haul	**$ 315,000**	**$241,000**	**$ 172,000**	Very limited data – assumed to be same as electric transit bus.
H2 FCEV truck – Class 8 long-haul	**$ 120,000**	**$116,000**	**$ 100,000**	Hunter, C. (2018); Wood et al. (2017).
Passenger rail (locomotive)	$ -		$ -	No incremental cost assumed.

[a] Where more than one value is cited per vehicle type, the value in bold is used.

Table 4-7 shows the estimated annual maintenance cost savings compared to an internal combustion engine vehicle.

Table 4-7 Annual Maintenance Cost Savings vs. Base Vehicle

Vehicle Type	Annual Maintenance Cost Savings[a]	Source/Notes
Electric transit bus	**$ 0 – 2022** **Increasing to $5,000 - 2032**	Using Wood et al. (2017) for long-term estimate, adjusted to be more conservative. Savings uncertain in short-term. Assuming that operation and maintenance (O&M) costs include midpoint battery replacement. [8]
	$ 6,947	Wood et al. (2017).

[8] Most battery electric bus (BEB) manufacturers are offering a standard 6-year warranty for the batteries to get operators through the midway point of bus life and offering extended warranties up to 12 years to mitigate further risk (Proterra 2017).

Vehicle Type	Annual Maintenance Cost Savings[a]	Source/Notes
	Varies	Wide range of O&M costs reported. 46% of operators reported lower O&M costs for BEBs, 23% reported higher costs. Hanlin (2018).
Electric school bus	**$ 0 – 2022** **Increasing to $2,000 - 2032**	Scaled from transit bus costs based on miles/year.
	$ 2,547	Casale, M., and B. Mahoney (2018).
Electric truck - MDT/urban	**$ 0 – 2022** **Increasing to $ 530 - 2032**	
	$ 531	Wood et al. (2017).
Electric truck - HDT/short-haul	**$ 0 – 2022** **Increasing to $5,000 - 2032**	Very limited data – assumed to be same as electric transit bus.
H2 FCEV truck – Class 8 long-haul	No data	
Passenger rail	No data	

[a] Where more than one value is cited per vehicle type, the value in bold is used.

Table 4-8 shows the assumed cost of a charging or refueling station on a per vehicle basis. On-route charging equipment may be deployed for longer bus routes and is around $500,000 per charger (Hanlin 2018).

Table 4-8 Charging or Refueling Station Cost per Vehicle

Vehicle Type	Cost per Vehicle[a]	Source/Notes
Electric transit bus[9]	**$143,000 – 2022** **$120,000 – 2032**	Depot – $50k for charger, $20k for installation, $50k for infrastructure, divided 1 per 2 buses; $500k for on-route charger, 1 per 6 buses. Infrastructure costs only first 10 years. Estimates based on range of experience from Hanlin (2018) & Massachusetts DOT. For large scale applications, there may be additional upstream infrastructure costs (e.g., switchgear, transformers, substation upgrades) that are likely to be application-specific.
	$ 40,000	Wood et al. (2017), rough midpoint of range cited (charger only).
	$ 67,000	Average – depot equipment + installation. Hanlin (2018).
Electric school bus	**$ 40,000 – 2022** **$ 25,000 – 2032**	
	$ 25,000	$25k per charger plus $125-175k equipment and systems per site in 2015 (lower cost today) – VEIC (2018).
Electric truck - MDT/urban	**$ 40,000 – 2022** **$ 25,000 – 2032**	Assuming same as electric school bus.
		Wood et al. (2017). Range of $9k – $35k depending on rate of tech advancement.

[9] For future reference, consider different costs for urban/suburban systems vs. rural systems. Rural: $50k for charger, $20k for installation, 1 per bus, infrastructure upgrades not needed for small system.

Vehicle Type	Cost per Vehicle[a]	Source/Notes
		Borlaug et al (2021): 50kW DCFC = $30,000 - $82,000 procurement + installation per plug; most needs can be met without infrastructure upgrades.
Electric truck - HDT/short-haul	**$ 40,000 – 2022** **$ 25,000 – 2032**	Assuming same as electric school bus and MDT. Borlaug et al (2021) notes that most needs for HDT short-haul applications can be met with similar requirements. Larger fleets may require additional infrastructure upgrades, e.g., consistent with electric transit bus costs cited above.
H2 FCEV truck – Class 8 long-haul	$ 55,000	Giuliano et al. (2018) cites total incentive cost of $153-170 million needed to build out 100-station H2 refueling infrastructure in California, or about $1.6M per station (noted as being 70-85% of total capital costs). Assuming refueling takes 8 minutes, stations are used 12 hours/day, and have a 33% utilization rate, this equates to about 30 trucks per station or $55,000 per truck.
Passenger rail – cost per system-mile electrified	$ 2,800,000	Web source citing Amtrak New Haven-Boston electrification (1996-2000) at $310M for 155 route-miles ($2M/mile), inflated to 2018 dollars. http://cs.trains.com/trn/f/111/t/189389.aspx. This value includes substations, bridge work, etc. Note that Caltrain electrification and North-South Rail Link studies were consulted, but stand-alone estimates of electrification infrastructure costs (independent of other study components, such as locomotive purchase, PTC, etc.) could not be readily identified.

[a] Where more than one value is cited per vehicle type, the value in bold is used.

Table 4-9 shows the average annual miles driven per year per vehicle. To account for vehicle turnover, annual mileage of trucks varies depending on the age of the truck, and the average across all model years (computed as total miles driven divided by total vehicle stock in calendar year 2032) is taken from the Argonne National Laboratory VISION model v. 2019.

Table 4-9 Miles Driven per Year per Vehicle

Vehicle Type	Miles per Vehicle[a]	Source/Notes
Electric transit bus[10]	**26,000**	Lower estimate questionable as a regional fleet average, but perhaps reasonable given limited range of BEBs – likely used for lower-mileage applications, at least at early stages.
	36,000	Assumed 12 hours/day of operation at 10 mi/hr. Validated as consistent with assumptions in EPA MOVES2014 model (EPA 2016).
	26,000	MassDOT/Massachusetts Bay Transportation Authority (MBTA).
	37,000	Hanlin (2018).
Electric school bus	**10,000**	Low end of national estimates considering limited range of BEBs.
	9,900	EPA (2016) sourcing 1997 School Bus Fleet Fact Book.
	12,000	National averaged cited in VEIC (2018).
Electric truck - MDT/urban	**18,387**	VISION model (v. 2019) average across all vehicle ages for Class 3-6 trucks.
	21,000	EPA (2016) for single-unit short-haul truck, 5 years age (sourcing 2002 Vehicle Inventory and Use Survey).
Electric truck - HDT/short-haul	**25,185**	Using estimate based on Gao, which is generally consistent with U.S. EPA assumptions in MOVES of a short-haul mileage accumulation roughly ½ that of long-haul applications.
	25,185	Gao et al. (2017) observes 69 miles per day for class 7 local food delivery truck application in Knoxville, TN.
	50,000	50,000 miles per year per vehicle for “short haul” according to Miller, Wang, and Fulton 2017
Class 8 long-haul truck (H2 FCEV)	**41,628**	VISION model (v. 2019) average across all vehicle ages for Class 7-8 trucks – note, this includes likely repurposing of older trucks into short-haul applications.
	94,000	EPA (2016) for combination long-haul truck, 5 years age (sourcing 2002 Vehicle Inventory and Use Survey).
Passenger rail	22,746	MBTA data reported in National Transit Database, as cited in CS (2019).

[a] Where more than one value is cited per vehicle type, the value in boldface/shaded cell is used.

[10] The miles per vehicle estimate for electric transit buses was made assuming these miles are the same as the miles driven by diesel buses.

Table 4-10 shows Reference Case fuel costs. A time stream of costs for each year is included in the Tool. Costs for 2022 and 2032 are shown as representative of the study period.

Table 4-10 Fuel Costs

Fuel Type	Cost – 2022	Cost - 2032	Source/Notes
Gasoline (per gallon)	$ 2.40	$ 2.74	AEO 2020 Reference Case.
Diesel (per gallon)	$ 3.31	$ 3.37	AEO 2020 Reference Case.
Electricity	13.1 c/kwh = $ 4.44 /GGE	12.9 c/kwh = $4.39 /GGE	AEO 2020 Reference Case.
			Demand charges can have a significant impact, increasing fuel cost by 50-180% or more (Hanlin (2018) based on Gallo et al.) – 80% increase observed in MA school bus pilot (VEIC 2018). Charges can be reduced with charge management strategies. An option is suggested for adjustment as follows: 2022: 80% higher than AEO market rate; 2032: 40% higher than AEO market rate, per scenarios shown in Figure 9 of Hanlin (2018) & VEIC (2018).
Hydrogen from natural gas steam reformation (per GGE)	$ 4.35	$ 3.60	McKinney (2015): *Most common current price is $13.99/kg ($5.60/gge). While future price is uncertain, NREL estimates that hydrogen fuel prices may fall to the $10 to $8 per kg range in the 2020 to 2025 period*. We assume price falls to $9/kg in 2025, level thereafter.
Hydrogen from wind electrolysis on-site (per GGE)	$ 7.77	$ 6.43	Ratio of wind electrolysis to natural gas reformation estimated from Figure ES.3 of Hunter et al. (2018). Assumed constant in future.

Table 4-11 shows the years of fuel and maintenance cost savings that are considered when determining the amount of subsidy needed per vehicle. The full lifespan of the vehicle is considered for public sector vehicles, compared to a much shorter timespan for privately purchased vehicles.

Table 4-11 Years of Fuel and Maintenance Cost Savings Considered

Vehicle Type	Years of Fuel and O&M Cost Savings Included	Source/Notes
Electric transit bus	12	Average lifespan of bus.
Electric school bus	12	Average lifespan of bus.
Electric truck - MDT/urban and HDT/short-haul	3	Typically 3-5 years for consumer decisions; NEMS model coefficients infer about 3 to 4 years considered (per OnLocation staff).
Class 8 long-haul truck (CNG or H2 FCEV)	3	
Passenger rail – cost per system-mile electrified	12	Set to be the same as for bus replacement.

Fleet Turnover Models

Fleet turnover models were used to convert sales of new electric and alternative fuel vehicles in a given year to vehicle stock and VMT in future years. Models internal to the Tool were only used for the heavy-duty vehicle categories, since light-duty vehicle turnover is accounted for in NEMS. The models use miles driven per year and survival rates by vehicle age taken directly from the Argonne National Laboratory VISION model v. 2019, for Medium Trucks (Class 3-6) and Heavy Trucks (Class 7-8). For transit buses, a mileage accrual rate of 26,000 miles per year is used as described above, with a survival rate from MOVES2014 for years 1-12, and no survival after year 12. For school buses, a mileage accrual rate of 10,000 miles per year is used with a 100 percent survival rate for 15 years.

4.3 Vehicle Travel Reduction

4.3.1 Shared Ride Incentives

Overview of Methodology

This strategy is assumed to represent subsidies for users of shared-ride ride-hailing services. Data from the Carbon-Free Boston study (Porter et al., 2019) was used to estimate the cost-effectiveness of this service. In this study, travel demand forecasting methods were used to estimate the trip and VMT changes resulting from a $1.00 cross-subsidy from ride-alone to shared-ride services ($1.00 fee on ride-alone trips, and $1.00 subsidy for shared-ride). For the TCI study,[11] it was assumed that only a subsidy for shared-ride services was provided, and no additional fee was collected on ride-alone services. The cost-effectiveness would therefore be based on the VMT shift from a $1.00 reduction in the cost of a shared-ride trip.

Key Assumptions

- For the Boston area, the $1.00 cross-subsidy resulted in 155 million *total* shared-ride trips in 2050, leading to a reduction of 20 million VMT compared to a situation without the subsidy.[12]
- The net VMT reduction considers point-to-point mode shifts as estimated from mode choice modeling. In addition, new VMT provided by shared mobility services is increased by 30 percent to account for “deadheading,” based on data from TNC operations in a number of U.S. cities.
- GHG emission factors by year are applied to the VMT change per dollar in this analysis.
- Administrative costs were estimated at $0.01 per transaction/trip.

[11] https://www.transportationandclimate.org/sites/default/files/TCI%20Invest-Tool-Documentation_09212020_final.pdf

[12] The VMT reduction is not higher because (1) many people would still have taken shared-ride trips without the subsidy, and (2) there is some circuity involved in serving multiple passengers, so trip reduction does not correspond 1:1 with VMT reduction.

4.3.2 Micromobility: Shared E-bikes and E-scooters

Overview of Methodology

Data from shared mobility systems on average cost per trip, trips per day, trip length, and prior auto mode shares are used for these strategies. Assumptions are also made about offsetting GHG emissions from equipment purchase and servicing, and about the relative amount of physical activity of a user compared to walking or biking. Unless noted, data are from Portland Bureau of Transportation (PBOT) (2020) and/or North American Bikeshare Association (NABSA) (2020).

Key Assumptions

- Investment split 50%/50% between shared e-bikes and shared e-scooters.
- Average cost per trip of $3.00. This is assumed to fully cover the capital and operating costs of the system.
- Average of 2.6 e-bike and 3.2 e-scooter trips per vehicle per day, which results in an annual capital and operating cost of $2,850 for an e-bike and $3,500 for an e-scooter.
- Average trip length of 1.1 miles (e-scooter) or 1.4 miles (e-bike).
- Prior auto mode share (including drive, taxi, and TNC) of 40 percent based on Buehler et al (2019), Mobility Lab (2019), NABSA (2020), Ramboll (2020), and MacArthur et al (2018).
- Physical activity equivalency factor (relative activity per person-mile compared to biking or walking of 76 percent for e-bikes (Langford et al, 2017) and 20 percent for scooters (assuming 20 percent of trip is walk access/egress).

4.3.3 Micromobility: E-bike Ownership

Overview of Methodology

This strategy is evaluated similar to shared e-bikes, but based on the cost per bike and with different parameters. This strategy appears more cost-effective due to a longer vehicle lifetime, no service costs, and lower lifecycle GHG emissions.

Key Assumptions

- Cost per new e-bike of $2,000 (eBikesHQ.com, 2019). Price elasticity is unknown, so it is assumed that $2,000 investment or subsidy results in one new e-bike.
- Lifetime of e-bike: 6 years (ITF, 2020).
- Trips per bike per week: 6 (1 round-trip, 3 days a week), with an average trip length of 5 miles, results in 1,560 miles per bike per year (matches assumption from ITF, 2020).

- Prior auto mode share (including drive, taxi, and TNC) of 40 percent based on Buehler et al (2019), Mobility Lab (2019), NABSA (2020), Ramboll (2020), and MacArthur et al (2018).

- Physical activity equivalency factor (relative activity per person-mile compared to biking of 50 percent (Langford et al, 2017).

4.3.4 Land Use/Smart Growth

Overview of Methodology

Land use/smart growth strategies include infill, compact development, and transit-oriented development, which may be achieved through land use planning, public investment (e.g., complete streets projects, pedestrian infrastructure), and/or funding incentives to municipalities. Most analyses of the GHG benefits of these strategies assume that a certain amount of population or activity can be shifted into more transportation-efficient locations. Costs for administrative and planning activities are usually nominal compared to the capital investment costs required for most transportation strategies. However, additional costs may be incurred, such as infrastructure investment in targeted growth areas, or incentives to cities and towns to encourage rezoning.

There has not been a comprehensive assessment of land use strategy costs on which to base a GHG cost-effectiveness metric. Therefore, assumptions needed to be made for this analysis to tie funding to effectiveness. The metric used is the cost to government to implement policies that result in the shift of one person or household from a dispersed land use type into a more compact land use type. The approach to this strategy is to shift population from lower-density area types into higher-density area types; therefore, cost-effectiveness by area type is not defined and only a regionwide cost-effectiveness value is computed. Illustrative values are shown below.

Key Assumptions

- Research was conducted in 2019 to look at program evaluation data on funding incentives and new housing units from state and metropolitan programs where such data were available.[13] Findings are shown in Appendix A, Section A.1. Based on the program reviews, a value of $25,000 per household shifted was selected.

- The model includes a three-year lag to reflect the time required for new incentives to have an impact on policy and development patterns. The three-year lag is built between investment and response to account for planning, permitting, and construction time. Therefore, funding incentives starting in 2022 first start to have an effect in 2025.

- VMT per capita by area type is taken from the county level data in the emission inventory and forecast prepared for Northeast and Mid-Atlantic states(CS, 2015a). Here, the “medium urban” and “suburban” area types are combined into the suburban area type.

- Illustrative assumptions for the Northeast and Mid-Atlantic are shown in Table 4-12. In this example, about 304,000 people are shifted at the average funding level of $217 million a year and $25,000 per

[13] As of February 2017, 38 smart growth districts had been approved with a capacity for 13,715 zoned units, and over 3,000 building permits had been issued. See: http://www.mass.gov/hed/docs/dhcd/cd/ch40r/40ractivitysummary.pdf

household shifted. This population is shifted out of rural and suburban areas (equally split) and into urban and core areas (again, equally split). The 2032 reference case and scenario population are shown, and the VMT and GHG change is computed based on VMT per capita by area type.

Table 4-12 Illustrative Land Use Scenario

Affected population:	NYC	Core	Urban	Suburban	Rural	Total
VMT per capita	2,272	3,168	7,636	10,553	13,672	
2014 population	8,354,889	8,171,479	14,064,410	25,733,975	15,156,606	71,481,360
2014 population (%)	12%	11%	20%	36%	21%	100%
2032 growth (default)	443,983	434,236	747,390	1,367,516	805,429	3,798,554
2032 reference case population	8,798,872	8,605,716	14,811,800	27,101,491	15,962,035	75,279,914
Scenario pop shift @ funding level						303,962
Pop shift fraction to:		50%	50%	0%	0%	100%
Pop shift fraction from:				50%	50%	100%
2032 population shift	-	151,981	151,981	(151,981)	(151,981)	-
2032 scenario population	8,798,872	8,757,697	14,963,781	26,949,510	15,810,054	75,279,914
2032 scenario population (%)	12%	12%	20%	36%	21%	100%

4.3.5 Bicycle Investment

Overview of Methodology

This strategy includes various forms of bicycling infrastructure, such as bike lanes, separated bike lanes, shared-use paths, and bike boulevards.

The approach in this analysis is to assume an increase in bicycle-miles of travel (BMT) per new facility-mile of investment. This increase varies by area type and facility type. Unit costs per mile by facility type are combined with an investment mix by facility type and area type to determine the amount of new facilities that can be constructed at a given investment level.

Key Assumptions

- Growth in usage (new cyclists per day per mile by facility type) – the Tool projects about 150 new utilitarian bicycle trips per day for new bike lanes in the “NYC” and “core” area types, based on data from a New York City study (Gu, Mohit, and Muenniq, 2018). This is scaled to about 80 trips per day for a new bike lane in the “urban” area type and 25 trips per day in the “suburban” area type, based on their lower population densities compared to “core” areas. More detail on the bicycle impact assumptions and the various data sources reviewed is provided in Appendix A, Section A.2.

- New facility-miles: calculated from investment level, distribution of investment by area type and facility type (regionwide shown as example), and cost per mile of facility.

- Default cost per mile: bike lanes - $25,000; at-grade protected lanes/bike boulevard - $125,000; grade-separated protected lanes - $500,000; shared use paths - $1,000,000.
- Prior drive mode share of new bicyclists varies by area type with the same defaults as described in Appendix A, Section A.3 for transit investment.
- Bicycle trip length = 2.3 miles from the 2009 National Household Travel Survey.
- There is a one-year lag between investment and benefits to account for construction time.

4.3.6 Pedestrian Investment

Overview of Methodology

Pedestrian investment includes reconstruction of streets as “complete streets,” improvement of sidewalks and pedestrian infrastructure, traffic calming, or other infrastructure improvements that make it safer, easier, and more attractive to walk.

No reliable data was identified linking a program of pedestrian investments to a specific mode shift and corresponding VMT and GHG reduction. An alternative approach was taken to construct a hypothetical program of pedestrian improvements, estimate the costs of these improvements, and estimate response based on literature linking pedestrian demand to “pedestrian environment factors” (PEF) that describe the quality of the pedestrian environment based on factors such as sidewalk completeness, street crossings, topography, etc.

Key Assumptions

Sample projects were evaluated using an approach similar to the approach in Massachusetts DOT’s Congestion Mitigation and Air Quality Improvement Program (CMAQ) Project Worksheet for Complete Streets. Key assumptions and sample calculations are shown in

- Table 4-13.
- There is a one-year lag between investment and benefits to account for construction time.

Table 4-13 Pedestrian Investment Key Assumptions and Sample Calculations

	NYC	Core	Urban	Suburban	Rural	Units
Persons per square mile		>10,000	4,000 - 10,000	500 - 4,000	<500	
Facility Length (L):	1.0	1.0	1.0	1.0	1.0	Miles
Service Area Radius for Walking (RW):	0.25	0.25	0.25	0.25	0.25	Miles
Service Area of Community(ies) for Walking (SAW): L * 2RW = SAW	0.5	0.5	0.5	0.5	0.5	Sq. Miles
Population Density of Neighborhoods Served (PD):	20,000	15,000	7,500	2,000	500	Persons/Sq. Mile
Population Served by Facility for Walking (PW): PD * SAW = PW	10,000	7,500	3,750	1,000	250	Persons
Trips per Person per Day in Service Area (T):	4.7	4.7	4.7	4.7	4.7	Trips
Baseline Walk Mode Share in Service Area (MSW):[a]	40.0%	30.2%	18.7%	3.6%	2.4%	Percent
Relative Increase in Service Area Walk Mode Share from Improvements (WI):[b]	7.5%	7.5%	7.5%	7.5%	7.5%	Percent
New Walk Trips (WT): PW * T * MSW * WI = WT	1,410	798	247	13	2	1-Way Trips/Day
Average Walk Trip Length (LW):[c]	0.7	0.7	0.7	0.7	0.7	Miles
New Daily Walk Miles of Travel (BWM):	987	559	173	9	1	Miles per Day
Prior Drive Mode Share of New Walk Trips (MSD):[d]	38%	47%	59%	60%	75%	Percent
VMT Reduced per Day (VMTR): BWM * MSD = VMTR	370	264	103	5	1	Miles per Day
VMTR * Operating Days Per Year	135,096	96,387	37,421	1,945	397	VMTR Per Year
Incremental Complete Streets capital cost per mile[e]	$ 900,000	$ 900,000	$ 850,000	$ 750,000	$ 250,000	
Incremental annual maintenance cost per mile[f]	$ 63,000	$ 63,000	$ 59,500	$ 52,500	$ 17,500	

[a]Walk mode shares based on default mode shares by density in the MassDOT tool, which are based on analysis of the 2011 Massachusetts Household Travel Survey. These are: 4.7% (<1,000 ppsm); 7.2% (1,000 – 7,500 ppsm); 30.2% (>7,500 ppsm).

[b]Relative mode share increase of 7.5% is based on 0.15 PEF elasticity from Ewing and Cervero (2010) times assumed 50% increase in PEF as a result of improvements.

[c]Average walk trip length from 2009 National Household Travel Survey.

[d]Prior drive mode share uses the same defaults as described in Appendix A, Section A.3 for transit investment.

[e]Incremental cost of pedestrian improvements per mile is based on new sidewalk on 2 sides + 4 intersection curb extension retrofits + 16 new striped crosswalks + 8 new ped signals at 4 intersections, based on costs in Bushell et al., 2013.

[f]Annual maintenance costs estimated at 7% of capital costs, consistent with the transit investment analysis.

4.3.7 Travel Demand Management

Overview of Methodology

Travel demand management includes strategies such as employer outreach, rideshare and vanpool programs, subsidized transit passes, development requirements, neighborhood trip reduction programs, etc. to encourage alternatives to automobile travel for commuting and potentially other purposes. The basic approach for the TDM analysis is similar to other strategies in assuming a tons per dollar effectiveness based on evidence from the literature. Unlike most strategies, which accumulate benefits over time as investment is made in infrastructure, clean vehicles, or land use change, the TDM strategy is assumed to result in benefits in the year the money is spent.

A “two-tiered” cost-effectiveness scale is included.

- It is assumed that the first tier of spending is directed into employer outreach to achieve “low-hanging fruit” by working with employers and transportation management associations to offer information, incentives, and policies to support worksite vehicle trip reduction.

- Once outreach efforts have achieved as much as they can, additional funding is placed into direct incentives (modeled here as transit pass cost reductions) to workers, with a lower cost-effectiveness.

Key Assumptions

- High cost-effectiveness is estimated to be 10,000 tons/$million (~$100/ton), reflecting expanded employer outreach programs, based on information on employer/worksite TDM and rideshare programs from a U.S. DOT Report to Congress,[14] and evaluations of Metro Washington Council of Governments’ Commuter Connections program.[15]

- A reduced cost-effectiveness of 500 tons/$million (~$2,000/ton) is assumed for spending above a specified level. As a default in the Tool, this level is set at $179 million nationwide or $3.5 million per state, reflecting an average of $500,000 for five metro areas in each state plus $1 million for statewide programs covering other areas. Additional program funds beyond this level are assumed to be placed into commuter incentives for mode-switching, with impacts based on modeling for Moving Cooler.[16] The Moving Cooler results are based on modeling of subsidized transit passes using EPA’s Commuter Model, and are a function of baseline mode share by area type (higher non-auto share = higher cost-effectiveness).

[14] U.S. Department of Transportation (2010). *Report to Congress on Transportation’s Role in Reducing Greenhouse Gas Emissions.*

[15] LDA Consulting et al for MWCOG (2009). *Transportation Emission Reduction Analysis Report, FY 2006–2008*; data from this report analyzed in Cambridge Systematics, Inc. and Sprinkle Consulting, Inc. (2011). *Transportation Demand Management Project Evaluation and Funding Methods in the Denver Region*, prepared for Colorado Department of Transportation.

[16] CS for Urban Land Institute (2009), *ibid.*

(Footnote continued on next page...)

- Area type-specific factors are scaled from "regionwide" value based on cost-effectiveness ($/ton) by metro area size from Moving Cooler:
  - "Large metro" area type is set to the regionwide average cost-effectiveness value and corresponds to Moving Cooler "medium" metro area (750,000 – 2 million population) - $1.92/VMT reduced.
  - "Very large metro" area type corresponds to Moving Cooler "large" metro area (population >2 million)[17] - $0.85/VMT reduced.
  - "Medium/small metro" area type corresponds to Moving Cooler "small" metro area (population <750,000) - $3.33/VMT reduced.

4.4 System Efficiency and Capacity Expansion

System efficiency strategies reduce GHG emissions by reducing vehicle emissions per mile rather than reducing overall miles of travel. System efficiency strategies in the Tool include highway system operations, freight intermodal investment (shifting goods movement from truck to rail), highway preservation, and highway capacity expansion.

4.4.1 System Operations

Overview of Methodology

System operations strategies include "intelligent transportation systems" (ITS) strategies such as signal timing and coordination, adaptive signal control, ramp metering, incident response, traveler information, advanced traffic management systems, and integrated corridor management (the last two combining elements of the others). These strategies can reduce GHG emissions by reducing congestion and helping traffic flow more efficiently. However, if travel times are improved, there may be some offsetting effects of "induced demand" as it becomes easier to drive.

A similar approach to other capital investment strategies – GHG reductions per dollar of investment – was taken with this set of strategies. Such projects typically require expensive simulation modeling to accurately estimate fuel consumption and emissions benefits, and project-specific information on the GHG benefits of these strategies is therefore very limited, so information for this strategy is based on national literature rather than region-specific project data.

[17] All Moving Cooler results are for "high transit" metro areas, considered more representative of the Northeast and Mid-Atlantic than "low transit" metro areas

(Footnote continued on next page...)

Key Assumptions

- Cost-effectiveness of 250 annual $ per annual ton GHG reduced from Moving Cooler (CS, 2009), which modeled a range of ITS programs, and project evaluations listed in the U.S. DOT ITS Benefits database.[18]
- A 7 percent annualization factor to convert capital $ from annual $ (consistent with the transit investment analysis).
- Fuel savings and delay reduction estimates (for economic analysis) were back-calculated from GHG reductions, using a value of 0.44 gallons fuel saved per hour of delay saved from Texas A&M Transportation Institute (TTI) 2021 Urban Mobility Report (UMR) adjusted to future year values (0.34 gallons fuel saved per hour of delay saved or 0.0028 tons CO_2/hour of delay saved in 2032) based on the ratio of evaluation year to 2021 average fuel economy.
- Some VMT increase from induced demand would be observed, but is not currently reported as part of the economic impacts analysis. The GHG impacts of the VMT increase are accounted for in the Moving Cooler analysis and cost-effectiveness estimates.
- Area type-specific factors are scaled from “regionwide” value based on gal/hr of fuel savings for operational improvements by metro area size from the 2012 TTI UMR:[19]
  - TTI “very large” metro area (population >3 million) – 0.60 gal/hr saved.
  - TTI “large” metro area (population = 1 - 3 million) – 0.42 gal/hr saved.
  - TTI “medium” and “small” metro area and “other” area (pollution <1 million) – ~0.25 gal/hr saved for all these area types.
  - The “regionwide” value is related to the “national urban” total from TTI (0.52 gal/hr) and the area type values scaled accordingly.

Uncertainties are noted in the estimates for this strategy, as for all strategies. The data used to support the Tool value is shown in Table 4-14 along with other studies. There are few good studies and quite a range of estimates within those studies. The value used is primarily based on the Moving Cooler report, which conducted systems-level modeling using the FHWA Highway Economic Requirements System (HERS) model, which accounts for induced demand. Strategies modeled included ramp metering, advanced traffic management and integrated corridor management, and traveler information.

[18] CS (2009), *ibid.* Moving Cooler used the FHWA Highway Economic Requirements System (HERS) model, which has built-in demand elasticities, to estimate that a systemwide average reduction in delay of one hour per 1,000 VMT results in a systemwide increase in VMT of 2.13 percent. This increase in VMT results in a proportionate increase in fuel consumption and GHG emissions. The short-run increase was assumed to be half of this long-run increase. See Appendix B of the Moving Cooler report for further discussion.

[19] The 2012 UMR was used in the first iteration of Tool development and the scaling factors based on this report were not updated since they would not be expected to change significantly.

Table 4-14 Estimates of System Efficiency Cost Effectiveness

Source	Description	Cost, Capital	ΔGHG, tons, annual	(annual) $/ (annual) ton	annual tons/ annual $ (millions)	Timeframe
CS (2009)	Ramp metering			45	22,222	2020-2050
CS (2009)	Advanced traffic management/ integrated corridor management			290	3,448	
CS (2009)	Traveler information			330	3,030	
ITS Benefits Database	Pittsburgh Advanced Traffic Signal Control	$ 683,000	558		120	10-year life
ITS Benefits Database	Allegheny Co, PA corridor traffic signal optimization	$ 30,459	666		71,814	10-year life
Baker and Khatani (2017)	Traffic operational improvements	$ 3,080,000	76		247	
CS and OSA (2016)	Analysis of ITS strategies using the FHWA Energy and Emissions Reduction Policy Analysis Tool		(3,000)		NA	

4.4.2 Freight/Intermodal

Overview of Methodology

Freight/intermodal strategies in this analysis include investments to encourage freight modal shift from truck to rail. Examples include relieving capacity constraints at critical freight rail bottlenecks, particularly in access corridors to intermodal facilities and in high-volume freight corridors; addressing rail infrastructure constraints, such as low clearance bridges and low railcar weight limits; and improving accessibility to intermodal facilities.

The basic approach to analyzing this strategy is similar to the analysis of transit investment. Cost-effectiveness data (changes in truck VMT and rail ton-miles per capital dollar) were taken from the national literature and from project studies conducted in the Northeast and Mid-Atlantic region. Studies that looked at just GHG benefits per dollar were also considered, since not all studies reported VMT and ton-mile changes. The level of uncertainty related to freight investment GHG benefits is substantial. There are few studies that quantify freight infrastructure GHG benefits, and freight analysis methods are not well-developed, so broad assumptions about mode shift potential are generally employed. A mid-range effectiveness per dollar value based on existing studies is built into the Tool as the default value.

Key Assumptions

- A range of cost-effectiveness values, as described in changes in GHG per dollar of investment, was identified based on project and program-level analyses from states of the northeast and mid-Atlantic (see Appendix A, Section A.4 for more details and references).

  - Low: based on Connecticut and Massachusetts freight studies and a few individual Northeast and Mid-Atlantic region project evaluations – 40 tons GHG per $million.
  - Medium: based on Moving Cooler study (nationwide analysis) – 140 tons GHG per $million.
  - High: based on Mid-Atlantic Rail Operations Study – 1,165 tons GHG per $million.

- Changes in annual truck-miles and rail ton-miles per cumulative dollar of investment were also identified from these studies either directly, or based on the GHG reductions. For example, the Mid-Atlantic Rail Operations Study provided estimates of changes in truck VMT (600,000 annual truck VMT reduced per $million) and rail ton-miles (8.5 million rail ton-miles increased per $million). These estimates were down-scaled based on the ratio of “low” or “medium” to “high” GHG effectiveness shown above.

- Changes in truck VMT and rail ton-miles were projected for each future year based on cumulative spending and the cost-effectiveness estimated from the project studies.

- Changes in fuel consumption and GHG emissions were estimated based on the changes in truck VMT, combined with fuel consumption rates taken from NEMS; and changes in rail ton-miles, based on nationwide rail CO_2 intensity projections from the AEO Reference Case (0.023 kg CO2 per ton-mi in 2022, declining to 0.20 kg per ton-mi in 2040).

4.4.3 Highway System Preservation

Overview of Methodology

Highway system preservation includes investments to keep roadways functioning safely, reliably, and at expected levels of service. Examples include pavement preservation to minimize increased user costs associated with rough pavement; bridge preservation to avoid the need for unplanned closures or weight restrictions; and resiliency enhancements to withstand extreme weather events.

Only one study – for the Mississippi DOT – was located that looked specifically at the impacts of highway system preservation on economic benefits. This study was compared with information from the FHWA Conditions & Performance Report as a point of reference. For the Conditions & Performance report, FHWA uses the Highway Economic Requirements System model to estimate the user benefits and economic return of different levels of highway system investment (FHWA, 2015). The results from the two studies were found to be reasonably comparable.

Highway system preservation benefits are not assumed to vary by area type.

Key Assumptions

- Time savings and fuel cost savings per billion of investment are estimated using data from a study conducted by CS (2016) for Mississippi DOT, which compared an “expected funding” scenario with an “adequate funding” scenario looking at the period 2015 – 2040. The study looked at the impacts of deteriorating pavement condition on vehicle operating costs, congestion and delay costs, and safety costs. The study found that an increase in pavement investment from $372 to $694 million per year ($323 million increase) would reduce total user costs by $82.5 billion over the study period, including about $800 million in fuel costs, or $32 million per year. This equates to about 6.5 million gallons of fuel saved per year, or 1,400 gallons per million of cumulative spending over the investment period.

4.4.4 Highway Expansion

Overview of Methodology

Highway system expansion includes investments to add capacity (widening) to freeways and/or major arterials. Capacity additions can reduce GHG emissions in the short term by reducing congestion and delay, but in the long term may increase emissions as a result of induced demand effects. The Tool considers both delay reduction and induced demand effects, and allows for sensitivity testing to induced demand estimates. It is assumed that expansion projects would be constructed in heavily traveled corridors where the potential for near-term delay reductions would be significant. This strategy is not intended to evaluate new roadway infrastructure in lower-traffic rural areas that is built for the purpose of providing improved access to communities rather than reducing congestion.

Key Assumptions

- Freeway and arterial expansion costs average $5.0 million and $1.5 million per lane-mile, respectively, based on Florida DOT cost estimation data.[20].
- Expanded roads have a base VMT of approximately 20,000 VMT per lane-mile for freeways and 10,000 VMT per lane-mile for arterials. This assumes a freeway lane capacity of 2,000 vehicles per lane per hour with 10 percent of daily traffic in the peak hour. Arterial capacities are reduced by half to account for intersection delay. Analysis of modeling conducted by CS for a hypothetical freeway widening project in Virginia confirms that 20,000 VMT per lane-mile is a reasonable value.
- Different long-run induced demand elasticities can be tested. The demand elasticity measures the % change in VMT divided by the % change in lane-miles. The “High” value in the Tool is 1.0 for freeways and 0.75 for arterials, based on Volker and Handy (2020). The default, or “Moderate,” value is 0.67 for freeways based on recent CS modeling of a hypothetical freeway widening project in a large metropolitan area in Virginia. A custom value for freeways may also be used. Arterial values are scaled to 75 percent of freeway values.
- The Tool assumes a lag between year of expenditure and year open for traffic of 2 years for freeways and 1 year for arterials.
- The Tool assumes it takes five years to reach full response to induced demand, with effects in years 1-4 scaled up linearly between 0 and the final value.
- Delay savings (minutes saved per base VMT) are estimated based on recent CS modeling of a hypothetical freeway widening project in Virginia. The value is 0.20 minutes per VMT at a demand elasticity of 0.67, which corresponds to a 3 mph average speed increase compared with a base speed of

[20] https://www.fdot.gov/programmanagement/estimates/lre/costpermilemodels/cpmsummary.shtm, Accessed August 2021.

30 mph. The delay savings are scaled to be zero at an induced demand elasticity of 1.0, and to increase in inverse proportion to the elasticity.

- Fuel savings per hour of delay saved are the same as noted for the "system operations" strategy.

4.5 Urban & Intercity Transit

4.5.1 Fixed-Guideway Investment

Overview of Methodology

Fixed-guideway transit investment may include bus rapid transit (BRT), light and heavy rail, commuter rail, and intercity rail. In this analysis, distinct factors are developed for each mode. The basic approach is to estimate the annual change in automobile and transit VMT reduced per dollar of capital investment. This information is taken from recent planning studies of projects in the Northeast and Mid-Atlantic region and elsewhere across the U.S.

Key Assumptions

- The automobile VMT change per $million invested is based on data from 23 projects in the Northeast and Mid-Atlantic region and elsewhere in the U.S., with data obtained from a combination of Federal Transit Administration (FTA) New/Small Starts submissions, environmental documents, agency capital plans, and CS calculations. An average value for the reduction in automobile VMT per dollar is calculated for each mode based on projects of that mode. Detailed data are shown in Appendix A, Section A.3.

- For rail investments, the increase in rail vehicle VMT is estimated to be 3 percent of the decrease in automobile VMT, based on data from a sample of nine projects applying for FTA New Starts funding.

- For bus (BRT) investments, the increase in bus vehicle VMT is estimated to be 27 percent of the decrease in automobile VMT, based an average of modeled auto and transit VMT changes for 12 BRT projects across the U.S. as reported in FTA New Starts/Small Starts submissions and environmental documentation.

- GHG change per cumulative $million invested (capital and operating costs) are calculated from automobile and transit VMT changes and assumptions referenced elsewhere in the tool about emissions per mile by mode. All BRT projects are assumed to be electrically powered given a clear trend seen in recent New Starts and Small Starts submissions towards this power source (9 out of 11 projects in submissions for FY 2021 through FY 2023).

- Annual operating costs are estimated at 7 percent of up-front capital costs, or 37 percent of the annualized capital cost over an 11-year period.[21]

[21] The 7% annualization factor is based on CS analysis of a number of transit project applications for FTA New Starts funding that was conducted for Transit Cooperative Research Program (TCRP) Project H-41 (TCRP Web-Only Document 55, Assessing and Comparing Environmental Performance of Major Transit Investments, 2013). The factor

(Footnote continued on next page...)

- The transit investment cost-effectiveness assumptions do not vary by area type due to insufficient data, and also many transit projects or systems serve multiple area types (e.g., BRT or rail line serving both suburbs and the central business district).
- A one-year lag is built in between investment and benefits for BRT, and two years for rail, to account for construction time.

4.5.2 Bus Operating Improvements

Overview of Methodology

Bus operating improvements are investments that improve existing or add new fixed-route bus services. These may include:

- Service expansion that adds vehicle revenue-miles (VRM) through extension of service-hours, more frequent service, or new routes;
- Operational improvements that reduce run times and therefore can potentially attract new riders without adding new service, as well as reducing emissions associated with delay and idling; and
- Fare reductions to attract more riders to existing service.

The basic approach is to apply ridership elasticities (percent change in riders with respect to a percent change in service or fare levels) along with assumptions about avoided drive mode share and trip lengths. Note that fare revenue increases due to increased transit ridership are included as an offset against government costs in the economic impacts reporting.

Key Assumptions – Bus Service Expansion

- Cost per VRM based on 2014 NTD operating statistics for individual systems, to estimate the new VRM achieved with a given investment level.
- Ridership elasticities (percent change in ridership per percent change in service level) of 0.8 (urban), 0.9 (suburban), and 1.0 (rural). These are at the high end of the range of 0.3 – 1.0 found in the literature and assume that service is added where it is most effective at increasing ridership. This may include suburban and rural areas and off-peak hours, all of which have a higher percentage of “choice” riders than urban, peak-period service.
- Default values for prior drive mode share for transit riders are explained in Appendix A.

Key Assumptions – Bus Service Efficiency

- Results are scaled based on sample calculations for an investment of $80 million annually supporting the following improvements on 7 percent of route-miles: transit signal priority (2 intersections/mile), queue jump lanes (2 intersections/mile), curb extensions at stops (2 stops/mile), and stop consolidation.

is a composite reflecting a discount rate and useful life spans of different transit project elements from FTA’s Standard Capital Cost worksheets.

- Deployed on routes with average 15 minute headways.
- Travel time reductions by strategy (if applied on entire route) are based on literature, as documented in Appendix A. For the example investment level, this yields a total average travel time reduction of 2.8 percent (based on route-miles affected).
- Change in ridership and reduced automobile VMT based on:
  - Ridership elasticity with respect to travel time of 0.4 based on midpoint of typical range of 0.3 to 0.5 found in literature; and
  - Change in auto VMT based on assumed prior drive-alone mode share, which varies by area type (see Appendix A) and average trip length of 3.1 miles (unlinked passenger miles/unlinked passenger trips from 2014 NTD for bus systems).

Key Assumptions – Fare Reductions

- Ridership elasticity with respect to fare of -0.24 (urban), -0.30 (suburban), and -0.35 (rural). This is based on elasticities for large (population >1 million), medium (population = 500,000 – 1 million), and small (population <500,000) metro areas based on data cited in Mayworm, Lago, & McEnroe (1980) as cited in TCRP Report 95 Chapter 12.[22]
- Average bus fare of $1.09 per unlinked trip, from American Public Transportation Association Fact Book (2015). At a Northeast and Mid-Atlantic regionwide subsidy of $100 million, this represents a 4.7 percent reduction in fare (based on total unlinked trips in the region from 2014 NTD).

4.5.3 Electric Microtransit

Overview of Methodology

This strategy is evaluated similar to the optional parametric evaluation approach for other transit strategies, using factors such as passenger loads, trip lengths, mode shift, etc. Default values are based on data for the Rhode Island Public Transit Authority (RIPTA), but these can be replaced with system-specific or region-wide averages.[23]

Key Assumptions

- Investment supports capital and operating costs for smaller (12 to 15 passenger) vehicles providing app-enabled, flex-route service.

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[22] Mayworm, Lago, & McEnroe (1980) as cited in Pratt, R., et al (2004), Transit Cooperative Research Program (TCRP) Report 95 Chapter 12, Traveler Response to Transportation System Changes: Transit Pricing and Fares. While the data are from an old study, they are in the same range as elasticities more recently observed in the literature, and provide the closest basis for urban-suburban-rural distinction. Other research has also found higher elasticities in lower-density markets.

[23] RIPTA data were used because this module was originally developed for a project conducted for Rhode Island (see: State of Rhode Island, 2021). The data should be reasonably representative of similar services in other states.

- Capital cost (vehicle + EVSE) of $93,000 per vehicle, which is the average assumed for an electric medium-duty truck over the 2022 – 2032 time period. Vehicle has a 12-year lifetime.
- Operating cost of $75 per vehicle revenue-hour, the cost for RIPTA demand responsive service as reported in the 2018 NTD.
- Average occupancy of 3.8 persons per vehicle, the average of RIPTA vanpool (6.2) and demand response (1.4) service as reported in the 2018 NTD.
- Average trip length of 10 miles, from RIPTA demand-responsive service as reported in the 2018 NTD.
- Average of 30,000 miles per vehicle and 1,500 VRH per vehicle per year, from RIPTA demand-responsive service as reported in the 2018 NTD.
- Prior drive mode share of 59 percent, similar to bus expansion assumptions.

4.5.4 Transit State of Good Repair

Overview of Methodology

Transit state of good repair includes investments to keep transit systems running safely, reliably, and at expected levels of service. Examples include vehicle replacement on schedules consistent with industry standards; track, bridge, and tunnel work to avoid the need for slow zones or the risk of a system failure; and resiliency enhancements to withstand extreme weather events.

There is little information that has been developed specifically on the impacts of transit state of good repair on GHG or economic benefits. The basic approach in this analysis is to assume a ridership loss over time (and corresponding mode shift to vehicles) due to increasing system unreliability and degraded performance if a state of good repair is not maintained. Estimates of state of good repair investment requirements are taken from a review of Northeast and Mid-Atlantic region transit agencies' capital plans and needs studies.

Key Assumptions

- Based on multi-year investment needs assessments for a variety of transit systems in the Northeast and Mid-Atlantic region (see Appendix A).
- Assuming the following loss of ridership between 2022 and 2032 from failure to make investments in transit state of good repair (i.e., only covering operating expenses):
  - 50 percent for bus systems, assuming average 20-year lifespan of bus system components (e.g., 12 years for buses, 50 years for buildings/facilities).
  - 25 percent for rail systems, assuming average 40-year life of rail system components (e.g., 25 years for rolling stock, 50 to 125 years for fixed assets).
- Average trip lengths by mode specific to systems analyzed, from NTD data on annual ridership and passenger-miles by system.

- Fraction of shifted trips resulting in a new vehicle trip equals prior drive mode share as assumed for other transit strategies (see Appendix A).

- The systems upon which data are based typically cover both urban and suburban area types; therefore, a different cost-effectiveness is not assigned by area type.

5.0 Using the Tool for Economic Impact Assessment

5.1 Overview of Economic Benefits Modeled

The economic benefits of clean transportation investment can be analyzed using outputs from the Tool that are fed into the Regional Economic Models, Inc. (REMI) Policy Insight (PI+) model. REMI is the premier economic simulation model in the U.S. and is a dynamic model, measuring interactions among all sectors of the economy over time. The model provides forecasts on a year-by-year basis through 2050. The model is set up with data from each state, plus the District of Columbia, for 23 economic sectors. Results of an economic analysis of clean transportation strategies were first reported in CS (2015b). The Tool also has the capability to support economic analysis of a national or multi-state program of investments.

REMI measures the flow of money throughout the economy. Benefits are reported in terms of jobs, gross regional product, and personal disposable income. Inputs from the Tool include costs incurred and cost savings by user group (businesses, consumers, and government). The economic analysis is *not* a social benefit-cost analysis and does not attempt to monetize non-monetary benefits such as travel time savings for personal travel or other welfare effects. Due to the various simplifying assumptions and general approximations that are required for a program-level analysis, as compared to project-specific analysis, the results are representative of an "order of magnitude" of effects rather than a precise estimate.

The economic analysis considers the net economic effects to the region from the following impacts:

- **Travel time savings** accruing to businesses, due to reductions in congestion and delay. These include time savings for truckers, other commercial vehicle operators, and other "on-the-clock" travel. Congestion and delay are reduced through investments in traffic flow improvements (system efficiency); VMT reductions from travel reduction strategies are also estimated to reduce congestion.

- **Savings in fuel and vehicle maintenance** (for businesses and consumers), as a result of strategies (such as investment in transit and nonmotorized infrastructure) that allow travelers to reduce VMT.

- **Shipping cost savings** for businesses that can ship by rail rather than truck, as a result of improved freight rail infrastructure.

- **Increased spending on vehicles** (for electric vehicle and natural gas truck purchases) and electricity and natural gas to run these vehicles; these spending increases are offset by reduced petroleum fuel costs.

- **New government investment** in transportation infrastructure and services, made possible by the new funding mechanisms.

- **Changes in consumer spending** on non-transportation goods and services. Consumers will pay more in VMT, fuel costs (associated with the price of carbon emission allowances), and for electric vehicles.

However, these costs will be offset to varying degrees by the above monetary cost savings. The net of these two effects is an increase or decrease in money available to spend on other items.[24]

Money transfers (such as paying taxes to support increased infrastructure investment) do not by themselves increase or decrease wealth or jobs, they just transfer wealth from one entity to another. However, they can shift the balance of where money is spent in the economy, which can affect the benefits captured within any specific state or region.

The relationship between GHG reduction strategies and the drivers of economic impacts is shown in Table 5-1.

Table 5-1 Economic Impact Drivers by Strategy

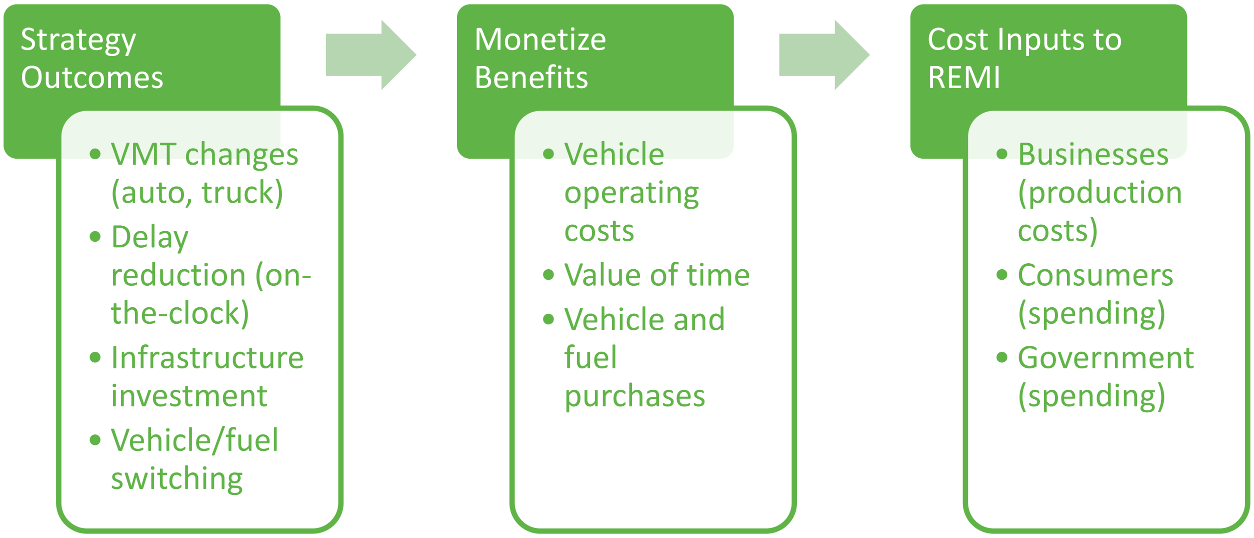
Primary Effect	Secondary Effect	Electric/Alt Fuel Vehicles	Land Use/ Smart Growth	Active Transportation	TDM	System Operations	Freight/ Intermodal	Transit	Highway Preservation
Reduced VMT	Vehicle Operating Cost Savings		✓	✓	✓			✓	
	Delay Reduction		✓	✓	✓			✓	
Delay Reduction						✓			✓
Vehicle Purchase Costs		✓							
Vehicle Operating Cost Savings		✓							✓
Modal Cost Savings							✓		

5.2 Key Assumptions

Figure 5.1 shows the basic analysis approach. Strategy outcomes such as changes in vehicle sales, VMT, delay, and fuel use by fuel type are first tabulated. These are then monetized using various factors such as vehicle operating costs, value of time, and fuel cost. Finally, the monetary costs are tabulated in a form that can be input to REMI. The inputs include changes in business production costs, consumer spending, and government spending.

[24] Changes in consumer spending in other sectors of the economy could increase or decrease GHG emissions in these sectors. Accounting for changes in non-transportation GHG emissions was beyond the scope of this analysis.

Figure 5.1 Economic Analysis Approach



5.2.1 VMT Changes

To monetize VMT changes, the following values from sources widely accepted in transportation analysis were used:

- Fuel costs – based on the fuel efficiency and fuel price assumptions from NEMS as used in the GHG analysis.
- Maintenance costs – **$0.10 per mile** for light-duty vehicles, based on the FHWA Highway Economic Requirements System (HERS) model Technical Report (2005).[25]

Note that VMT and associated fuel and maintenance cost savings for trucks resulting from freight intermodal investments are not considered separately. These are already considered in the changes in shipping costs as a result of truck-rail mode shifts.

5.2.2 Changes in Truck and Rail Ton-Miles

Freight/intermodal infrastructure investment supports a shift in freight ton-miles from truck to rail. To estimate this shift, a *change in rail ton-miles per capital dollar invested* was estimated as described in Section 4.4.2. To monetize the benefits of a shift in traffic, a value of $0.04 in shipper savings per ton-mile shifted from truck to rail was used. This value was taken from the Massachusetts Department of Transportation Freight Plan (MassDOT, 2010, p. 4-10).

[25] HERS is used as the basis for the U.S. DOT's annual "Conditions and Performance" Report which describes the status of the nation's highways, bridges, and transit and describes investment needs.

5.2.3 Time Savings

Time savings from two sources were estimated:

- Investment in system operations/efficiency strategies for GHG reduction, such as ITS, traffic signal coordination, capacity expansion, etc. to reduce delay.
- Reduced congestion as a result of reduced VMT.

Hours of delay reduced per VMT reduced were estimated based on the Texas Transportation Institute's 2012 Urban Mobility Report (Schrank, Eisele, and Lomax, 2012), which estimates the cost of congestion nationwide. To analyze reduced congestion as a result of reduced VMT, the reported nationwide hours of delay reduced from public transportation (865 million in 2012) was divided by the estimated VMT reduced from public transportation (44.8 billion) to obtain a factor of **0.02 hours of delay reduced per VMT reduced**. This factor was then multiplied by the VMT change estimated for the investment strategy to obtain an overall delay reduction.

For system operations/efficiency, the 2021 UMR estimated that nationwide, operational improvements were saving 182 million hours of delay and 79 million gallons of fuel annually, for a savings of 0.44 gallons of fuel per hour of delay reduced in 2021, with values in future years adjusted based on fuel efficiency (see Section 4.4).

Time savings (delay reductions) were allocated between light-duty VMT and truck VMT in proportion to the VMT by each mode. They were then monetized using a value of $27.90 per hour for business travel and $30.80 per hour for truck drivers, based on U.S. DOT guidance (U.S. DOT, 2021).

For truck VMT, all time savings are assumed to accrue to businesses. For passenger travel VMT, 6.3 percent of travel was assumed to be "on-the-clock" (CS, 2014).

5.2.4 Alternative Fuel Vehicle Costs

Assumptions regarding costs for electric and alternative fuel vehicle purchases, refueling infrastructure, and fuel are described in Section 4.2.

5.2.5 Highway Preservation

Benefit data are derived from the 2013 Conditions and Performance Report (U.S. DOT, 2013), pp. 7-20 and 7-21. The report includes highway investment scenarios analyzed at a national level using the HERS model. Multiple investment scenarios are shown for average annual spending (2010 $billions) and total user costs ($/VMT). The differences between successive scenarios shown in these tables are used to derive an average cost savings ($/VMT) per $billion invested.

The scenarios are a mix of capacity expansion, preservation, ITS, and safety. This mix is internally determined by HERS algorithms. The report does not have scenarios that only include preservation, so the impacts of the different investment types cannot be distinguished. Instead, spending on highway preservation is assumed to have the same economic benefit per dollar as the other types of investment assumed in HERS.

The report states that 44.9 percent of user costs are time, and 41.5 percent are vehicle operating (the remainder are crash costs). The resulting values are $412 in time savings and $381 in vehicle operating cost savings per million VMT. These savings are multiplied by total VMT and allocated amongst business and personal travel consistent with the other elements of the analysis as described above.

5.3 Preparation of REMI Inputs

Cost changes can be reported as a stand-alone output of the Tool. The cost changes are also rolled up to REMI inputs as are shown in

Table 5-2. Only the shaded rows (which are sums of other rows) are actual REMI inputs.

Table 5-2 Cost Changes Rolled Up to REMI Inputs

Sector and Category	Description
Business Expenditures	
Time (Productivity)	Business share of travel time savings from system efficiency and VMT reduction
Fuel (Liquid Fuels, Hydrogen)	Business share of fuel cost savings from alternative fuel vehicles, system efficiency, and VMT reduction
Electricity	Electricity expenditures for electric trucks
Vehicle Purchase	Vehicle and refueling infrastructure capital cost for electric MDTs and electric and hydrogen HDTs, plus business share of light duty EV costs
Vehicle Maintenance/Repair	Business share of maintenance cost savings from VMT reduction and state of good repair
Transportation Services (Shipping)	Reduced costs for shifting from truck to rail
Carbon costs[a]	Business share of new taxes, fees, or carbon costs paid (fuel purchases for commercial vehicles)
Transit Fares	Business share of transit fare changes (on-the-clock travel, new service and reduced fares)
Incentives	Spending returned to businesses in the form of incentives for alternative fuel vehicles and infrastructure
Business Production Cost Change	Sum of the above consumer categories
Consumer Expenditures	
Fuel (Liquid Fuels, Hydrogen)	Consumer share of fuel cost savings from alternative fuel vehicles, system efficiency, and VMT reduction
Electricity	Electricity expenditures for light duty EVs
Vehicle Purchase	Consumer share of light duty EV costs
Vehicle Maintenance/Repair	Consumer share of maintenance cost savings from VMT reduction and state of good repair
Carbon costs[a]	Consumer share of new taxes or fees, or carbon costs paid (fuel purchases for commercial vehicles)
Transit Fares	Consumer share of transit fare changes (on-the-clock travel, new service and reduced fares)
Incentives & Indirect Revenue Recycling	Spending returned to consumers in the form of incentives for light-duty EVs and charging equipment, plus new proceeds returned directly to consumers
Consumer Spending - Other Items	Negative of the sum of the above consumer categories
Government Expenditures	
Transportation Infrastructure	New government expenditure on transportation infrastructure
Transportation Services	New government expenditure on transportation services
Utilities Infrastructure	New government expenditure on utilities infrastructure
Incentives: Business	New spending returned to businesses in the form of incentives for alternative fuel vehicles and infrastructure
Incentives: Consumers	New spending returned to consumers in the form of incentives for alternative fuel vehicles and infrastructure
Cost Savings and New Revenue	Cost savings to public fleets from reduced fuel and maintenance costs associated with electric buses and trains, plus new transit fare revenue
Total Government Infra & Services	Sum of new expenditures on transportation infrastructure, transportation services, and utilities infrastructure

[a]The “carbon cost” category was used in the TCI analysis to account for the effects of new carbon costs paid by consumers and businesses, but would also represent the effects of taxes or fees collected to fund investment programs funded through other mechanisms.

Costs need to be allocated to states and industry sectors for use in REMI. The first step in this process is to allocate regional cost changes to states, using each state's estimated share of carbon emissions (from gasoline and diesel fuel). This estimate was made for 2032 using forecasts of VMT and fuel efficiency by vehicle type consistent with the evaluation scenario.

Cost changes to businesses also need to be allocated across 19 industry sectors (the other four sectors in the 23-sector model are for federal, state, and local government and consumer spending). This is done using the total gross product in each state and industry (extracted from the REMI model) and the transportation satellite accounts (TSA) of transportation spending by industry. TSAs are the ratio of dollars spent on transportation services within each industry to total expenditures. TSA values were obtained from the Bureau of Transportation Statistics 2016 TSA Industry Snapshots as shown in

Table 5-3. Industry spending by state is multiplied by the TSA value to get the total proportion of regional business expenses by state and industry. Note that the allocation of total costs by category and year to states and industry sectors is done outside of the Tool itself, in a post-processing Excel workbook.

Table 5-3 Transportation Satellite Accounts by Industry

Industry	Transportation $ per Total $
Forestry, Fishing, and Related Activities	0.0109
Mining	0.0420
Utilities	0.0490
Construction	0.0290
Manufacturing	0.0360
Wholesale Trade	0.0090
Retail Trade	0.0090
Transportation and Warehousing	0.0180
Information	0.0130
Finance and Insurance	0.0070
Real Estate and Rental and Leasing	0.0240
Professional, Scientific, and Technical Services	0.0240
Management of Companies and Enterprises	0.0240
Administrative and Waste Management Services	0.0220
Educational Services	0.0140
Healthcare and Social Assistance	0.0140
Arts, Entertainment, and Recreation	0.0260
Accommodation and Food Services	0.0260
Other Services, except Public Administration	0.0220

6.0 Safety, Health, and Emissions Output Assumptions

6.1 Safety Benefits

To estimate safety benefits, fatality and injury motor vehicle crashes are assumed to be reduced in proportion to VMT reduced. Average rates of 0.013 fatalities and 0.195 injuries per million vehicle-miles are used, based on Fatality Analysis Reporting System (FARS) fatality data from 2000-2009 and injury rates reported by the Bureau of Transportation Statistics (BTS) in National Transportation Statistics (Table 2-17: "Motor Vehicle Safety Data").[26] These rates were recommended by Cambridge Systematics for the Federal Transit Administration (FTA) in 2012 and are still being applied by FTA for use in New Starts and Small Starts project evaluation.[27]

Crash reduction benefits are valued at $9.6 million per fatality based on 2016 U.S. DOT guidance on value of a statistical life. Disabling injuries are valued at $490,000 based on the value provided in FTA's latest (FY 2021) New Starts and Small Starts reporting templates. The injury value has been inflated by FTA since the original 2012 work (when it was $323,000) and is meant to be applied to the fatality and injury rates stated in the previous paragraph.

The analysis does not account for any increases in fatal or injury crashes that may occur as a result of increased levels of bicycling and walking. The literature is not conclusive on whether bicycle and pedestrian investments produce net benefits to traffic safety. Investments in bicycle and pedestrian infrastructure result in a higher total number of bicyclists or pedestrians, and therefore greater exposure (person-miles of travel), but also tend to be associated with a lower risk per mile biked or walked, due to the "safety in numbers" effect and to safety improvements introduced by the infrastructure improvements (c.f. Castro et al., 2018). These two effects offset to an unknown degree, which appears to vary depending upon the context. As one example, no clear increase in bicycle fatalities or reported crashes occurred in Portland between 1991 and 2006, despite a three- to four-fold increase in bicycling (Gotschi, 2011).

Data on bicycle and pedestrian fatality and injury rates per person-miles of travel (PMT) is not as robust as motor vehicle crash data since there is very limited exposure data (total PMT) compared to estimates of motor vehicle VMT, and since injuries tend to be underreported. However, Buehler and Pucher (2017) make some estimates using rates of walking and bicycling estimated from the 2008-2009 National Household Travel Survey (NHTS) combined with injury data reported by the Centers for Disease Control and Prevention (Buehler and Pucher, 2017). They estimate fatality rates of 7.5 per 100 million PMT bicycled and 15.5 per 100 million PMT walked, and injury rates of 331 per 100 million PMT bicycled and 117 per 100 million PMT walked. Applying these rates to scenario increases in walk and bike PMT, and assuming no "safety in numbers" effect or safety benefits of the infrastructure improvements, the increases in bicycle and pedestrian fatalities and injuries are greater than the estimated decreases in motor vehicle crash fatalities and injuries. The large majority of this increase is for bicyclists (over 95 percent of additional injuries and over 80 percent of additional fatalities), so the question of the "safety in numbers" effect for bicyclists is paramount.

[26] The latest reported rates, for year 2017, are 0.012 fatalities and 0.201 crashes per million vehicle-miles. Since the original values are close to the latest reported values, they were not adjusted. See: https://www.bts.gov/content/motor-vehicle-safety-data, Table 2-17 for data for all years.

[27] See: Federal Transit Administration, New Starts Environmental Benefits Template, available at http://www.fta.dot.gov/12304.html.

6.2 Physical Activity Benefits

The estimates of deaths prevented from physical activity are based on a 2020 study of the Transportation, Equity, Climate and Health (TRECH) Project study that that estimated air pollution and public health benefits for states and counties in the Northeast and Mid-Atlantic (TRECH, 2020). That study used the World Health Organization (WHO) Health Economic Assessment Toolkit (HEAT) to estimate the lives saved and value of lives saved from increased bicycling and walking under various investment scenarios.[28] The HEAT analysis was based on inputs of the daily increase in walk or bicycle person-kilometers traveled for different investment scenarios, as predicted by the TCI Investment Strategy Tool[29]. Low, medium, and high benefits were estimated reflecting uncertainties in various parameters. In the Tool, the benefit for each state is weighted by the population of the state to develop an average impact factor, which is applied to the U.S. as a whole. Table 6-1 shows the factors that were derived to convert change in person-miles traveled by walking and bicycling into deaths prevented.

Table 6-1 Annual Deaths Prevented per Million Person-Miles Traveled

Mode	Low	Medium	High
Walking	0.55	0.82	1.08
Bicycling	0.18	0.26	0.35

For the “medium” estimate of statistical value of lives saved, deaths prevented by physical activity were valued at the same $9.6 million value of a statistical life used in the safety analysis. The value of life used in the TRECH study was lower for the “low” estimate and higher for the “high” estimate.

6.3 Air Pollution Benefits

Reductions in emissions of air pollutants from motor vehicles are assumed to be proportional to reductions in VMT. Emissions changes were estimated by applying emission factors in grams per mile (g/mile) to changes in VMT by vehicle type to estimate changes in emissions of fine particulate matter ($PM_{2.5}$), oxides of nitrogen (NO_x), and volatile organic compounds (VOC).

The change in premature deaths from air pollution and the value of air pollution reduction was based on the 2020 TRECH study (TRECH, 2020) findings for the Northeast and Mid-Atlantic region. This study took county-level estimates of changes in emissions from the TCI Investment Strategy Tool[30] for various scenarios evaluated in 2020, and used these as inputs to an air quality model and a health effects model to estimate health outcomes at the county level. The average benefit values per unit of air pollution reduced (based on TRECH state-level results, weighted by state population) were applied to national emission reduction levels in the Tool.

[28] The HEAT tool and documentation are available at: https://www.who.int/gho/health_equity/assessment_toolkit/en/

[29] https://www.transportationandclimate.org/sites/default/files/TCI%20Invest-Tool-Documentation_09212020_final.pdf

[30] https://www.transportationandclimate.org/sites/default/files/TCI%20Invest-Tool-Documentation_09212020_final.pdf

6.3.1 Emissions Estimates

Separate emission factors are applied by vehicle type (light-duty autos and trucks, medium-duty trucks, heavy-duty trucks, and buses). These factors are applied to changes in non-electric VMT.

Representative emission factors were developed using MOVES2014 for runs conducted in June 2021 using national default inputs. MOVES2014 inventory runs were performed for July 2032 and July 2040, and total running emissions by vehicle class were divided by total VMT by vehicle class to obtain average g/mile rates. These rates do not account for changes in emissions related to changes in vehicle population (e.g., evaporative emissions) or truck hoteling. The emission factors used in this analysis are shown in Table 6-2. The factors are a combined factor that reflects the weighting of the fuel types in each vehicle category assumed within MOVES2014.[31]

Table 6-2 Emission Factors

Pollutant/Vehicle Class	2032 Factor (g/mi)	2040 Factor (g/mi)
Primary Exhaust PM2.5 - Total		
Light-Duty Autos & Trucks	0.004	0.003
Buses	0.037	0.016
Medium (Single Unit) Trucks	0.016	0.015
Heavy (Combination) Trucks	0.044	0.034
Oxides of Nitrogen (NOx)		
Light-Duty Autos & Trucks	0.083	0.060
Buses	1.370	0.971
Medium (Single Unit) Trucks	0.697	0.646
Heavy (Combination) Trucks	3.130	2.877
Volatile Organic Compounds (VOC)		
Light-Duty Autos & Trucks	0.014	0.011
Buses	0.121	0.083
Medium (Single Unit) Trucks	0.132	0.133
Heavy (Combination) Trucks	0.098	0.091

[31] These emission factors were applied to VMT estimates that include both gasoline and diesel vehicles, which is why composite factors are reported.

7.0 Reporting of State-Level Results

The Tool was enhanced to provide detailed reporting of investment plan outcomes in 2032 and 2040 at the state level. The state-level reporting is intended to provide an approximate measure of how the benefits and impacts of a nationwide or multi-state investment program would be distributed if investment were distributed across states in proportion to measures such as vehicle-travel or population. It does not capture any differences in effects that may relate to different characteristics of the states, such as degree of urbanization, transit-intensiveness, population density, vehicle fleet composition, or freight market characteristics. It also does not capture any potential differences in how specific states may choose to allocate funding that they are provided through a national or multi-state clean transportation program.

State-level metrics are provided for the following measures:

- Change in VMT by vehicle type and fuel type (13 total vehicle/fuel type combinations). The change in total VMT for each vehicle/fuel combination was apportioned among states based on the projected share of VMT by vehicle type in each state in 2032 and 2040.
- Change in diesel freight rail ton-miles. The total change was apportioned among states based on the share of heavy-duty truck VMT in each state.
- Change in energy use as a result of efficiency improvements. The total change was apportioned among states based on the share of light-duty VMT in each state.
- Change in PMT. The total change in PMT was apportioned among states based on the projected share of population in each state.
- Change in GHG emissions, petroleum use, and electricity demand. These were calculated based on the state-apportioned changes in VMT and energy using efficiency and carbon content factors as described in Section 3.3.
- Health benefits (safety, physical activity, and air pollution lives saved and value of savings).
  - Safety benefits were calculated based on the apportioned changes in VMT by state and injury and fatality rates per mile as described in Section 6.1.
  - Physical activity benefits were calculated based on total benefits apportioned by the PMT change for each state.
  - Air pollution were calculated based on total benefits apportioned by the change in total VMT for each state.

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Appendix A. Additional Documentation of Assumptions

A.1 Land Use/Smart Growth Program Data

Evaluation data from metropolitan- and state-funded smart growth programs was investigated to estimate funding/incentive costs per new household shifted to a smart growth area, as described below.

Atlanta Regional Commission - Livable Centers Initiative

Program data:

- Planning and transportation project grants to support smart growth in designated “livable centers”.
- $184M in grants awarded 2000-2014.
- $221M total assuming 20% local match.
- 76,000 new housing units in LCI communities (+ 90M square feet commercial).
- **$2,900** per new LCI community housing unit.

Comments on program:

- Investment per new unit is similar to Massachusetts Chapter 40R incentive value to local governments of approximately $3,000 per unit in smart growth districts.
- Atlanta-based estimate is probably low since all new community housing units are counted, not just those influenced by grant funds.

Minneapolis-St. Paul Metro Council - Livable Communities Program

Program data:

- Grants for transit-oriented development (TOD), affordable housing, and contaminated site cleanup for redevelopment since 1996.
- $66M in grants awarded 2014-2017.
- $473M in “other public funds leveraged”.
- 10,810 new housing units created (46% affordable) + 11,600 jobs.
- $6,100 Met Council $ per new housing unit.
- **$49,800** public $ per new housing unit.

Comments on program:

- Not clear what "other public funds leveraged" includes.
- Investment per new unit may be high for purposes of the Tool since some of the program costs cover the affordability component.

California Transit-Oriented Development (TOD) Housing Program

Program data:

- Funds developments within ¼ mile of transit meeting density thresholds and other criteria; affordable housing component.
- $271M in grants awarded 2007-2008.
- 6,158 housing units created.
- **$44,000** per new housing unit.

Comments on program:

- Investment per new unit may be high for purposes of the Tool since some of the program costs cover the affordability component.
- Could not locate more recent program evaluation data.

A.2 Bicycle Investment Assumptions

This section demonstrates how estimates of new annual bicycle-miles of travel (BMT) per new facility-mile are developed and provides sample data illustrating the bicycle investment assumptions and impacts.

There are very few studies that measure or cite impacts in terms of BMT per new facility-mile, but this is the most useful way to connect the policy lever (amount of investment) to VMT and GHG outcomes. Table A.1 shows four independent estimates of new BMT per new facility-mile:

- Line (1) is based on a regression model developed by CS in Los Angeles County, CA relating 2009 American Community Survey (ACS) data on work trips to existing demographic, land use, and infrastructure variables including proximity to existing bicycle facilities (Stinson et al., 2014). It is the most conservative model.
- Line (2) is based on the CS TCI region investment method, documented in CS (2015b), using a method similar to the Moving Cooler study (CS, 2009). This method assumes that with a full build-out of bicycle facilities, bicycle mode shares of up to 10 percent could be achieved in core urban areas, consistent with mode share trends seen in leading U.S. cities and also in European cities (considering differences in economic and cultural factors). Correspondingly lower "build-out" mode shares are found in lower-density areas. The method also assumes a facility density at build-out. The assumed mode shares and facility

densities are shown in Table A.2. The “core” and “high urban” area types are consolidated, as well as the “medium urban” and “suburban” area types.

- Line (3) applies elasticities from the literature to a hypothesized starting and ending density of bike facilities and starting mode share. Buehler & Pucher (2012) report an elasticity of percent change in bike commuters with respect to a percent change in bike lanes of approximately 0.3. At 4.7 person-trips per day and 2.3 miles per trip (per NHTS), and a modest starting grid of bicycle facilities, the resulting change in BMT per new facility-mile is shown.[32] The details of the elasticity calculation are shown in Table A.3.

- Line (4) provides an estimate based on a study of new bike lanes in New York City (Gu, Mohit, and Muenniq, 2016). They find that construction of 45.5 miles of bike lanes has increased the number of bicyclists by 9.950 daily. Applying CS estimates of three days a week per new bicyclist and the NHTS value of 2.3 miles per trip, that equates to 7,140,000 new miles per year, or 157,000 new bike-miles per new facility-mile, which is applied in Table A.1 to the “core/high urban” area type.

Table A.1 Scenarios of New Bicycle-Miles Traveled per New Facility-Mile

	Core/High Urban	Medium Urban/ Suburban	Rural
(1) LA Metro Model	35,000	5,000	200
(2) TCI Region Analysis with “Build-Out” Mode Share Assumptions	146,000	26,000 – 82,000	5,000
(3) Elasticity Approach (Sample Scenario)	151,000	53,000	7,000
(4) New York City study	157,000		

[32] The elasticity approach will give different results depending upon the starting amount of bike facilities. The smaller the starting amount, the larger the percent change, and hence the larger the change in bicyclists per new investment. This is not necessarily consistent with expected real-world impacts, where there may be economies of scale as network effects are realized, at least up to a certain point.

Table A.2 Assumptions for TCI Region Bike Investment Analysis

	Core	High Urban	Medium Urban	Suburban	Rural
Bike Trip Mode Share at Build-Out:					
Now	2.0%	1.5%	1.0%	0.5%	0.5%
At Network Build-Out	10.0%	8.0%	6.0%	2.0%	1.0%
Facility Density at Build-Out (mi/sq mi):					
Bike lane	4.0	4.0	2.0	2.0	0.1
Boulevard			2.0		
Cycle track	2.0	2.0			
Separated path				0.1	0.1
Investment Assumptions:[a]					
% by Place Type:	9%	10%	20%	36%	25%
Expenditure by 2032 ($M) [b]	$218	$250	$470	$860	$591
% of Build-Out Achieved by 2032:	100%	100%	36%	35%	4%
Impacts (2032):					
New bike facility-miles	1,800	2,067	2,785	12,037	1,154
New bike-miles (millions)	215	247	262	139	15
New bike-miles per new facility mile	145,647	145,647	82,113	25,631	5,107

[a]The investment assumptions are for an illustrative scenario with $5.2 billion average annual funding from 2022 – 2032 and a distribution of 4.2% of that funding to bicycle facilities (investment portfolio A). The investment mix by area type is adjusted to cap funding to achieve 100% network build-out for the higher density area types (given the default mix of investment by facility type in each area type).
[b]At 7.5% of annual ~$3 billion in TCI base scenario. Note – facility costs per mile by facility type are $25,000 for bike lanes, $200,000 for bicycle boulevards, $500,000 for cycle tracks, and $750,000 for separated paths.

Table A.3 Sample Elasticity Scenario Applied to a 1-Square Mile Census Tract

	Urban	Suburban	Rural
Population	7,500	2,250	300
Land area (sq mi)	1	1	1
Starting mi bike lanes	1	0.5	0.25
Starting bike mode share	1.7%	1.0%	0.5%
Post-investment mi bike lanes	2	1	1
New bike mode share[a]	2.2%	1.3%	1.0%
Change in cyclists/day	180	32	6
New annual BMT/new lane-mi	150,921	53,266	7,102

[a]Sample calculation for urban area type: Percent change in bike mode share = elasticity * % change in miles of bike lanes = 0.3 * (2 – 1)/1 = 30%. New bike mode share = starting mode share * (1 + % change) = 1.7% * (1 + 0.30) = 2.2%.

Sample bicycle strategy assumptions are shown in Table A.4. The default investment mix by area type is based on population by area type. The default investment mix by facility type is shown, but can also be modified. The new facility miles are based on the illustrative TCI scenario with $5.2 billion average annual funding from 2022 – 2032 and a distribution of 4.2% of that funding to bicycle facilities.[33]

Table A.4 Sample Bicycle Strategy Assumptions

Affected population:	NYC	Core	Urban	Suburban	Rural
% Investment by area type:	12%	11%	20%	36%	21%
% Investment by facility type:			*Enter value:*		
Bike lanes	10%	10%	10%	10%	10%
At-grade protected lanes/bike blvd	20%	20%	20%	20%	0%
Grade-separated protected lanes	50%	50%	50%	0%	0%
Shared use paths	20%	20%	20%	70%	90%
New facility-miles:					
Bike lanes	870	999	1,880	3,439	2,365
At-grade protected lanes/bike blvd	348	400	752	1,376	-
Grade-separated protected lanes	218	250	470	-	-
Shared use paths	44	50	94	602	532
Total	1,479	1,698	3,195	5,417	2,898
Growth in usage - new utilitarian cyclists per day per mile by facility type:					
Facility Type			*Default values:*		
Bike lanes	150	150	80	25	5
At-grade protected lanes/bike blvd	203	203	108	34	-
Grade-separated protected lanes	257	257	137	43	-
Shared use paths	327	327	174	55	11
Prior drive mode share of new bicyclists:	38%	47%	59%	60%	75%

The other assumption in the analysis is the relative effectiveness of different types of bicycle facilities at inducing ridership. Taking bicycle lanes as a starting point, an effectiveness factor of 1.71 was set for separated lanes and 2.18 for shared use paths. These are based on Broach, Gliebe, & Dill (2012), who create a bicycle route choice model developed using observed data from GPS units. The authors find that a 1 percent decrease in travel distance leads to a 5 percent increase in probability of choosing a route (for non-commute travel). They further find that travel on a bike boulevard (used as a proxy here for separated lanes) is equivalent to an 11 percent decrease in distance and travel on a separated path is equivalent to a 16 percent decrease in distance. CS computes the 1.71 factor as $(1 + 0.05)^{11}$ and the 2.18 factor as $(1 + 0.05)^{16}$. The calculated factor for commute trips is considerably larger, so the non-commute factor is used as a more conservative estimate. The effectiveness factor for at-grade protected lanes/bike boulevards is taken as half of the relative effectiveness factor for grade-separated protected bike lanes.

[33] https://www.transportationandclimate.org/sites/default/files/TCI%20Invest-Tool-Documentation_09212020_final.pdf

To derive the estimates of new utilitarian cyclists per day by facility type shown in Table A.4, an annualization factor of 365 and an average trip length of 2.3 miles were used to convert new bike-miles per facility mile into new cyclists per day, and the values were adjusted so the results were in the ballpark of those show in Table A.1, lines (2), (3), and (4). For example, 150 new cyclists per day (bike lanes, NYC, and core area types) is equivalent to about 126,000 new annual bike-miles per facility-mile, while 203 new cyclists per day (protected lanes) is equivalent to about 170,000 new annual bike-miles per facility-mile.

Health Benefits

Health benefits related to physical activity are reported under "other benefits" in the form of lives saved, value statistical lives (VSL) saved, and annual healthcare cost savings. The lives saved and VSL are from analysis using the World Health Organization Health Economic Analysis Tool (HEAT), consistent with reporting in the 2015 report (CS, 2015b).

The healthcare costs savings estimate is based on a value of $0.21 per new mile of bicycling. Gotschi (2011) analyzed three investment plans in Portland, Oregon. Bicycle health benefits are estimated using a per-capita healthcare costs of $544 annually in 2008$ attributable to inactivity (i.e., less than 30 minutes of activity per day), which he derives from three literature sources published in 1987, 1996, and 2001, with values adjusted for inflation. New bicyclists are assumed to realize these benefits by increasing physical activity from 15 to 45 minutes daily. Gotschi's resulting estimates of cumulative bike miles and cumulative healthcare savings between 1991 and 2040 equate to about $0.18 in benefit per additional bike mile of travel. This was inflated to $0.21/mile to account for inflation since the time of study publication.

Other studies have reported higher health benefits per mile. For example, Rabi and de Nazelle (2012) estimate that switching from driving to bicycling for a 5 km one-way commute 230 days per year provides physical activity benefits worth 1,300 euros. Converting to U.S. units this equates to a benefit of about $1.11 per mile of bicycling. However, this study is based on valuation of a life saved, like the HEAT tool provides, which includes more than just healthcare cost savings. The New Zealand Transport Agency's Economic (NZTA) Evaluation Manual (2010) provides a value of $1.92 per mile (converted to 2008 dollars) for improved health and reduced congestion from active transport. About 10 percent of this value is due to congestion reduction, 3 percent to safety, and 87 percent to health, making the health benefit $1.72 per mile. However, a basis for the NZTA estimate could not be located in the source document.

A.3 Transit Investment Assumptions

Prior Mode Share Assumptions

"Prior drive mode share" is defined as the fraction of transit riders (or other modal users, such as bicyclists) who would have driven if the transit option was not available. Single-occupant for-hire services, such as taxi, Uber, and Lyft, are counted as driving since they involve a vehicle-trip that would not otherwise have been taken. Prior drive mode share is a parameter than can vary greatly depending upon the type of transit service and market served. It can be quite low in urban settings with high fractions of zero-vehicle households and good modal options, or it can be quite high for commuter-focused transit services in suburban settings that compete mainly with driving.

One way of estimating prior drive mode share is to assume that transit riders would be distributed among other modes in proportion to the fraction of travelers using those other modes. Prior drive mode share can then be estimated from travel surveys. The 2009 National Household Travel Survey indicates that approximately 60 to 70 percent of trips not taken by transit were taken by driving, considering trips for all purposes. State-level data show modest variation across the Northeast and Mid-Atlantic region; it is 50 percent in the fully urban District of Columbia, about 60 percent in New York State (reflecting the influence of New York City), and close to 70 percent in all other states (Table A.5).

Table A.5 Private Vehicle Trip Share of Non-Transit Trips from 2009 NHTS

State	% Trips by Driving as Share of all Non-Transit Trips
Connecticut	71.4%
Delaware	70.5%
District of Columbia	50.3%
Maine	72.0%
Maryland	68.9%
Massachusetts	68.0%
New Hampshire	71.2%
New Jersey	69.4%
New York	60.3%
Pennsylvania	69.9%
Rhode Island	69.8%
Vermont	71.2%
United States	69.9%

Source: CS analysis of 2009 NHTS. Calculated as total private vehicle trips divided by total person-trips by modes other than transit.

Journey-to-work data from the 2014 ACS (based on five-year 2010-2014 data) was also reviewed to similarly examine the distribution of trips by mode by urbanized area size for UZAs in the Northeast and Mid-Atlantic region. Table A.6 shows the "prior drive mode share" as well as the percent drive alone trips. This information is for commute trips only, so auto mode shares are higher than for all trips. People who worked from home are excluded from the calculations.

Table A.6 Vehicle Commute Trips from 2014 ACS

UZA Size	% Trips by Driving as Share of all Non-Transit Trips[a]	% Trips by Drive Alone
Large (>1 million)	91%	63%
Medium (200,000 – 1 million)	95%	79%
Small (<200,000)	94%	80%
TCI region average	92%	68%
New York metro area	87%	50%

[a]# of driving commuters = drove alone + carpooled/2.3

The 2008 New York City Travel Survey asked respondents about their usual commute mode for work or school. As expected, transit is quite high (57 percent for work trips and 66 percent for school trips). The combined auto drive + taxi share was 24 percent for work trips and 13 percent for work trips. Therefore, for workers who did not use transit, about 57 percent drove (or rode in a hired vehicle). The "drive" share of non-transit trips for both work and school was 54 percent. The data are shown in Table A.7.

Table A.7 Mode Shares from 2008 New York City Travel Survey

Mode	Percent of Work Modes	Percent of School Modes	Work + School Weighted
% of sample	*69%*	*12%*	*81%*
New York City Subway	44.5	49.4	45.2
Auto Driver	23.1	13.1	21.6
New York City Transit Bus or MTA Bus	12.6	16.9	13.2
Walk	9.3	10.6	9.5
Home Work/School	4.2	0.3	3.6
Taxi, Limo, Car Service	1.2	0.2	1.1
Auto Passenger	1.1	0.9	1.1
Bike	1.0	1.9	1.1
All Others	3.0	6.7	3.5
Total	**100.0**	**100.0**	**100.0**
Subway + bus	57.1	66.3	58.5
Auto drive + taxi	24.3	13.3	22.7
Other	18.6	20.4	18.9
(Auto drive + taxi) / all except subway + bus	56.6	39.5	54.1

Source: New York City Travel Survey 2008, Table E5: Usual Commute Modes (Weighted Data)

Some indication of prior drive mode share may also be available from transit rider surveys. Many transit agencies conduct rider surveys, but these rarely include a question on how the traveler would have made the trip if the transit option were not available. Automobile availability may also be used as an indicator of whether the traveler would have driven.

- A 2015 survey of Advance Transit riders in the Hanover/Lebanon area of New Hampshire found that 48 percent said they had no car available. Previous surveys found rates of 47 to 75 percent (dating back to 1999). The 2015 survey data would suggest a 52 percent “prior drive mode share.”

- For specific projects in specific contexts, the prior drive mode share may be much lower. For example, the New York City DOT uses a factor of 20 percent in their capital investment programming analysis (e.g., for the Woodhaven BRT project listed later in this section). This is a project that is replacing high-frequency bus service with premium bus service and serving a population with relatively low auto ownership, and may be drawing riders mainly from existing service.

- Transit Cooperative Research Program (TCRP) Report 107 on commuter benefits looked at surveys of transit benefit recipients that determined which recipients were new riders, vs. which were previous riders. The percent new riders ranged from less than 10 percent to as high as 50 to 60 percent, with east coast cities (Harrisburg, New York, Pittsburgh, Philadelphia) falling in the 15 to 40 percent range. The areas with large existing transit mode share, such as Philadelphia and New York, tended to have the largest share of recipients who were existing transit riders (ICF & CUTR, 2005).

The various available data show a wide range of values that could be used for the "prior drive mode share" parameter. To obtain the default values in the Tool, the prior drive mode share for small UZAs for the transit strategies (or for the suburban area type for bicycling) was set at 60 percent for bus and urban rail transit and bicycling, and 75 percent for commuter and intercity rail. The mode share was then scaled for larger UZAs or for denser area types (including New York City) based on the ratios of drive alone commute percentages from the ACS. For example, the default prior drive mode share for New York City bus riders would be 60% * 50%/80% = 38%.

Bus Service Enhancement

Table A.8 illustrates the sensitivity of the bus service expansion estimates to ridership elasticity and prior drive mode share.

Table A.8 GHG Change (mmt) for $1 Billion Investment in Bus Service Expansion

	Ridership Elasticity							
Prior Drive Modeshare	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
30%	0.072	0.064	0.056	0.047	0.039	0.031	0.023	0.015
40%	0.064	0.053	0.042	0.031	0.020	0.009	-0.002	-0.013
50%	0.056	0.042	0.028	0.015	0.001	-0.013	-0.026	-0.040
60%	0.047	0.031	0.015	-0.002	-0.018	-0.035	-0.051	-0.067
70%	0.039	0.020	0.001	-0.018	-0.037	-0.056	-0.076	-0.095

Table A.9 illustrates the assumptions to estimate the impacts of bus efficiency strategies. Data are from TCRP Synthesis 83 (Danaher, 2010).

Table A.9 Bus Efficiency Strategy Assumptions

Efficiency Strategy	% Travel Time Decrease	Costs - Upfront	Costs - Annual	# Deployed Regionwide[a]
Transit signal priority - intersection improvement	10%	$20,000	$2,000	7,500
Transit signal priority bus upgrades (per bus)	-	$2,000	$200	21,000
Queue jump signal upgrade and restriping (per intersection)	10%	$12,000	$1,200	7,500
Curb extensions (per stop)	7%	$40,000	$4,000	7,500
Stop consolidations (per mile)	5.7%	$5,000	$0	3,700

[a]Quantity deployed at ~$80 million annual average investment

Fixed-Guideway System Investment

Table A.10 presents data on cost, ridership, GHG reductions, and VMT reductions as available for 13 sample Northeast and Mid-Atlantic region projects. Tabled A.11 presents data for 13 BRT projects reviewed, including 11 additional projects from a review conducted in early 2022 to supplement the previous data which had identified only two projects in the TCI region. GHG reductions shown in these tables are reported from the project studies and are shown for comparison. The tool calculates GHG reductions based on VMT changes by mode, to ensure consistency in the application of emission rates across studies.

Transit State of Good Repair

Table A.12 presents data from Northeast and Mid-Atlantic region transit system investment plans and needs assessments. Data from individual systems were averaged to develop average tons of GHG avoided per $million investment and VMT reduction per $million investment by mode.

Table A.10 Northeast & Mid-Atlantic Region Fixed-Guideway Transit Investments

Source	Description	Cost, Capital	Cost, Annualized	project length (mi)	cost/mi (millions)	Change in GHG, tons, annual	annual tons/ annual $MM	Auto VMT change	annual VMT/ cumulative $millions	Source Notes
BRT										
MA - Silver Line Gateway	Diesel hybrid BRT	$ 62,308,800	$ 5,975,414	2.3	$ 27	(381)	64	(1,544,776)	(18,466)	CS analysis for MassDOT CIP; Silver Line SEIS
NY - Woodhaven BRT	Diesel BRT	$ 225,800,000	$ 21,654,220	14	$ 16	(1,001)	46	(490,000)	(1,616)	FTA Small Starts FY2018 Submission
Light/Heavy Rail										
MA - GLX	LRT	$ 2,288,600,000	$ 219,476,740	4.3	$ 532	(33,345)	152	(82,718,400)	(26,921)	CS analysis for MassDOT CIP; GLX EIS
MD - Purple Line	LRT	$ 2,160,000,000	$ 207,144,000	16	$ 135	(38,800)	187	(108,506,667)	(37,416)	CS analysis for Maryland DOT
MD - Red Line	Heavy rail	$ 2,640,000,000	$ 253,176,000	14	$ 189	(13,100)	52	(36,673,000)	(10,347)	CS analysis for Maryland DOT
NY - 2nd Ave Subway	Heavy rail		$ -	This project increases GHG emissions						
Commuter Rail										
MA - South Coast Rail	Diesel commuter rail	3,300,000,000	$ 316,470,000	52	$ 63	(36,485)	115	(78,212,742)	(17,653)	Calculations by CS for FTA, data from EIS
MA - South Station Expansion	Diesel commuter rail	$ 1,600,000,000	$ 153,440,000			(22,290)	145	(40,458,000)	(18,834)	CS analysis for MassDOT CIP
NY - LIRR East Side Access	Electric commuter rail	$ 10,178,000,000	$ 976,070,200			(7,160)	7	(105,500,000)	(7,720)	LIRR ESA FEIS VMT change + CS calculations based on TCI, FTA and eGrid emission factors
MA - DMU Implementation	DMU urban	$ 190,000,317	$ 18,221,030			(481)	26	(3,205,377)	(12,565)	CS analysis for MassDOT CIP
Intercity Rail										
MA/CT - Springfield - New Haven (	Intercity rail	$ 693,000,000	$ 66,458,700	65	$ 11	(25,000)	376	(100,000,000)	(107,478)	http://www.nhhsrail.com/benefits/
MA/CT/VT - Vermonter	Intercity rail	$ 25,000,000	$ 2,397,500	30	$ 1	(46)	19	(305,274)	(9,095)	CS analysis for MassDOT CIP
NEC - Preferred Alternative	Intercity rail	$ 125,000,000,000	$ 11,987,500,000	200 (est)	$ 625	(750,000)	63			NEC FEIS

Table A.11 U.S. Bus Rapid Transit Investments

Source	Description	Cost, Capital	Cost, Annualized	ΔGHG, tons, annual	$/tonne (midpoint)	annual tons/ capital $ (millions)	Auto VMT change	Transit bus VMT change - Diesel/ hybrid / CNG	Transit bus VMT change - Electric	Ratio, bus / auto VMT change	annual VMT/ capital $mm	annual VMT/ cumulative $millions	Source Notes
MA - Silver Line Gateway	Diesel hybrid BRT	$ 62,308,800	$ 5,975,414	(381)	$ 15,684	6	(1,544,776)				0.025	(18,466)	CS analysis for MassDOT CIP; Silver Line SEIS
NY - Woodhaven BRT	Diesel BRT	$ 225,800,000	$ 21,654,220	(1,001)	$ 21,633	4	(490,000)	(223,000)		0.46	0.002	(1,616)	FTA Small Starts FY2018 Submission
TX - Austin Expo Center	Electric BRT	$ 46,400,000	$ 4,449,760	(1,331)	$ 3,343	29	(1,825,000)		785,000	(0.43)	0.039	(29,295)	FTA Small Starts FY2023 Submission
TX - Austin Pleasant Valley	Electric BRT	$ 50,500,000	$ 4,842,950	(1,684)	$ 2,876	33	(2,160,000)		965,000	(0.45)	0.043	(31,858)	FTA Small Starts FY2023 Submission
MN - Metro Gold Line	Diesel & hybrid BRT	$ 477,200,000	$ 45,763,480	(3,286)	$ 13,927	7	(4,103,000)	2,308,000		(0.56)	0.009	(6,404)	FTA Small Starts FY2023 Submission
PA - Pittsburgh DUO	Electric BRT	$ 234,600,000	$ 22,498,140	(2,013)	$ 11,176	9	(623,000)	734,000		(1.18)	0.003	(1,978)	FTA Small Starts FY2023 Submission
SC - Low Country Rapid Transit	Diesel BRT	$ 522,400,000	$ 50,098,160	(1,161)	$ 43,151	2	(2,178,000)	(565,000)	1,430,000	(0.40)	0.004	(3,105)	FTA Small Starts FY2023 Submission
UT - Mid-Valley Connector	Electric BRT	$ 106,300,000	$ 10,194,170	(9,227)	$ 1,105	87	(547,000)	(396,000)	350,000	0.08	0.005	(3,833)	FTA Small Starts FY2023 Submission
WA - Seattle RapidRide J Line	Electric Trolley BRT	$ 107,400,000	$ 10,299,660	(135)	$ 76,294	1	(528,000)		50,000	(0.09)	0.005	(3,662)	FTA Small Starts FY2022 Submission
WA - Seattle Madison Street BRT	Electric Trolley BRT	$ 59,900,000	$ 5,744,410	(350)	$ 16,413	6	(1,198,000)	136,000	(18,000)	(0.10)	0.020	(14,896)	FTA Small Starts FY2021 Submission
CA - San Bernardino West Valley Connector	CNG & Electric BRT	$ 246,000,000	$ 23,591,400	(1,298)	$ 18,175	5	(1,887,000)	126,000	659,000	(0.42)	0.008	(5,713)	FTA Small Starts FY2022 Submission
WI - Milwaukee East-West BRT	Electric BRT	$ 51,000,000	$ 4,890,900	(644)	$ 7,595	13	(567,000)	(619,000)	583,000	0.06	0.011	(8,281)	FTA Small Starts FY2022 Submission
MN - Rochester Rapid Transit	Electric BRT	$ 100,800,000	$ 9,666,720	(724)	$ 13,352	7	(1,348,000)	3,799	242,000	(0.18)	0.013	(9,961)	FTA Small Starts FY2022 Submission
BRT Average		**$ 176,200,677**	**$ 16,897,645**	**(1,787)**	**$ 9,454**	**10**	**(1,461,444)**	**167,200**	**560,667**	**(0.27)**	**0.008**	**(6,178)**	

Table A.12 Northeast & Mid-Atlantic Region Transit System Investment Needs Assessments

	MTA (All)	MTA Bus	Metro-North	LIRR	NYC Transit	WMATA	WMATA - Momentum	WMATA - 10-yr CIN	MBTA	MBTA - Bus	MBTA - LR/HR	MBTA - CR	SEPTA	NJ Transit	RIPTA (bus)
Source	MTA 2015-2034 Capital Needs Assessment	MTA 2015-2034 Capital Needs Assessment	MTA 2015-2034 Capital Needs Assessment	MTA 2015-2034 Capital Needs Assessment	MTA 2015-2034 Capital Needs Assessment	Metro Forward	Momentum - Strategic Plan 2013-2025	Capital Needs Inventory & Prioritization, 2017-2026	2015-2019 Capital Investment Program	2015-2019 Capital Investment Program	2015-2019 Capital Investment Program	2015-2019 Capital Investment Program	FY2017-2028 Capital Program Proposal in FY2017 Budget	FY2016-2020 TRANSPORTATION CAPITAL PLAN	FY2017-FY2022 Capital Improvement Plan
Dominant mode		Bus	CR	CR	HR	HR	HR	HR		Bus	HR	CR			Bus
Investment needs over X year period ($billions)	$ 105.00	$ 2.50	$ 8.90	$ 15.00	$ 68.00	$ 5.00	$ 5.50	$ 17.00	$ 4.20	$ 0.38	$ 1.93	$ 0.84	$ 7.30	13.8	0.116
period X (years)	20	20	20	20	20	6	12	10	5	5	5	5	12	10	6
million annualized investment	$ 5,250	$ 125	$ 445	$ 750	$ 3,400	$ 833	$ 458	$ 1,700	$ 840	$ 76	$ 386	$ 168	$ 608	$ 1,380	$ 19
Total annual ridership in billions of trips	3.756	0.125	0.086	0.099	3.446	0.407	0.450	0.407	0.406	0.134	0.237	0.033	0.344	0.277	0.018
Total annual pax-mi (billions)	17.610	0.371	2.340	2.220	12.679	2.032	2.247	2.032	1.776	0.335	0.734	0.678	1.530	3.402	0.085
Assumed ridership loss by 2032 from failure to invest	26%	50%	25%	25%	25%	25%	25%	25%	33%	50%	25%	25%	25%	25%	50%
Number of trips lost (billions)	0.970	0.063	0.022	0.025	0.862	0.102	0.113	0.102	0.135	0.067	0.059	0.008	0.086	0.069	0.009
Average trip length (mi)	4.7	3.0	27.2	22.4	3.7	5.0	5.0	5.0	4.4	2.5	3.1	20.5	4.4	12.3	4.7
Vehicle mode share for lost riders	41%	46%	51%	51%	41%	41%	41%	41%	43%	46%	41%	51%	51%	51%	46%
Increased annual VMT from lost riders (billions)	1.900	0.085	0.296	0.280	1.286	0.206	0.228	0.206	0.255	0.076	0.074	0.086	0.193	0.430	0.019
kg/mi GHG (core place type, 2030)	0.293	0.293	0.293	0.293	0.293	0.293	0.293	0.293	0.293	0.293	0.293	0.293	0.293	0.293	0.293
Increased annual VMT from lost riders (billions)	1.876	0.085	0.296	0.280	1.286	0.206	0.228	0.206	0.255	0.076	0.074	0.086	0.193	0.430	0.019
added kg GHG (billions) = added tons GHG (millions) = added mmt GHG	0.550	0.025	0.087	0.082	0.377	0.060	0.067	0.060	0.075	0.022	0.022	0.025	0.057	0.126	0.006
tons GHG avoided per $million annual investment	105	198	195	110	111	72	146	36	89	296	56	149	93	91	293
million auto VMT avoided per $million annual investment	0.4	0.7	0.7	0.4	0.4	0.2	0.5	0.1	0.3	1.0	0.2	0.5	0.3	0.3	1.0
million auto VMT avoided per $million cumulative investment		0.06	0.06	0.03	0.03	0.02	0.05	0.01	0.03	0.09	0.02	0.05	0.03	0.03	0.09

A.4 Freight Intermodal Data

Table A.13 shows the freight intermodal project data used to inform the cost-effectiveness estimates for this strategy. The top two rows are data from national studies. The remaining rows include state studies and project-specific examples.

Table A.13 Freight Intermodal Cost-effectiveness Data

Source	Ref	Description	Cost, Capital	Change in GHG, tons, annual	$/tonne (range)	$/tonne (midpoint)	annual tons/ capital $ (millions)	Truck VMT change (millions)	Rail ton-mi change (millions)	annual trk VMT/ capital $ (millions)	annual rail ton-mi/ capital $ (millions)
USDOT Report to Congress	(1)	Intermodal infrastructure			$80 - $200	$ 140	500				
Moving Cooler	(2)	Rail capacity			$450 - $500	$ 500	140				
MA - State Freight Plan	(3)	4 sets of freight rail investments	$ 692,000,000	(8,000)		$ 6,055	12				
CT DEEP - Freight Air Quality Plan	(4)	Rail/intermodal improvements	$ 2,000,000,000	(83,000)		$ 1,687	42	(39)		(19,500)	
NY - Arlington Intermodal Yard	(5)	capacity improvements to a rail yard	$ 9,000,000	(52,909)		$ 12	5,879	(37)		(4,059,987)	
PA - Norfolk Southern Rail Ext & Rehab	(5)	track extension	$ 12,500,000	(755)		$ 1,158	60	(1)		(41,739)	
PA - Westmoreland intermodal	(5)	New facility	$ 9,500,000	(405)		$ 1,640	43	(0)		(29,474)	
MAROps priority investment	(6)	5-state (Mid-Atlantic) rail improvements	$ 6,000,000,000	(6,990,687)		$ 60	1,165	(3,585)	50,937	(597,500)	8,489,500
Use this value:							**140**			**72,000**	**1,021,000**

References: (1) U.S. DOT, 2010. (2) CS, 2009. (3) MassDOT, 2010. (4) de la Torre Klausmeier Consulting, ERG, and CS, 2013. (5) Grant et al., 2008. (6) I-95 Corridor Coalition, 2009.