Transportation and Climate Initiative - 2019/2020 TCI Investment Strategy Tool Documentation

prepared for

Georgetown Climate Center

prepared by

Cambridge Systematics, Inc.

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Executive Summary

Overview of Tool

This document describes the key methods and assumptions embedded in the Transportation and Climate Initiative (TCI) Investment Strategy Tool[1] and how the tool was used in the 2019/2020 analysis for TCI. This tool is a Microsoft Excel workbook developed to help participating TCI jurisdictions understand the changes to vehicle-miles of travel (VMT) and other outcomes that could result from state investments of cap-and-invest program proceeds into a wide range of 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.

The tool takes inputs in the form of investments (expressed in dollar values) for clean 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 air pollution, safety, physical activity, and related health benefits.

The tool is also capable of estimating greenhouse gas (GHG) emission reductions, but in the 2019/2020 application described in this document, all GHG reductions were estimated using a version of the National Energy Modeling System (NEMS) – modified for TCI (TCI-NEMS) – based on changes in VMT and fuel consumption output from the tool.

The TCI Investment Strategy Tool is intended for region-wide or state-level, programmatic-level analysis of investment across various clean transportation strategies. It is not intended for detailed, project-level analysis.

Other Tools Used For TCI

The TCI Investment Strategy Tool is part of a suite of tools applied to obtain a comprehensive understanding of the benefits and impacts of cap-and-invest programs for the transportation sector. It is used in conjunction with TCI-NEMS to understand the travel and GHG reductions and carbon allowance prices corresponding to a particular GHG emissions cap. (NEMS is the model on which the U.S. Department of Energy's Annual Energy Outlook is based.)

The TCI jurisdictions are using TCI-NEMS, an integrated energy system model, to understand how key regional program design elements could affect the broader energy system, including changes in energy supply, demand, imports, prices, and technology, including vehicle electrification. In particular, outputs from TCI-NEMS policy scenarios inform state decisions regarding program ambition, i.e., the appropriate level for a regional cap on carbon emissions from on-road fuels in the transportation sector.

[1] The document specifically describes Investment Strategy Tool version 2.3, October 2019.

An important benefit of using an integrated energy system model such as NEMS is that it provides results that 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 light-duty, medium-duty, and heavy-duty vehicles, TCI-NEMS provides information about increases in electricity demand and other changes in the electric sector. OnLocation has enhanced the current model structure to improve its ability to represent the TCI region and to analyze potential regional caps covering emissions from on-road gasoline and diesel combustion. Where necessary, OnLocation has also adjusted VMT assumptions in TCI-NEMS to reflect specific policies (e.g., mass transit) modeled by Cambridge Systematics (CS) with the TCI Investment Strategy Tool.

To explore the potential implications of different TCI policy options, modeling and analysis has compared outcomes under policy cases—with declining emissions caps and associated investments in low-carbon transportation—against a TCI Reference Case, in which federal and state policies currently in effect are assumed to remain in place, but there is no emissions cap or associated investments. This Reference Case reflects a variety of assumptions about how energy markets, technology costs, federal and state regulatory requirements, and other factors are likely to change under "business as usual." The policy cases represent options for the design of the emissions cap, including its initial level and the rate at which it declines over time. Policy cases have been modeled with "investment portfolios," which represent illustrative portfolios of low-carbon transportation investment strategies that TCI jurisdictions may pursue with the proceeds generated through the sale of emissions allowances. In addition, several additional analyses may be undertaken to explore the sensitivity of the model to various reference and policy case assumptions.

The TCI-NEMS modeling for TCI follows the Energy Information Administration's 2018 Annual Energy Outlook (AEO) for a number of assumptions about fuel prices, technology costs, economic and population growth, and other factors. As with AEO 2018, the TCI Reference Case also assumes that current federal vehicle emissions standards will remain in place through 2025. To ensure that the modeling reflects current policies and the technology outlook of TCI jurisdictions, the TCI Reference Case includes several assumptions that differ from those of AEO 2018. These include different electric vehicle technology costs and EV model introduction years, projections of VMT based on state estimates, electric power sector assumptions based on the most recent Regional Greenhouse Gas Initiative (RGGI) modeling, and other assumptions.[2]

The policy cases start with the assumptions from the Reference Case discussed above and then add different potential cap levels and illustrative investment portfolios (discussed below). In the policy scenarios, the TCI-NEMS model treats the cap level as an emissions constraint, and calculates an emissions price that results in emission reductions to the level specified by the cap. TCI-NEMS also contains built-in assumptions about the costs of emissions reduction strategies (e.g. the incremental cost of light-duty electric vehicles), relevant technology constraints (e.g., need for EV charging infrastructure), consumer behavior (e.g., preferences among vehicle classes and responses to price changes), and other relevant variables. Allowance prices calculated by TCI-NEMS will reflect the combined effect of the emissions constraint and these specified assumptions.[3]

[2] To learn more about TCI Reference Case assumptions: https://www.transportationandclimate.org/tci-webinar-reference-case-results

[3] https://www.transportationandclimate.org/modeling-methods-and-results

The TCI Investment Strategy Tool is also 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 cap-and-invest program.

For example, Cambridge Systematics has run the Regional Economics Models, Inc. (REMI) model to estimate the economic implications of a regional cap-and-invest program. The REMI model uses capital expenditures, fuel expenditures, and other types of outputs from TCI-NEMS and the Cambridge Systematics TCI Investment Strategy Tool as inputs to estimate macroeconomic impacts of different policy scenarios. The REMI model has provided estimates of changes in jobs, income, and gross domestic product (GDP) that could result from analyzed regional policy scenarios.[4]

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. A multi-university team led by researchers at the Center for Climate, Health, and the Global Environment at the Harvard T.H. Chan School of Public Health (Harvard C-CHANGE), is using outputs from TCI-NEMS and the TCI Investment Strategy Tool to estimate changes in criteria pollutant emissions and increases in active transportation. The research team is analyzing the health benefits from changes in air quality and active mobility under the illustrative TCI scenarios. . Results from their analysis will include maps of estimated air quality changes at a 12x12 kilometer scale and estimated active mobility and air quality-related health outcomes at the county scale for the full TCI region..[5]

Baseline Data

Baseline data are included in the investment tool for population, VMT, vehicle fleet 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) and to downscale regional and state level results to the county level. County level data are used by research partners to conduct more detailed health and incidence analysis.
- VMT projections by state and county, for five vehicle types, were developed based on available VMT data and forecasts provided by the states. 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, and vehicle sales and stock are taken from the TCI-NEMS model as run by OnLocation.

Key Strategy Assumptions

The tool takes an overall dollar value of investment (based on the anticipated annual revenues from the auction of carbon allowances beginning in 2022) across a portfolio of clean transportation strategies (in accordance with illustrative investment portfolios (See Appendix A) formulated by TCI jurisdiction staff) to develop a program of investment (billions of dollars) by strategy and year, for the period 2022 through 2032.

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[4] https://www.transportationandclimate.org/modeling-methods-and-results

[5] Find out more about the Transportation, Equity, Climate, and Health Study (TRECH Study): https://hsph.me/TRECH

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 both light and medium/heavy-duty vehicles (trucks and buses).

  - The effects of light-duty EV consumer incentives are 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 medium and heavy-duty vehicles, including electric medium trucks and buses, natural gas and hydrogen-heavy trucks, 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 Annual Energy Outlook/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 from TCI region 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, and travel demand management.

  - A variety of data and methods are used to estimate the benefits and impacts of these strategies per dollar spent, including studies of specific projects and programs from within the TCI region, as well as national studies.

  - 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), and highway preservation. 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, especially projects within the TCI region, are also considered. Benefits per dollar are applied to TCI region 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.

- **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 TCI region. 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 TCI 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.

Economic Impacts

The regionwide economic benefits of clean transportation investment were analyzed using outputs from the TCI tool that were fed into the Regional Economic Models, Inc. (REMI) Policy Insight (PI+) model. Inputs from the TCI tool include costs incurred and cost savings by user group (businesses, consumers, and government). Benefits are reported in terms of jobs, gross regional product, and personal disposable income. 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. The following cost changes are considered:

- Travel time savings accruing to businesses due to reductions in congestion and delay are monetized for truckers, other commercial vehicle operators, and other “on-the-clock” travel. Travel time savings resulting from system efficiency strategies are estimated based on studies of the relationships between operational improvements and traveler delay. VMT reduction strategies are also estimated to reduce congestion, based on relationships between VMT and congestion from national studies. Travel time savings are considered as business productivity benefits. Personal travel time savings for off-the-clock-travel are not included in the economic analysis.

- Savings in fuel and vehicle maintenance are estimated based on VMT changes (costs per mile by vehicle type). Shipping cost savings are estimated for truck-rail mode shift strategies based on average shipping costs by mode.

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

- New government sector spending on investment in transportation infrastructure and services is considered, as made possible by the new funding mechanisms.

- Changes in consumer spending on non-transportation goods and services are estimated. Consumers will pay more per VMT due to the costs of fuel (associated with the price of carbon emission allowances) and 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.

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.

- 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 monetized and also translated into health outcomes based on information contained in U.S. EPA rulemakings for light and heavy-duty GHG/fuel efficiency standards.

1.0 Overview of Tool

1.1 Tool Purpose

The Transportation and Climate Initiative (TCI) Investment Strategy Tool is a Microsoft Excel workbook developed to help participating TCI jurisdictions understand the changes to vehicle-miles of travel (VMT) and other outcomes that could result from state investments of cap-and-invest program proceeds into a wide range of 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 strategies;
- 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 clean transportation 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 air pollution, safety, physical activity, and related health benefits.

The tool is also capable of estimating GHG emission reductions, but in the 2019/2020 application described in this document, all GHG reductions were estimated using a modified version of the National Energy Modeling System (TCI-NEMS) based on changes in VMT and fuel consumption output from the tool.

The tool is intended for region-wide or state-level, programmatic-level analysis of investment across various clean transportation strategies. It 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.

1.2 Relationship to Other TCI Analysis Tools

The TCI Investment Strategy Tool is part of a suite of tools applied to obtain a comprehensive understanding of the benefits and impacts of cap-and-invest programs for the transportation sector. The tool has been developed and updated by Cambridge Systematics, Inc. (CS) under contract to the Georgetown Climate

Center of Georgetown University. The relationships among these tools are illustrated in Figure 1.1. Key relationships between the Investment Strategy Tool and other tools are described below.

- The **National Energy Modeling System (NEMS)** is an economic and energy model of U.S. energy markets created at the U.S. Energy Information Administration. OnLocation developed a modified version of NEMS for use by TCI (i.e., TCI-NEMS). For policy case modeling runs, the Investment Strategy Tool is designed to be used iteratively with TCI-NEMS. The first step was to modify assumptions used by EIA for Annual Energy Outlook (AEO) 2018 to develop a TCI Reference Case of projected future emissions. Policy scenarios were then defined by simulating a policy that caps carbon dioxide emissions from the combustion of gasoline and diesel fuels. TCI-NEMS was used to estimate the carbon price resulting from the cap defined for a given scenario. TCI-NEMS was also used to estimate VMT changes as a result of the carbon price, as well as the effects of electric vehicle (EV) consumer incentives on EV uptake, VMT, fuel consumption, and emissions. The Investment Strategy Tool was used to allocate proceeds from the auction of carbon emission allowances under the regional cap to specific strategies and estimate the changes in VMT resulting from those investments, as well as changes in medium and heavy-duty truck and bus fuel consumption. These changes were then fed back into TCI-NEMS, affecting carbon emissions and the resulting carbon price, which affected the level of investment. The tools were iterated a few times until close to equilibrium was reached. The TCI-NEMS modeling was performed by OnLocation, who also used the Investment Strategy Tool to support iteration.

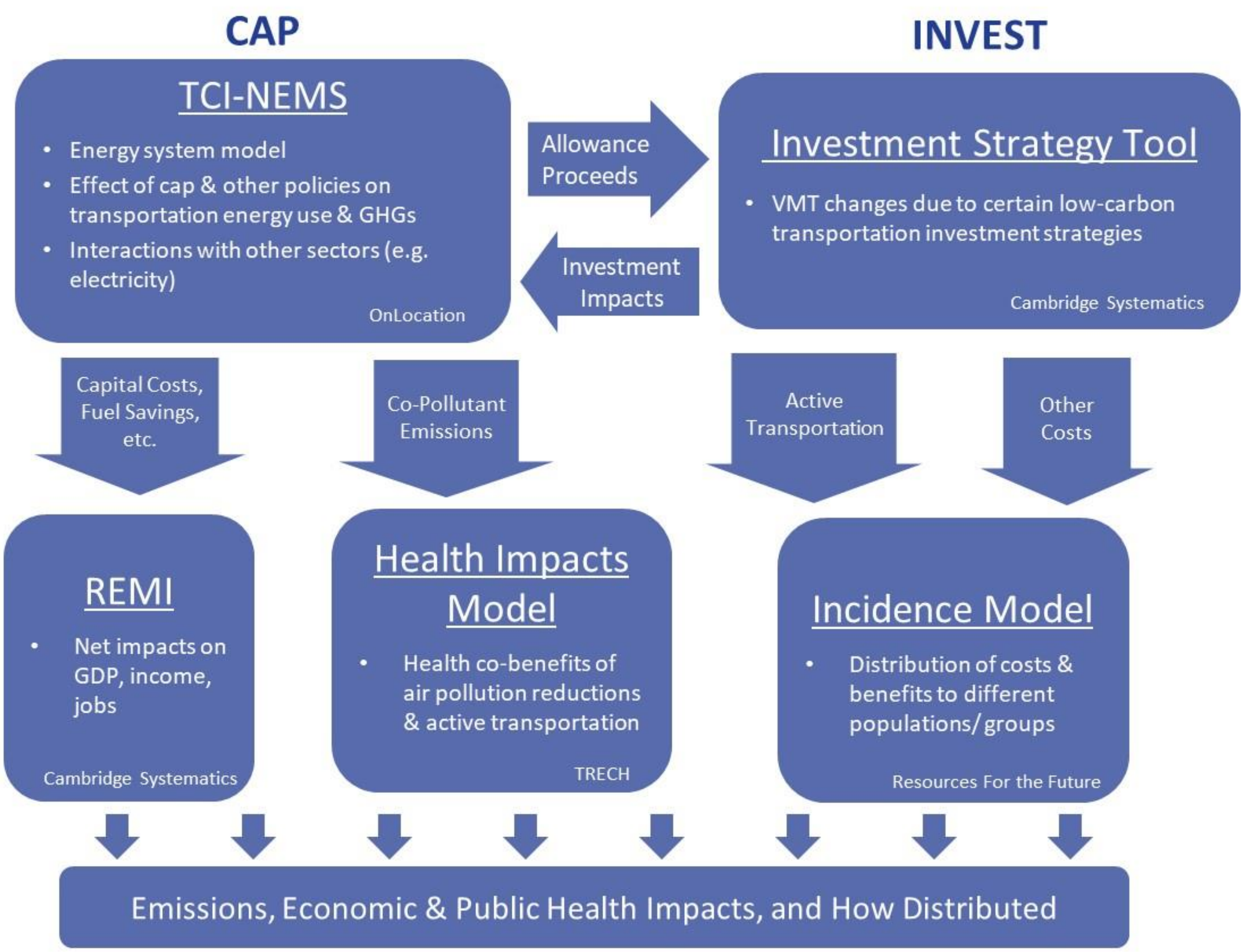
  Cambridge Systematics provided OnLocation with three different file versions of the investment tool that represent the three different investment portfolios being modeled (i.e., investment portfolios A, B and C).

  An initial level of investments are input into the tool based on an expectation of the proceeds that will be generated by a given emissions cap. Based on those investments, the tool calculates the percentage VMT reductions each year for light-duty vehicles, medium-duty trucks, heavy-duty trucks, and buses that are passed back to TCI-NEMS and applied to the model's internally computed VMT projections. The changes in diesel fuel consumption due to truck and bus electrification and alternative fuels are also supplied by the tool, as are changes in fuel consumption related to system efficiency strategies. These changes are subtracted from the TCI-NEMS fuel consumption. Information on the annual expenditures for EV subsidies from 2022 to 2032 are also used as a guide to set the TCI-NEMS EV subsidy amounts.

  Once TCI-NEMS is run with the impacts of a specific investment level, the total proceeds generated by TCI-NEMS are compared to the amount invested for that portfolio. If TCI-NEMS proceeds are below or above the amount invested, a revised total level of investment is input into the Investment Strategy Tool to compute new VMT and reductions in fuel consumption by trucks. In addition, the total EV subsidy expenditures projected by TCI-NEMS are compared to the investment tool target for EV subsidies. The subsidy level is adjusted for the next run if they differ by more than roughly 5 percent. This iteration of altering investment levels and EV subsidies continues until the TCI-NEMS total proceeds roughly matches the amount invested in the Investment Strategy Tool cumulatively over the policy period 2022 to 2032.

- The **Regional Economic Models, Inc. (REMI**) model is a dynamic economic simulation model. For this project, the model was set up with data from each of the 12 TCI states plus the District of Columbia, along with the rest of the U.S. REMI measures the flow of money throughout the economy. Inputs from the TCI tool include costs incurred and cost savings by user group (businesses, consumers, and government). The economic analysis is described in more detail in Section 1.0 of this document.

Figure 1.1 Tools to Evaluate Cap-and-Invest for Transportation



- A set of **health impacts models** was developed by researchers from the Harvard School of Public Health, Boston University, and University of North Carolina**.** Air quality models take outputs of changes in vehicle travel and vehicle populations from the Investment Strategy Tool and translate them into changes in air pollutant emissions, exposure, and resulting health outcomes. Separate models take changes in physical activity (person-miles of travel for walking and biking) from the tool and translate them into health outcomes.
- An **incidence model** was developed by Resources for the Future that indicates how different investments and outcomes will affect different population groups. The Investment Strategy Tool provides outputs of changes in VMT by county and changes in consumer costs that are used as inputs to the incidence models. Some REMI outputs are also used for the incidence modeling.

2.0 Description of Strategies

Table 2.1 provides a brief description of the clean transportation investment strategies modeled in the TCI Investment Strategy Tool version 2.3.

Table 2.1 Clean Transportation Strategies

Strategy	Description
EV/alternative fuel incentives	
Light-duty EV's	Consumer incentives to purchase full battery electric (BEV) and plug-in hybrid electric (PHEV) light-duty vehicles. (Note – effectiveness modeled in NEMS in the 2019/2020 analysis, with results passed through to the Investment Strategy Tool.)
CNG trucks	Incentives (rebates, cost discounts, tax credits, etc.) for heavy-duty truck fleet operators or owner/operators to purchase new trucks powered by compressed natural gas (CNG) or retrofit existing trucks. Incentives may include rebates for the vehicle itself and/or subsidies for needed refueling 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 - MDT/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.
Hydrogen trucks - long-haul	Incentives (rebates, cost discounts, tax credits, etc.) for heavy-duty truck (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.
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.

Strategy	Description
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.
Urban & intercity transit	
Bus rapid transit	Construction and operation of new bus rapid transit services, including infrastructure, vehicles, 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.
Transit fare reduction	Reduced public transit fares.
Transit state of good repair	

Strategy	Description
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.
Indirect (non-GHG reducing)	Money that is returned directly to consumers (e.g., tax refunds) in ways that do not directly reduce transportation GHG emissions.

3.0 Baseline Data

Baseline data are included in the tool for population and VMT.

3.1 Population

Population forecasts are used in the land use/smart growth strategy to assist the user in determining an appropriate shift in population among area types. They are also used for downscaling pedestrian and bicycle investment impacts to the county level.

Base year population data by state for 2014 are from the U.S. Bureau of the Census.[6] State level forecasts for 2020, 2030, and 2040 are mainly taken from state-specific forecasts compiled by the Weldon Cooper Center for Public Service, Demographics Research Group, as of December 2018.[7] 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, and to support downscaling of outputs to the county level. The default area type distributions by state were developed from the 2014 American Community Survey (ACS) five-year population estimates at the census tract level (2010-2014) for the 2017 version of the tool. Updated estimates of population by area type at the county level were developed from 2017 ACS data as described in Section 4.1.

3.2 Vehicle-Miles of Travel

VMT baseline estimates for 2017 and forecasts for 2020, 2030, and 2040 were obtained from states as available at the state and county level. VMT forecasts were obtained by vehicle type. The vehicle types varied by state and were standardized into five types for use in the tool:

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

For states that did not forecast through 2040, 2020 and 2030 forecasts or historical trendlines were extrapolated.

[6] https://www2.census.gov/programs-surveys/popest/tables/2010-2018/state/totals/nst-est2018-01.xlsx

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

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 (UZA) types used for classifying systems in the National Transit Database (NTD). The analysis is built on NTD data for TCI 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 2030 million dollars spent annually between now and 2030. 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 Vehicles

The effects of light-duty electric vehicle consumer incentives for the TCI 2019/2020 analysis was modeled using NEMS. NEMS reports the following output for each scenario modeled, as well as the Reference Case, which is pulled into the tool for the purpose of developing economic impacts:

- Light-duty vehicle sales for EV and PHEV.
- Light-duty vehicle stock for EV and PHEV.
- Light-duty VMT for EV and PHEV.
- Purchase value of cars and light trucks.

- Cumulative light-duty EV subsidy provided.

4.2.2 Alternative Fuel Medium- and Heavy-Duty Vehicles

Five classes of alternative fuel vehicles are included in the tool: (1) electric transit buses; (2) electric school buses; (3) electric medium-duty trucks; (4) hydrogen fuel cell electric vehicle (H2 FCEV) long-haul heavy-duty trucks; and (5) commuter rail electrification. Truck electrification was limited to the medium-duty/short-haul sector 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 4.2, measured in miles per gallons gasoline-equivalent (MPGGE). Future year efficiencies are increased in proportion to AEO MPG forecast for trucks.

Table 4.2 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 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 4.3 shows the energy efficiency ratio (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 4.3 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). Recommended EERs are slightly lower than shown in CARB data to account for cold-climate inefficiencies.
Electric school bus	3.5	
Electric truck - MDT/urban	3.5	
H2 FCEV truck – Class 8 long-haul	1.5	Hunter (2018) shows H2-FCEV MPGGE of 10 v. 7 for diesel.

Vehicle Type	EER	Source/Notes
Passenger rail	2.3	CS (2019), based on previous analysis of National Transit Database energy consumption for diesel and electric commuter rail systems.

Table 4.4 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 of 2020 and 2025 are also estimated.

Table 4.4 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).
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 4.5 shows the estimated annual maintenance cost savings compared to an internal combustion engine vehicle.

Table 4.5 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).
	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).
CNG or 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 4.6 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 4.6 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).

[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).

[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
Electric school bus	**$ 40,000 – 2022** **$ 25,000 – 2032**	Add 100% to MDT charger cost for installation costs and infrastructure upgrades.
	$ 20,000	MDT charger (Wood et al. 2017, rough midpoint of a range cited).
	$ 25,000	Plus $125-175k equipment and systems per site in 2015 (lower cost today) – VEIC (2018).
Electric truck - MDT/urban	$ 25,000	Wood et al. (2017). Range of $9k – $35k depending on rate of tech advancement.
CNG truck – Class 8 long-haul	$ 6,900	Smith & Gonzales, 2014: $1.2-1.8M for large, fast-fill station (avg. $1.5M) dispensing 1,500 – 2,000 GGE/day (avg. 1,750), at 16 GGE/day/truck (CS calculations based on average annual miles and MPG of a CNG truck) = 109 trucks served/day. 50% of cost assumed to be covered with incentive based on common state practice (e.g., MD caps alt fuel infra grants at 50% of costs, up to $500k for NG station). $750,000 / 109 = $6,900.
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 4.7 shows the average annual miles driven per year per vehicle. With the new turnover models introduced in tool v2.3, 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 4.7 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).

[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.

Vehicle Type	Miles per Vehicle[a]	Source/Notes
	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).
Class 8 long-haul truck (CNG or H2 FCEV)	**41,628**	VISION model (v. 2019) average across all vehicle ages for Class 7-8 trucks.
	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.

Table 4.8 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 4.8 Fuel Costs (Per GGE)

Fuel Type	Cost – 2022	Cost - 2032	Source/Notes
Gasoline	$ 3.03	$ 3.42	AEO 2019 Reference Case.
Diesel	$ 3.31	$ 3.85	AEO 2019 Reference Case.
Electricity	$ 7.70	$ 6.00	2022: 80% higher than AEO market rate; 2032: 40% higher than AEO market rate, to account for demand charges, per scenarios shown in Figure 9 of Hanlin (2018) & VEIC (2018).
	12.6 c/kwh = $ 4.28 /gge	13.4 c/kwh = $4.55 /gge	AEO 2019 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.
Hydrogen from natural gas steam reformation	$ 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	$ 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 4.9 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 4.9 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	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. (Assumptions beyond 11 years are irrelevant for the current 2022-2032 analysis period.)

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, 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.[11]
- 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 for 2032 are applied to the VMT change per dollar in this analysis.
- Administrative costs were estimated at $0.01 per transaction/trip.

4.3.2 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

- Updated 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.[12] Findings are

[11] 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.

[12] 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

shown in Appendix B, Section B.1. Based on the program reviews, along with the Massachusetts incentives program information, 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 TCI (CS, 2015a). Here, the “medium urban” and “suburban” area types are combined into the suburban area type.

- Illustrative assumptions for the TCI region are shown in Table 4.10. In this example, about 304,000 people are shifted at the average funding level of $217 million a year and $25,000 per 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 4.10 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%

4.3.3 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 a user-input 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 projections used in the 2019/2020 TCI analysis equate to 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 B, Section B.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 B, Section B.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.

4.3.4 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 4.11.

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

Table 4.11 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 B, Section B.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.

4.3.5 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,[13] and evaluations of Metro Washington Council of Governments' Commuter Connections program.[14]

- A reduced cost-effectiveness of 500 tons/$million (~$2,000/ton) is assumed for spending above the user-specified level. This level was set at $77 million in the 2019/2020 TCI analysis, representing a maximum estimated spending on employer outreach programs, based on a build-up of $5 million per large metro area (the approximate annual budget for the DC Commute Connections program) and $3.5 million per state (covering medium and small metro areas and non-metro 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.[15] 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).

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

[14] 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.

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

- 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)[16] - $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

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), and highway preservation.

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.

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.[17]

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

[17] 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

- 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 0.52 gallons fuel saved per hour of delay saved from Texas A&M Transportation Institute (TTI) 2012 Urban Mobility Report (UMR) adjusted to future year values (0.32 gallons fuel saved per hour of delay saved or 0.0030 tons CO_2/hour of delay saved in 2032) based on the ratio of evaluation year to 2012 average fuel economy and 2012 GHG emission factors as developed in the 2015 TCI region GHG inventory and forecast (CS, 2015a).
- 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:
  - 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 4.12 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.

Table 4.12 Estimates of System Efficiency Cost Effectiveness

Source	Description	Cost, Capital	∆GHG, 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	

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.

Source	Description	Cost, Capital	ΔGHG, tons, annual	(annual) $/ (annual) ton	annual tons/ annual $ (millions)	Timeframe
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 TCI 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 was used in the 2019/2020 TCI analysis.

Key Assumptions

- A range of GHG cost-effectiveness was identified based on project and program-level analyses from states of the northeast and mid-Atlantic (see Appendix B, Section B.4 for more details and references).
  - Low: based on Connecticut and Massachusetts freight studies and a few individual TCI region project evaluations – 40 tons per $million.
  - Medium: based on Moving Cooler study (nationwide analysis) – 140 tons per $million.
  - High: based on Mid-Atlantic Rail Operations Study – 1,165 tons per $million.

- The Mid-Atlantic Rail Operations Study provided corresponding 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 “medium” to “high” GHG effectiveness shown above.
- Rail fuel consumption is based on a nationwide average of 3.81 ton-miles per 1,000 British Thermal Units in 2030 (per 2017 AEO Reference Case projection). Truck fuel consumption rates are taken from NEMS.

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.

4.5 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 VMT reduced per dollar of capital investment. This information is taken from recent planning studies of projects in the TCI region.

Key Assumptions

- VMT cost-effectiveness (annual auto VMT reduced per cumulative $millions invested) is based on data from 13 projects in CT, MA, MD, NY, and the region (Northeast Corridor), with data obtained from a combination of environmental documents, Federal Transit Administration (FTA) New/Small Starts submissions, agency capital plans, and CS calculations. Detailed data are shown in Appendix B, Section B.3.
- Annual operating costs are estimated at 7 percent of up-front capital costs, or 37 percent of the annualized capital cost over the TCI evaluation period.[18]
- 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 13 to 26 percent of the decrease in automobile VMT, based on calculations for the bus operating improvements strategy as described below, considering average load factors, operating cost per mile, and prior drive mode, each varying by urbanized area size. Load factors and operating costs are regional average values for bus service by urbanized area size as taken from the 2014 NTD. Default prior drive and bus mode shares are documented in Appendix B.
- 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., commuter rail serving suburbs and 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;

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

- 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, although the new fare revenue is not "recycled" back into TCI strategy investment.

Key Assumptions – Bus Service Expansion

- Cost per VRM based on 2014 National Transit Database (NTD) operating statistics for individual TCI region 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 B.

Key Assumptions – Bus Service Efficiency

- Regional investment of $80 million annually (for a sample scenario) into bus efficiency supports 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.
- 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 B. 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 B) and average trip length of 3.1 miles (unlinked passenger miles/unlinked passenger trips from 2014 NTD for TCI region 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.[19]

- Average bus fare of $1.09 per unlinked trip, from American Public Transportation Association Fact Book (2015). At a regionwide subsidy of $100 million, this represents a 4.7 percent reduction in fare (based on total unlinked trips in TCI region from 2014 NTD).

4.5.3 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 TCI 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 TCI region (see Appendix B).

- 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.

[19] 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.

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

5.1 Overview of Economic Benefits Modeled

The regionwide economic benefits of clean transportation investment are analyzed using outputs from the TCI Investment Strategy 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. For this project, the model was set up with data from each of the 12 TCI states plus the District of Columbia along with the rest of the U.S., for 23 economic sectors. Results of a regionwide economic analysis of clean transportation strategies were first reported in CS (2015b).

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 TCI Investment Strategy 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.

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.[20]

[20] 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.

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 the TCI 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

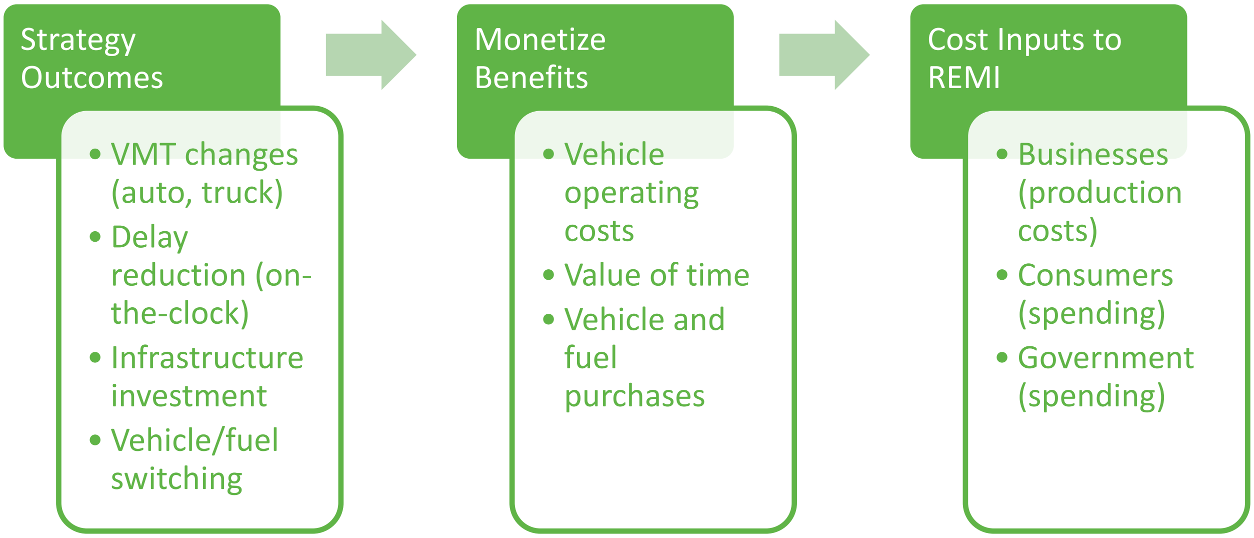
Primary Effect	Secondary Effect	Electric/Alt Fuel Vehicles	Land Use/ Smart Growth	Active Transportation	TDM	System Operations	Freight/ Intermodal	Transit	Highway Preservation
Reduced VMT	Vehicle Operating Cost Savings		✓	✓	✓			✓	
	Delay Reduction		✓	✓	✓			✓	
Delay Reduction						✓			✓
Vehicle Purchase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

5.2 Key Assumptions

The analysis of GHG strategies described here was by necessity “high-level” since it was not possible to define and model specific transportation investments across the entire TCI region and analysis period. As described in previous sections, various simplifying assumptions and general approximations had to be made. The results are therefore representative of an “order of magnitude” of effects rather than a precise estimate.

Figure 5.1 shows the basic analysis approach. Strategy outcomes (some computed for the GHG estimates, others which needed to be computed for the economic analysis) are first tabulated. These are then monetized using various factors such as value of time. 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.

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 used in the GHG analysis, which are reported from NEMS output.
- Maintenance costs – **$0.10 per mile** for light-duty vehicles, based on the FHWA Highway Economic Requirements System (HERS) model Technical Report (2005).[21]

Note that VMT and associated fuel and maintenance cost savings for trucks 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).

[21] 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, 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 was then multiplied by the VMT change estimated for the TCI strategy analysis to obtain an overall delay reduction.

For system operations/efficiency, the report estimated that nationwide, operational improvements implemented through 2012 were saving 374 million hours of delay and 194 million gallons of fuel annually, for a savings of 0.52 gallons of fuel per hour of delay reduced in 2012, with values in future years adjusted based on fuel efficiency (see Section 4.4).

Time savings (delay reductions) were allocated between personal light-duty VMT, commercial light-duty VMT, and truck VMT in proportion to the VMT by each mode in the TCI region. They were then monetized using a value of $24.90 per vehicle-hour, based on U.S. DOT guidance (U.S. DOT, 2012).

For commercial light and heavy 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 Highway Economic Requirements System (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 VOC savings per million VMT. These savings are multiplied by TCI region 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, Natural Gas, Hydrogen)	Business share of fuel cost savings from alternative fuel vehicles, system efficiency, and VMT reduction
Electricity	Electricity expenditures for medium-duty electric trucks
Vehicle Purchase	Vehicle and refueling infrastructure capital cost for electric MDTs and CNG 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	Business share of new carbon fees paid (fuel purchases for commercial vehicles)
Transit Fares	Business share of transit fare changes (on-the-clock travel, new service and reduced fares)
Incentives	New TCI proceeds 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, Natural Gas, 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	Consumer share of new carbon fees 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	New TCI proceeds returned to consumers in the form of incentives for light-duty EVs and charging equipment, plus new proceeds returned directly to consumers

Sector and Category	Description
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 TCI revenue returned to businesses in the form of incentives for alternative fuel vehicles and infrastructure
Incentives: Consumers	New TCI revenue 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

Costs needed to be allocated to states and industry sectors. The first step in this process was to allocate regional cost changes to states, using each state's estimated share of covered carbon emissions (from gasoline and diesel fuel), and therefore proceeds generated. 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 needed 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 was 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 was multiplied by the TSA value to get the total proportion of regional business expenses by state and industry.

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

Industry	Transportation $ per Total $
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 Emissions, Health, and Safety 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").[22] 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.[23]

Crash reduction benefits are valued at $9.6 million per fatality based on the latest (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.

[22] 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.

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

6.2 Physical Activity Benefits

Output from the World Health Organization (WHO) Health Economic Assessment Toolkit (HEAT) developed for a previous study done in Massachusetts was used to estimate the benefits of increased bicycling and walking. HEAT provides estimates of benefits in terms of reduced mortality but does not provide estimates of other health benefits. HEAT requires inputs of the number of people increasing their physical activity, and the daily increase in walk or bicycle person-kilometers traveled or walk or bicycle person-hours traveled.[24]

To convert changes in PMT by walking and bicycling from the Investment Strategy Tool into HEAT outputs, information was used from an unpublished 2014 study by CS that estimated various benefits from transportation capital investments in Massachusetts. This study estimated an increase of 32.8 million annual walk miles and 100.9 million annual bike miles for transportation purposes, as a result of investments in Complete Streets and shared use pathways – similar to the types of investments anticipated from the TCI program. These values were converted into inputs to HEAT, in the form of increased hours of walking and bicycling per day spread across an assumed number of people (500,000 to 1 million) and days per year (200 to 365). Based on these inputs, HEAT provided estimates of 55 and 54 deaths prevented per year from increased walking and bicycling respectively. The walk and bike PMT increases and deaths prevented were used to estimate an overall rate of 1.7 deaths prevented per million new walking PMT, and 0.5 deaths prevented per million new bicycling PMT. These factors were applied to the estimated increases in walking and bicycling due to active transportation and public transportation investments in the Investment Strategy Tool.

Results from HEAT can vary somewhat depending on the assumptions about how the walking and bicycling increases are spread across the population, so an average of three scenarios was used in the Massachusetts analysis. An uncertainty range of plus or minus 10 percent is applied to the estimates, based on the approximate range of variation seen in the scenarios tested. Death rate is also an input to the Investment Strategy Tool and could have a modest effect on the reported outcomes; a value of 679 deaths per 100,000 population was used, based on data from the Massachusetts Department of Public Health.

Deaths prevented by physical activity were valued at the same $9.6 million value of a statistical life used in the safety analysis.

6.3 Air Pollution Benefits

Reductions in emissions of air pollutants from motor vehicles are also assumed to be proportional to reductions in VMT. The process for estimating air pollution benefits involved three steps:

- Apply emission factors (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).
- Monetize the value of these emission reductions using national average $/kg factors.

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

- Provide estimates of specific health benefit indicators using national average factors. These indicators are illustrative of the health benefits from reduced air pollution and are a subset of the total impacts that are monetized using the $/kg factors.

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. Separate factors are applied to changes in CNG heavy truck VMT.

For expediency, representative emission factors were developed using MOVES2014 for one county – Fairfax County, VA. A MOVES2014 inventory run was performed for July 2032, 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. County-specific emission rates for running, start/resting, and hoteling activity will be accounted for in the detailed health effects analysis. The emission factors used in this analysis are shown in Table 6.1.

Table 6.1 Emission Factors (g/mi)

Pollutant/Vehicle Class	Gasoline + Diesel	CNG
Primary Exhaust PM2.5 - Total		
Light-Duty Autos & Trucks	0.003	
Buses	0.063	0.005
Medium (Single Unit) Trucks	0.019	0.001
Heavy (Combination) Trucks	0.026	0.002
Oxides of Nitrogen (NOx)		
Light-Duty Autos & Trucks	0.067	
Buses	2.068	1.988
Medium (Single Unit) Trucks	0.678	0.651
Heavy (Combination) Trucks	1.223	1.176
Volatile Organic Compounds (VOC)		
Light-Duty Autos & Trucks	0.093	
Buses	0.142	0.101
Medium (Single Unit) Trucks	0.154	0.110
Heavy (Combination) Trucks	0.059	0.042

The gasoline + diesel factor is a combined factor that reflects the weighting of the fuel types in each vehicle category assumed within MOVES2014.[25] MOVES2014 does not report emissions for CNG trucks, so the truck factors were developed by applying the ratio of truck to bus gasoline/diesel emissions to the bus CNG

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

emissions factor. The factors also reflect VMT-based weighting across detailed source classifications within each vehicle type.

6.3.2 Monetization of Emission Changes

The costs of air pollution reductions reflect human health impacts – including mortality and morbidity – as well as crop and forest damage, ecosystem damage (e.g., from acid deposition, ozone damage, and particulate matter deposition), damage to buildings and materials, and reduced visibility. The costs of air pollution are primarily driven by human health.

Damage values ($/kg) are based on the U.S. EPA regulatory impact analysis for light-duty vehicle fuel economy and GHG standards (U.S. EPA, 2010), as reviewed by CS in 2012 for use in the FTA's New Starts Environmental Benefits Template. Table 6.2 shows the damage values used. The damage values are the same as used by FTA in its most current (FY 2021) version of the New Starts and Small Starts reporting templates, with the exception that 2010 dollars have been converted to 2017 dollars using a consumer price index multiplier of 1.12.[26] The EPA values are based on nationwide modeling using county-scale data on emissions, air pollution, and population exposure. The EPA and FTA sources list different damage values for mobile vs. electricity generation sources; the mobile source values are used here. Values provided by FTA for year 2035 are used.

Table 6.2 Pollutant Damage Values ($/kg)

Pollutant	Damage Value ($/kg)
$PM_{2.5}$	$1,004
NO_x	$18.14
VOC	$4.36

To provide a range of estimates in the overall value of air pollutant damages reduced, the median estimate derived from the damage value in Table 6.3 was adjusted based on the ratio of 5th and 95th percentile to median estimates found for $PM_{2.5}$ premature mortality (the primary driver of benefits) in Table 7-16 of EPA (2010a). The average ratios used are shown in the bottom line of the table.

Table 6.3 U.S. EPA Estimated Monetary Value of Changes in Incidence of Health and Welfare Effects for Premature $PM_{2.5}$ Mortality from 2012-2016 Light-Duty GHG Standards (Millions of 2007$, 3% Discount Rate)

	5th percentile	Median	95th percentile
Pope et al., 2002	$70	$510	$1,300
Laden et al., 2006	$190	$1,300	$3,300
Ratios to Median			
Pope et al., 2002	0.14		2.55
Laden et al., 2006	0.15		2.54

[26] https://data.bls.gov/cgi-bin/cpicalc.pl

	5th percentile	Median	95th percentile
Average	**0.14**		**2.54**

6.3.3 Other Health Benefit Indicators

$PM_{2.5}$ is responsible for the large majority of health effects from motor vehicle air pollution (U.S. EPA & NHTSA, 2011, 2012). Changes in key health outcomes – including premature deaths for adults age 30+, cases of chronic bronchitis for adults 26+, emergency room visits for asthma for children, and asthma symptoms/exacerbation – are estimated based on the $PM_{2.5}$ emission reductions. This was done using information from the Regulatory Impact Analyses for the EPA/NHTSA joint rulemaking for Model Year 2017-2025 light-duty vehicle GHG emissions and fuel economy, and for the agencies' joint rulemaking for Model Year 2014-2018 heavy-duty vehicle GHG emissions and fuel economy (U.S. EPA & NHTSA, 2011, 2012). The nationwide air pollution benefits in year 2030 (Table 8-12, EPA & NHTSA 2011; Table 6.3-3, EPA & NHTSA 2012) were divided by the nationwide emission reductions in year 2030 (Table 5-12, EPA & NHTSA 2011; Table 4.3-19, EPA & NHTSA 2012) to obtain a health benefit per unit of emissions reduced. These values are shown in Table 6.4, which shows a complete list of the health outcomes estimated in the EPA/NHTSA documents. This table also shows the 5th and 95th percentile of each estimate in addition to the average annual estimate. Selected outcomes, using the average value (shown in boldface in shaded cells), are reported in the summary of this analysis.

The values of the other health benefit indicators shown here and in the tool output are a subset of the impacts that are monetized using the values shown in Table 6.2. They are shown as another way of illustrating the nature and magnitude of health effects. The other health benefits should not be monetized, as they are already reflected in the total monetized value of air pollution benefits.

Table 6.4 Air Pollution Health Impact Factors (per 100 short tons $PM_{2.5}$)

Health Outcome	Auto - Average Annual, 2030	5th %ile	95th %ile	Truck - Average Annual, 2030	5th %ile	95th %ile
Premature mortality cases						
Adult, age 30+, ACS Cohort study (Pope et al., 2002)	9	2	15	6	2	9
Adult, age 25+, Six Cities Study (Laden et al., 2006)	**22**	10	35	**15**	8	21
Infant, age<1 year (Woodruff et al., 1997)	0	0	0	0	0	0
Cases of chronic bronchitis (adult, age 26 and over)	6	0	12	4	1	7
Non-fatal myocardial infarction (adult, age 18 and over)	10	3	18	11	4	17
Hospital admissions- respiratory (all ages)	2	1	3	1	1	2
Hospital admissions- cardiovascular (adults, age>18)	4	3	5	3	2	4

Health Outcome	Auto - Average Annual, 2030	5th %ile	95th %ile	Truck - Average Annual, 2030	5th %ile	95th %ile
Emergency room visits for asthma (age <=18)	6	3	9	6	3	9
Acute bronchitis (children, age 8-12)	13	-3	30	9	0	20
Lower respiratory symptoms (children, age 7-14)	167	61	271	116	54	174
Upper respiratory symptoms (asthmatic children, age 9-18)	128	21	231	87	27	145
Cases of asthma exacerbation (asthmatic children, age 6-18)	**279**	-10	774	**102**	12	290

Source: Cambridge Systematics analysis of U.S. EPA & NHTSA (2011, 2012)

7.0 Downscaling of Outputs to Counties

7.1 Overview

This section provides a description of the methods used to downscale output from the TCI Investment Strategy Tool and NEMS to the county level for the purposes of emissions modeling to support public health analysis.

The tool produces changes in VMT and nonmotorized PMT for the TCI region. For the public health analysis, the following data were needed so that appropriate emission factors could be applied from the MOVES2014 model:

- Changes in VMT, vehicle population, and truck hoteling[27] hours by vehicle type and non-electric fuel type by county.
- The above changes in county-level VMT, population, and hoteling hours broken out by detailed source classification code (SCC), which identifies 13 source (vehicle) types, as well as multiple fuel types (gasoline, diesel, natural gas, ethanol, and electricity), four road types (rural restricted access, rural unrestricted access, urban restricted access, and urban unrestricted access) and various emissions processes. The MOVES2014 model produces emission factors that vary by each of these SCC categories.[28]

The Investment Strategy Tool internally calculates county-level VMT and vehicle population changes for five vehicle types: light-duty autos, light-duty trucks, medium-duty trucks, heavy-duty trucks, and buses. An external spreadsheet postprocessor converts these changes into detailed VMT, population, and hoteling changes by SCC category. The postprocessor was also used to develop baseline 2017 and 2032 estimates of VMT, population, and hoteling hours by county and SCC category.

The steps of the downscaling process are described below.

7.2 Estimate Regional VMT Change by Area Type for Strategies that Affect Travel Demand

Some of the strategies that affect demand have different effectiveness values by area type, whereas others have a single region-wide effectiveness value. Also, area types are defined differently for different strategies, based on the available data regarding the strategies.

[27] Truck hoteling refers to extended idling, such as occurs when a long-distance truck parks at a truck stop, rest area, or other roadside parking area overnight to allow the driver to sleep. Unless the truck is equipped with an auxiliary power unit (APU) or is at a facility with plug-in capabilities, the engine is often left running to provide power for heating, air conditioning, and or electricity. This extended idling mode can be a significant source of air pollutant emissions from long-distance trucks.

[28] VMT is broken out by source type, fuel type, and road type. Population is broken out by source type and fuel type. Hoteling hours are broken out by fuel type since they occur only for source type 62 (long-haul combination trucks), as well as for two process types (extended idle and auxiliary power unit). For VMT and population, all pollutant processes are included in the same record (SCC process type 00).

- **Bicycle** and **pedestrian** strategies are based on five area type categories defined by population density (New York City; core = >10,000 persons per square mile, urban = 4,000 – 10,000 ppsm, suburban = 500 – 4,000 ppsm, rural = <500 ppsm).

- **Travel demand management** strategies are based on three area type categories defined by metropolitan statistical area (MSA) population (very large = >3 million, large = 1 – 3 million, medium/small = <1 million).

- **Transit investment/service** strategies are based on four area type categories defined by urbanized area (UZA) population (New York City, large = >1 million, medium = 200,000 – 1 million, small = <200,000, consistent with National Transit Database reporting). (The increase in transit VMT associated with new transit services is also estimated for the urbanized area types.)

- **Shared ride incentives**, **land use/smart growth**, **freight/intermodal**, **intercity rail**, and **transit state of good repair** do not have different effectiveness rates by area type since they are applied across area types.

7.3 Estimate Regional VMT Change by Vehicle Type and Fuel Type for Alternative Fuel Vehicle Strategies and Pricing

Tailpipe emissions are used in the public health analysis, and electric and fuel cell vehicles do not produce any tailpipe pollutant emissions. It is therefore necessary to know the change in non-electric VMT by fuel type, including gasoline, diesel, and natural gas, so that appropriate emission factors can be applied. Nationwide average gasoline/diesel fuel splits by vehicle class will be assumed by the health analysis team, so changes in gas/diesel VMT, as well as CNG VMT for heavy-duty trucks, are provided in this analysis.

This step draws on two primary sources:

- NEMS provides outputs of scenario and reference case light-duty electric vehicle VMT, which are imported into the Investment Strategy Tool. The imports from NEMS include (1) change in total light-duty VMT by Region (1, 2, 5) and (2) change in total EV and PHEV VMT for the entire TCI region.

- The Investment Strategy Tool provides estimates of changes in truck and bus VMT for the five vehicle/fuel types currently in the tool – electric transit buses, electric school buses, electric medium-duty trucks, CNG heavy-duty trucks, hydrogen fuel cell heavy-duty trucks, and electric commuter rail. The VMT generated by each alternative fuel vehicle type is estimated as the cumulative number of vehicles introduced as a result of TCI incentives times the average miles per vehicle per year. (Vehicle scrappage/turnover is also accounted for, but this effect is small in the 11-year analysis horizon.)

The NEMS light-duty total VMT change includes both the effects of VMT reduction strategies (modeled in the tool and input into NEMS) and the effects of the price response (increased carbon/ fuel prices as a result of the carbon cap). The effect of the price response alone is estimated by subtracting the VMT change from demand reduction strategies (as calculated by the tool) from the total VMT change provided by NEMS. For this step, it is assumed that the VMT change from demand reduction by Region is proportional to the total NEMS VMT change by Region.

7.4 Associate Counties with Geographies

The next step of the downscaling process was to tag all 378 counties in the TCI region with area type and other attributes, the key attributes being:

- Population and VMT by vehicle type (2017).
- Region (1 = New England; 2 = New York, New Jersey, Pennsylvania; 5 = Delaware, Maryland, Virginia, D.C.).
- Population density (population/land area in square miles) area type (NYC, core, urban, suburban, rural).
- Metropolitan area type (very large, large, medium/small).
- Urbanized area type (large, medium, small).

The geographic tags were assigned using 2017 American Community Survey population estimates and the latest available Census Topologically Integrated Geographic Encoding and Referencing database (TIGER) definitions of MSAs and UZAs. MSAs are defined based on county boundaries. Urbanized areas are not defined along county boundaries, so the following procedure was used to associate counties with UZAs: (1) If the centroid of at least one UZA falls within the county, the county is tagged with the largest UZA whose centroid falls within the county; (2) if not, if at least 50 percent of the county is covered by an UZA, the county is tagged with that UZA. If a county is not associated with any UZA from these steps, the UZA type is rural.

7.5 Distribute Regional VMT Changes across Counties

Regional VMT changes were distributed amongst counties using the following rules:

- VMT reductions from demand reductions by area type were distributed to the counties within each area type based on the county's share of baseline VMT within that area type. Changes in freight/intermodal VMT were assigned to heavy-duty trucks in proportion to baseline HDT VMT, and changes in all other VMT were assigned to light-duty vehicles in proportion to baseline LDV VMT.
- VMT reductions from other strategies were distributed in proportion to baseline VMT in each county. The distributions were made using the baseline VMT for the respective vehicle type (light-duty, medium-duty truck, heavy-duty truck, bus).

7.6 Distribute Regional Walk and Bike PMT Changes across Counties

Walk and bike strategies have different effectiveness levels by population density area type in the tool, being more effective in densely populated areas where there are a higher number of short trips that could be taken by foot or bicycle. The total change in walk and bike PMT in each area type category is distributed amongst counties in proportion to each county's population share within its respective area type.

Some increase in walk trips is also observed as a result of transit strategies (walk access to transit). The total change in transit walk access is estimated by UZA category and distributed to counties in each UZA category based on their share of population in the category.

7.7 Estimate Changes in Vehicle Population

Changes in vehicle populations by county were also needed for the emissions modeling. These were estimating by dividing change in VMT by county (for each vehicle type) by the respective average miles per year for each vehicle type.

7.8 Downscale County VMT, Vehicle Population, and Hoteling Changes to SCC Category

The downscaling to SCC categories is done in a converter spreadsheet separate from the Investment Strategy Tool. The converter uses the baseline VMT, population, and hoteling hours by county/SCC category from the 2014 National Emissions Inventory (NEI) to break out the VMT and population changes by SCC category. Within each of the five vehicle types and counties, the change in VMT (or population or hoteling hours) is further sub-allocated in proportion to the amount of baseline VMT (or population or hoteling hours) in each category. Changes in electric VMT and population are not provided since they do not generate direct emissions.

MOVES2014 does not produce emission rates for natural gas trucks and the 2014 MOVES NEI data does not include any VMT or population for natural gas trucks. Records for compressed natural gas trucks (fuel type 03) were created manually so that changes in VMT and population could be applied. Emission factors for natural gas trucks will need to be derived through other methods.

The change in truck hoteling hours is computed as the baseline (2032) hoteling hours (see below) multiplied by the scenario percent change in gasoline/diesel heavy-duty truck (HPMS type 60) VMT for the county.

7.9 2017 and 2032 Baseline VMT, Population, and Hoteling Estimates by SCC Category

The 2014 MOVES NEI data provide estimates of VMT, population, and hoteling by county and SCC. However, the VMT estimates by county and vehicle type are not necessarily consistent with the estimates provided by the TCI region states for the period 2017 – 2040 as used in the Investment Strategy Tool.

It was desired to develop base year (2017) and forecast year (2032) VMT estimates at the SCC category level that are consistent with the county/vehicle type estimates developed within the tool from data provided by the States. To do this, the following procedure was applied:

- 2014 MOVES NEI VMT by SCC was summarized at the level of the county and five vehicle types.
- These estimates were compared with the 2017 base year estimates developed from State data, and adjustment factors were developed for each county and vehicle type. A similar factor was developed to convert 2014 into 2032 VMT, e.g.:

- 2017Fact = 2017 state-provided VMT[29] / 2014 MOVES NEI VMT
- 2032Fact = 2032 state-provided VMT / 2014 MOVES NEI VMT

- The same adjustment factors were applied to vehicle population and truck hoteling hours.

Reasonableness checks were applied to the differences in VMT by county and vehicle type. Total 2017 VMT based on state data was 597 billion, compared to 603 billion from the 2014 MOVES data, a difference of 1 percent. The difference at the state level was less than 6 percent in all cases except for Massachusetts, where the 2017 estimate exceeded the 2014 estimate by 12 percent. The differences are likely due to differences in data sources and methods, as well as to actual changes in VMT between 2014 and 2017.

Looking at differences in specific vehicle type categories by county, relatively large percentage differences were observed in a few cases, mainly in truck and/or bus categories in selected states. This is likely due to differences in vehicle type/source type VMT estimation methods between the two datasets. Differences in light-duty VMT were generally smaller. Part of the reason for light-duty differences can also be ascribed to different assumptions regarding the split between light-duty autos and trucks, which is not accurately measured by traffic counting devices.

Another check was done to compare the average VMT per vehicle by state and vehicle type. For light-duty autos and trucks, VMT per vehicle was at least 8,000 and no more than 13,000, so the data seem reasonably consistent. The values for buses, single-unit trucks, and combination trucks varied much more widely – for example, for single-unit trucks, from a low of 3,700 in Massachusetts to a high of 64,000 in the District of Columbia. These discrepancies were observed both when dividing 2014 MOVES NEI VMT by population, and when dividing the adjusted 2017 VMT by adjusted population. Methods and data for estimating vehicle population for trucks and buses vary widely and can be very inconsistent. It appears that these inconsistencies underlie the population estimates provided for MOVES2014 for the NEI, and are not a product of the 2014-2017 adjustment method applied here. The difference in VMT per vehicle by state/vehicle type comparing the MOVES2014 NEI and 2017 state/adjusted data was less than 3 percent in most cases.

[29] As explained in the discussion of VMT estimates (Section 3.2), the 2017 VMT value was sometimes directly provided by the state, but in some cases, manipulation of state data (aggregation or disaggregation) was required to estimate VMT for a consistent set of five vehicle types. The 2017 values provided by states are taken as the reference value since they are consistent with the most recent state submissions of VMT data to the Federal Highway Performance Monitoring System. The 2032 estimate is usually an interpolation of 2030 and 2040 projections provided by the state.

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Appendix A. Tool Inputs and Sample Tool Outputs

In late 2019, the Investment Strategy Tool was applied in conjunction with NEMS to evaluate a variety of scenarios representing different (1) GHG emissions caps and (2) illustrative investment portfolios. Each combination of a GHG emissions cap and investment portfolio represents a particular level of average annual investment over the 2022 – 2032 period. The three illustrative investment portfolios modeled in 2019/2020 are shown in Table A.1. Portfolio A invests in all strategies included in the tool. Portfolio C invests in strategies that are identified by the tool as being the most cost-effective from the standpoint of carbon dioxide emission reductions during the time period of analysis, from 2022 to 2032. Portfolio B strikes a balance between the two.

Table A.1 Investment Portfolios Modeled

Strategy	Portfolio A	Portfolio B	Portfolio C
Light duty EV's	4.6%	30.0%	54.0%
CNG trucks	1.9%	1.5%	1.1%
Electric transit buses	4.6%	4.0%	2.5%
Electric school buses	4.6%	5.9%	7.1%
Electric trucks - MDT/urban	4.6%	9.0%	15.0%
Hydrogen trucks - long-haul	2.8%	1.0%	1.6%
Passenger rail electrification	2.8%	1.4%	0.0%
Shared ride incentives	1.9%	0.9%	0.0%
Land use/smart growth	4.2%	4.4%	4.5%
Bicycle investment	4.2%	5.1%	6.0%
Pedestrian investment	4.2%	3.0%	0.0%
Travel demand management	1.9%	0.5%	0.0%
System operations	1.9%	1.1%	0.4%
Freight/intermodal	1.9%	1.1%	0.4%
Highway preservation	3.3%	5.4%	7.4%
Bus rapid transit	2.8%	1.4%	0.0%
Urban rail	2.8%	1.4%	0.0%
Commuter rail	2.8%	1.4%	0.0%
Intercity rail	2.8%	1.4%	0.0%
Bus service: expansion	2.8%	1.5%	0.0%
Bus service: efficiency	6.1%	3.1%	0.0%
Transit fare reduction	4.2%	2.3%	0.0%
Bus state of good repair	3.3%	1.7%	0.0%
Urban rail state of good repair	3.3%	1.7%	0.0%
Commuter/intercity rail state of good repair	3.3%	1.7%	0.0%
Indirect (non-GHG reducing)	16.7%	8.3%	0.0%

Sample results are then shown for a scenario representing a 22 percent reduction in regional transportation GHG emissions between 2022 and 2032, and the investment portfolio B. Investment portfolio B at a cap level achieving a 22 percent carbon dioxide emission reduction from 2022 to 2032 generates about $3.2 billion in average annual proceeds for the region.

- Table A.2 shows the investment mix for investment portfolio B and the approximate amount of GHG-producing infrastructure, services, and vehicles this level of investment supports. Note that a small portion of funds are placed into "indirect (non-GHG reducing)" uses. These could take the form of rebates, spending, or other program investments to address non-GHG issues (for example, rebates to lower-income or rural households to address equity issues) rather than transportation investments that reduce GHG emissions.
- Table A.3 shows the cost-effectiveness of each strategy as measured in terms of dollars spent per VMT reduced. Strategies for which no values are shown do not reduce VMT.
- Table A.4 shows estimated changes in VMT, traveler delay, and petroleum fuel use in year 2032, compared to the Reference Case.
- Table A.5 shows changes in health and safety benefits in year 2032, compared to the Reference Case.
- Table A.6 shows changes in business, consumer, and government costs or expenditures.

Table A.2 Investment Portfolio B

Investment Mix by Strategy				
Strategy	Investment Mix	Avg Annual Investment (millions)	Investment is Equivalent To…	
EV/alt fuel incentives	52.7%	$ 1,691.1		
Light duty EV's	30.0%	$ 962.0	107,429	*Consumers per year benefiting from incentive*
CNG trucks	1.5%	$ 46.9	1,514	*Trucks per year benefiting from incentive*
Electric transit buses	4.0%	$ 128.3	2,285	*New electric transit buses per year*
Electric school buses	5.9%	$ 188.7	1,974	*New electric school buses per year*
Electric trucks - MDT/urban	9.0%	$ 288.6	3,869	*New electric trucks per year*
Hydrogen trucks - long-haul	1.0%	$ 32.1	217	*New hydrogen trucks per year*
Passenger rail electrification	1.4%	$ 44.5	18	*New miles of electrified rail per year*
Vehicle travel reduction	13.9%	$ 446.0		
Shared ride incentives	0.9%	$ 29.7	18	*Million shared ride trips per year*
Land use/smart growth	4.4%	$ 141.1	9,876	*Annual new housing units built in smart growth areas between 2025 and 2032*
Bicycle investment	5.1%	$ 163.0	796	*New miles of bike lanes and paths added per year*
Pedestrian investment	3.0%	$ 96.2	159	*New miles of Complete Streets per year*
Travel demand management	0.5%	$ 16.0	22,268	*Workers benefiting from $3/day transit or rideshare subsidy*
System efficiency	7.6%	$ 244.0		
System operations	1.1%	$ 35.6	1,995	*Miles of highway covered by new ITS infrastructure by 2032*
Freight/intermodal	1.1%	$ 36.1	8%	*of MAROPS 20-year program implemented*
Highway preservation	5.4%	$ 172.3	57	*Miles of highway reconstructed per year*
Urban & intercity transit	12.4%	$ 397.9		
Bus rapid transit	1.4%	$ 44.5	36	*Miles of new facility by 2032*
Urban rail	1.4%	$ 44.5	4	*Miles of new facility by 2032*
Commuter rail	1.4%	$ 44.5	14	*Miles of new facility by 2032*
Intercity rail	1.4%	$ 44.5	71	*Miles of improved facility by 2032*
Bus service: expansion	1.5%	$ 48.1	983	*Additional daily revenue-hours of bus service in 2032*
Bus service: efficiency	3.1%	$ 98.0	7,838	*Miles of bus routes with efficiency improvements by 2032*
Transit fare reduction	2.3%	$ 73.8	4%	*Average fare decrease across all trips*
Transit state of good repair	5.0%	$ 160.3		
Bus	1.7%	$ 53.4	89	*New hybrid buses purchased per year*
Urban rail	1.7%	$ 53.4	24	*New rail vehicles purchased per year*
Commuter/intercity rail	1.7%	$ 53.4	24	*New rail vehicles purchased per year*
Indirect (non-GHG reducing)	8.3%	$ 267.2		
Total	**100.0%**	**$ 3,207**		

Table A.3 Unit VMT Reductions: Year 2032 Annual Tonnes Reduced vs. Reference, Per $Million Average Annual Spending from 2022-2032: 22% Cap Reduction, with Investment Portfolio B

Unit VMT Reductions (year 2032 VMT reduced vs. reference, per $ avg annual spending from 2022-2032)						
Strategy	**NYC**	**Core**	**Urban**	**Suburban**	**Rural**	**State/ Region Wide**
EV/alt fuel incentives						
Light duty EV's						
CNG trucks						
Electric transit buses						
Electric school buses						
Electric trucks - MDT/urban						
Hydrogen trucks - long-haul						
Passenger rail electrification						
Vehicle travel reduction						
Shared ride incentives						0.08
Land use/smart growth						8.83
Bicycle investment	4.09	5.15	3.64	1.07	0.21	2.21
Pedestrian investment	1.47	1.05	0.43	0.03	0.02	
		V Lg Metro (>3M)	**Lg Metro (1-3M)**	**Md/Sm Metro**		
Travel demand management		23.80	10.58	6.10		
System efficiency						
System operations						
Freight/intermodal						0.79
Highway preservation						
Urban & intercity transit	**NYC Metro**	**UZA Pop >1M**	**UZA Pop 200k - 1M**	**UZA Pop <200k**		
Bus rapid transit	0.09	0.09	0.09	0.09		0.09
Urban rail	0.27	0.27	0.27	0.27		0.27
Commuter rail	0.15	0.15	0.15	0.15		0.15
Intercity rail	0.53	0.53	0.53	0.53		0.53
Bus service: expansion	0.33	0.25	0.37	0.42		
Bus service: efficiency	0.38	0.41	0.40	0.36		
Transit fare reduction	0.44	0.36	0.65	0.79		
Transit state of good repair						
Bus						0.90
Urban rail						0.23
Commuter/intercity rail						0.52

Table A.4 Changes in VMT, Delay, and Petroleum Fuel Use: 22% Cap Reduction, with Investment Portfolio B

Investment Mix and Net GHG Reduction			Transportation System Impacts (2032)			
Strategy	**Avg Annual Investment (millions)**		**Strategy**	**VMT Change (milllions)**	**Delay Change (1,000's of hours)**	**Petroleum Fuel Change (1,000's of GGE)**
EV/alt fuel incentives	**$ 1,691.1**		**EV/alt fuel incentives**	**-**	**-**	**(564,578)**
Light duty EV's	$ 962.0		Light duty EV's			(328,520)
CNG trucks	$ 46.9		CNG trucks			(66,115)
Electric transit buses	$ 128.3		Electric transit buses			(82,788)
Electric school buses	$ 188.7		Electric school buses			(20,300)
Electric trucks - MDT/urban	$ 288.6		Electric trucks - MDT/urban			(57,710)
Hydrogen trucks - long-haul	$ 32.1		Hydrogen trucks - long-haul			(7,253)
Passenger rail electrification	$ 44.5		Passenger rail electrification			(1,893)
Vehicle travel reduction	**$ 446.0**		**Vehicle travel reduction**	**(1,946)**	**(718,252)**	**(58,177)**
Shared ride incentives	$ 29.7		Shared ride incentives	(2)		(70)
Land use/smart growth	$ 141.1		Land use/smart growth	(1,246)	(468,810)	(37,785)
Bicycle investment	$ 163.0		Bicycle investment	(360)	(135,488)	(11,136)
Pedestrian investment	$ 96.2		Pedestrian investment	(35)		(1)
Travel demand management	$ 16.0		Travel demand management	(303)	(113,954)	(9,184)
System efficiency	**$ 244.0**		**System efficiency**	**(29)**	**(35,646)**	**(16,387)**
System operations	$ 35.6		System operations		(35,404)	(10,012)
Freight/intermodal	$ 36.1		Freight/intermodal	(29)	-	(3,972)
Highway preservation	$ 172.3		Highway preservation	-	(242)	(2,404)
Urban & intercity transit	**$ 397.9**		**Urban & intercity transit**	**(142)**	**(49,184)**	**(18,482)**
Bus rapid transit	$ 44.5		Bus rapid transit	(4)	(1,348)	(444)
Urban rail	$ 44.5		Urban rail	(12)	(3,816)	(1,253)
Commuter rail	$ 44.5		Commuter rail	(7)	(2,176)	(714)
Intercity rail	$ 44.5		Intercity rail	(24)	(7,590)	(2,492)
Bus service: expansion	$ 48.1		Bus service: expansion	(18)	(7,814)	(2,583)
Bus service: efficiency	$ 98.0		Bus service: efficiency	(39)	(12,098)	(5,104)
Transit fare reduction	$ 73.8		Transit fare reduction	(40)	(14,342)	(5,892)
Transit state of good repair	**$ 160.3**		**Transit state of good repair**	**(88)**	**(27,537)**	**(11,618)**
Bus	$ 53.4		Bus	(48)	(14,981)	(6,321)
Urban rail	$ 53.4		Urban rail	(13)	(3,929)	(1,658)
Commuter/intercity rail	$ 53.4		Commuter/intercity rail	(28)	(8,627)	(3,640)
Total	**$ 2,939.4**		**Total**	**(2,205)**	**(830,618)**	**(669,242)**
Baseline			**Baseline**	**668,912**		
			Change, %	**-0.33%**		

Table A.5 Changes in Health and Safety Benefits: 22% Cap Reduction, with Investment Portfolio B

Other Benefits	2032 - low	2032	2032 - high
Safety			
Change in fatalities		(59)	
Change in injuries		(888)	
Statistical value of fatalities and injuries reduced ($millions)		$ 569	
Physical Activity			
Change in deaths	(486)	(540)	(594)
Statistical value of lives saved ($millions)	4,669	$ 5,188	$ 5,706
Air Pollution			
Change in PM2.5 emissions (short tons)		(156)	
Change in VOC emissions (short tons)		(1,242)	
Change in NOx emissions (short tons)		(3,675)	
Change in premature deaths (adults age 30+)	(3)	(11)	(18)
Change in asthma symptoms/exacerbation	(131)	(665)	(1,420)
Value of air pollution reduction ($millions)	$ 29	$ 208	$ 529

Table A.6 Changes in Business, Consumer, and Government Costs/Expenditures: 22% Cap Reduction, with Investment Portfolio B

REMI Inputs: Cost (Change, $millions)	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Business Expenditures											
Time (Productivity)	$ (70)	$ (156)	$ (221)	$ (291)	$ (351)	$ (418)	$ (471)	$ (530)	$ (585)	$ (642)	$ (705)
Fuel (Liquid Fuels, NG, & H2)	$ (53)	$ (116)	$ (173)	$ (236)	$ (295)	$ (369)	$ (438)	$ (508)	$ (576)	$ (645)	$ (709)
Electricity	$ 9	$ 19	$ 28	$ 40	$ 51	$ 64	$ 76	$ 90	$ 102	$ 115	$ 127
Vehicle Purchase	$ 332	$ 341	$ 348	$ 356	$ 365	$ 377	$ 388	$ 400	$ 412	$ 432	$ 453
Vehicle Maintenance/Repair	$ (33)	$ (70)	$ (105)	$ (142)	$ (180)	$ (219)	$ (259)	$ (301)	$ (345)	$ (388)	$ (435)
Health Care/Medical	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Transportation Services (Shipping)	$ (1)	$ (3)	$ (4)	$ (5)	$ (7)	$ (8)	$ (10)	$ (11)	$ (13)	$ (14)	$ (16)
Fees & Taxes	$ 769	$ 804	$ 841	$ 879	$ 918	$ 960	$ 1,003	$ 1,048	$ 1,096	$ 1,151	$ 1,208
Transit Fares	$ 0	$ 1	$ 1	$ 1	$ 1	$ 1	$ 1	$ 1	$ 1	$ 2	$ 2
Incentives	$ (246)	$ (254)	$ (261)	$ (269)	$ (277)	$ (286)	$ (294)	$ (303)	$ (311)	$ (327)	$ (343)
Business Production Cost Change	$ 706	$ 567	$ 453	$ 331	$ 226	$ 101	$ (3)	$ (114)	$ (219)	$ (318)	$ (418)
Consumer Expenditures											
Fuel (Liquid Fuels, NG, & H2)	$ (111)	$ (295)	$ (424)	$ (606)	$ (777)	$ (1,006)	$ (1,205)	$ (1,452)	$ (1,607)	$ (1,781)	$ (1,950)
Electricity	$ 11	$ 35	$ 52	$ 80	$ 109	$ 147	$ 182	$ 223	$ 248	$ 275	$ 302
Vehicle Purchase	$ 148	$ 190	$ 203	$ 228	$ 262	$ 276	$ 282	$ 257	$ 186	$ 187	$ 185
Vehicle Maintenance/Repair	$ (122)	$ (258)	$ (378)	$ (504)	$ (623)	$ (750)	$ (867)	$ (991)	$ (1,113)	$ (1,240)	$ (1,376)
Health Care/Medical	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Fees & Taxes	$ 1,965	$ 2,016	$ 2,067	$ 2,117	$ 2,168	$ 2,218	$ 2,268	$ 2,318	$ 2,366	$ 2,485	$ 2,608
Transit Fares	$ 7	$ 9	$ 10	$ 12	$ 14	$ 16	$ 17	$ 19	$ 21	$ 23	$ 25
Incentives & Indirect Revenue Recycling	$ (942)	$ (972)	$ (1,002)	$ (1,032)	$ (1,063)	$ (1,095)	$ (1,127)	$ (1,160)	$ (1,193)	$ (1,253)	$ (1,315)
Consumer Spending - Other Items	$ (956)	$ (724)	$ (527)	$ (296)	$ (90)	$ 196	$ 449	$ 787	$ 1,092	$ 1,304	$ 1,521
Government Expenditures											
Transportation Infrastructure [Construction Industry]	$ 1,129	$ 1,164	$ 1,200	$ 1,237	$ 1,274	$ 1,312	$ 1,350	$ 1,389	$ 1,429	$ 1,501	$ 1,575
Transportation Services [State Government Spending]	$ 88	$ 89	$ 91	$ 92	$ 93	$ 95	$ 96	$ 97	$ 99	$ 102	$ 106
Utilities Infrastructure [Utility Industry]	$ 322	$ 332	$ 342	$ 353	$ 363	$ 374	$ 385	$ 396	$ 408	$ 428	$ 449
Incentives: Business	$ 246	$ 254	$ 261	$ 269	$ 277	$ 286	$ 294	$ 303	$ 311	$ 327	$ 343
Incentives: Consumers	$ 942	$ 972	$ 1,002	$ 1,032	$ 1,063	$ 1,095	$ 1,127	$ 1,160	$ 1,193	$ 1,253	$ 1,315
Cost Savings and New Revenue	$ (8)	$ (34)	$ (61)	$ (94)	$ (130)	$ (176)	$ (231)	$ (301)	$ (390)	$ (491)	$ (598)
Total Government Infra & Services	$ 1,539	$ 1,586	$ 1,633	$ 1,681	$ 1,730	$ 1,781	$ 1,831	$ 1,883	$ 1,935	$ 2,031	$ 2,131

Appendix B. Additional Documentation of Assumptions

B.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 TCI evaluation 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 TCI evaluation since some of the program costs cover the affordability component.
- Could not locate more recent program evaluation data.

B.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 B.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 B.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.[30] The details of the elasticity calculation are shown in Table B.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 B.1 to the “core/high urban” area type.

Table B.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		

Table B.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

[30] 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.

	Core	High Urban	Medium Urban	Suburban	Rural
% 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 B.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 B.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 be modified by the user. The new facility miles are based on the 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).

Table B.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%

Affected population:	NYC	Core	Urban	Suburban	Rural
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.

To derive the estimates of new utilitarian cyclists per day by facility type shown in Table B.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 B.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.

B.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 TCI 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 B.5).

Table B.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 TCI region. Table B.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 B.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 B.7.

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

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

Table B.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 B.10 presents data on cost, ridership, GHG reductions, and VMT reductions as available for the 13 sample TCI region projects. The GHG reductions were not used in the 2019/2020 TCI analysis but are included in the Investment Strategy Tool for potential stand-alone use independent of NEMS.

Transit State of Good Repair

Table B.11 presents data from TCI 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. The GHG reductions were not used in the 2019/2020 TCI analysis but are included in the Investment Strategy Tool for potential stand-alone use independent of NEMS.

Table B.10 TCI 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 B.11 TCI 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

B.4 Freight Intermodal Data

Table B.12 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 B.12 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.