Transportation Evaluation and Carbon Reduction Tool (TEA-CART)

User Guide and Methodology Documentation

prepared for

Georgetown Climate Center

prepared by

Cambridge Systematics, Inc.

November 2025

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List of Acronyms

AADT	Annual average daily traffic
ACC	Advanced Clean Cars
ACT	Advanced Clean Trucks
AEO	Annual Energy Outlook
AFDC	Alternative Fuels Data Center
BEV	Battery-electric vehicle
BMT	Bicycle-miles of travel
BTU	British thermal unit
CAPCOA	California Air Pollution Control Officers Association
CARB	California Air Resources Board
CMAQ	Congestion Mitigation and Air Quality Improvement Program
CNG	Compressed natural gas
CO_2	Carbon dioxide
DCFC	Direct current fast-charge
DOE	Department of Energy
DOT	Department of Transportation
DR	Demand Response
eGRID	Emissions & Generation Resource Integrated Database
EPA	Environmental Protection Agency
EV	Electric vehicle
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GHG	Greenhouse gas
ICCT	International Council on Clean Transportation
ICE	Internal combustion engine
IRA	Inflation Reduction Act
kWh	Kilowatt-hour
LCI	Livable Centers Initiative
LDV	Light-duty vehicle
MHDV	Medium- and heavy-duty vehicle

MPO	Metropolitan Planning Organization
MSA	Metropolitan statistical area
MWh	Megawatt-hour
NASEM	National Academies of Science, Engineering, and Medicine
NEMS	National Energy Modeling System
NHS	National Highway System
NHTS	National Household Travel Survey
NO_x	Oxides of nitrogen
NREL	National Renewable Energy Laboratory
NTD	National Transit Database
$PM_{2.5}$	Particulate matter less than 2.5 microns in diameter
TCI	Transportation and Climate Initiative
TCRP	Transit Cooperative Research Program
TDM	Travel demand management
TEA-CART	Transportation Evaluation and Carbon Reduction Tool
TOD	Transit-oriented development
UZA	Urbanized area
VMT	Vehicle miles traveled
VOMS	Vehicles operated in maximum service
VRM	Vehicle revenue-miles
ZEV	Zero-emissions vehicle

1.0 Overview

The *Transportation Evaluation and Carbon Reduction Tool (TEA-CART)* offers planning-level analysis to estimate the greenhouse gas (GHG) emission performance of transportation capital program investments. The primary purpose of TEA-CART is to help practitioners account for the environmental performance of proposed projects, so they can set meaningful targets for greenhouse gas or vehicle-miles traveled reduction and develop capital plans that prioritize transportation projects that will help achieve those goals. The functionality of the tool has been informed by transportation agency officials. It is designed to serve as a resource for state Departments of Transportation (DOT) and Metropolitan Planning Organization (MPO) practitioners conducting long-term planning, project prioritization, and performance management. TEA-CART was developed by Cambridge Systematics, Inc. under contract with the Georgetown Climate Center, which facilitated extensive input from state and federal officials.

TEA-CART is easy to use, accepting simple inputs to evaluate the GHG performance of surface transportation capital projects during the planning or programming stage. TEA-CART is also highly customizable. The tool is pre-populated with default assumptions for both the U.S. overall and for each individual state. Most assumptions can be substituted with user-provided data, when available, so it can also be used by local or regional governments such as MPOs.

Inputs: Inputs to the tool typically include those available during the state or MPO transportation capital program planning process. Examples include:

- New lane-miles of infrastructure.
- Number of new electric vehicle chargers.
- Number of diesel-powered buses replaced by electric buses.
- Dollars invested in electric bike incentives.
- Dollars invested in roadway resurfacing.

The tool is designed to be updated in real-time, so that results can be seen as soon as new project information is provided by the user.

Outputs: The tool generates valuable, customizable outputs, including:

- A baseline inventory and forecast of GHG emissions.
- Estimated GHG emissions and related impacts of a capital program -- or a hypothetical set of capital projects -- across user-selected horizon years.
- Information on the cost-effectiveness of various project types.

TEA-CART relies on data that is typical for projects of a given type. For more detailed, project-specific evaluation, users may want to refer to project-specific tools such as the Federal Highway Administration Congestion Mitigation and Air Quality Improvement Program (CMAQ) Emissions Calculator Toolkit.

2.0 User Guide

2.1 General Information

As users enter data, it is important to keep in mind the following:

- This application does not require a login and is free to use.
- In the left side panel, there is a button to "Download User Inputs." Clicking on this button also is how you save your work. It is essential that you **download data from the server** before exiting the application. If you need to leave the application before completing the analysis, you can later **upload the saved .csv file** to continue your work.
- The **About** and **How-to** sections of the tool (top-line tabs) provide **information about the tool** and how to use it.
- **Data are entered in tables** in the tabs under the **Inputs** tab**.** To begin entering (or editing) data, **double click** anywhere in the table using your mouse. When you are done entering data, press **CTRL + ENTER** on your keyboard (this initiates the calculation). Data can only be entered for one table at a time.
  - Note: Under the **Inputs** tab, users may either enter data under the **Projects** tab (using project-level information) or the **Budget** tab (i.e., dollar values), but not both.
- When you are ready to see the results of your analysis, proceed to the **Scenarios** tab under the **Inputs** tab and select scenarios for analysis. Either choose groups of projects (to support a comparison) or click the button to select all projects for each scenario.

2.2 Inputs

2.2.1 'Baseline' Tab

In the **Baseline** tab, tool users are prompted to enter baseline inputs to define the timing and scope of your TEA-CART analysis. Specifically, the following inputs should be entered:

- **State** – The state for which the user is conducting the analysis. The user may also conduct analysis for all 50 states if the United States option is selected.
- **Base Year** – This represents the first year of data for reporting in the analysis, and serves as the reference point for assuming baseline trends. Note that 2021 is the earliest year of data available in TEA-CART.
- **Horizon Years** – The horizon years represent the desired future "reporting" years (i.e., the years for which the user provides inputs and emissions outputs are reported). Up to three horizon years can be selected through 2050.
- **Transportation System Scope** – This represents the scope of the transportation system to be included in the analysis. Users are prompted to choose between two options:

- **All Roadways**: The tool will report emissions from on-road travel on all state roadways.
- **NHS Only**: The tool will report emissions from on-road travel on National Highway System (NHS) roadways only. This option is provided to assist in reporting for and aligning with any GHG performance measures that might be established specific to the NHS.

- **Select Mode**: The user selects either Capital Projects mode or Budget mode to indicate whether **input** data will be entered under the Projects tab (using project-level information) or the Budget tab (i.e., dollar values).
- **Emissions Scope** – This represents the scope of emissions to be included in the analysis. Users are prompted to define the scope of transportation emissions which are reported. By default, all direct emissions (emissions that occur at the vehicle tailpipe) are reported. However, users can select whether reported emissions should also include:
  - **Electricity**: Emissions associated with electricity generated by power plants to power electric vehicles. Data sources are described in Section 3.1, 'Greenhouse Gas Inventory.'
  - **Upstream Fuels**: Emissions associated with the production and transportation of fuels (other than electricity), including gas, diesel, and compressed natural gas (CNG). These types of emissions are typically included in full life-cycle or "well-to-wheels" analyses. Data sources are described in Section 3.1, 'Greenhouse Gas Inventory.'
- **Apply Land Use Multiplier to Transit Investment** – TEA-CART provides an option to apply the "land use multiplier" to transit investment. This multiplier represents total VMT reduction, including reductions related to more efficient land use patterns supported by transit, relative to the direct VMT reduction from increased transit ridership. See Section 3.2.2, 'Transit: Increased Fixed Route Service' for additional details on how the land use multiplier works.
- **VMT Forecast** – This represents the VMT forecast used for baseline projections. Users are prompted to select one of the following two options for the baseline VMT forecast:
  - **Default**: The default VMT forecast represents a state-specific forecast which takes state-level VMT data from the U.S. Department of Transportation (DOT) Highway Statistics series in 2019, and derives a forecast based on national projections from the U.S. Department of Energy Annual Energy Outlook (AEO) apportioned by state based on population forecasts as described in Section 3.1.1[1], 'On-Road Mobile Sources.' The forecast reports VMT across four vehicle categories: Passenger Cars, Light-Duty Passenger Trucks, Medium-Duty Trucks, and Heavy-Duty Trucks.
  - **Custom**: If the tool user would like to instead provide a custom VMT forecast for the state, the user will select the *Custom* option. Tool users will then go to the **Advanced** tab, which will direct them to enter a custom VMT forecast in the *Advanced 2* table. <u>Note</u> - the forecast must be entered between

[1] To create the default state-specific VMT forecasts, state VMT is first projected to increase from base year levels for the state at the same rate as the state's forecast population growth. The forecasts for each state are then adjusted based on the ratio of total U.S. VMT growth, as forecast by the AEO, to the total U.S. VMT growth based on the state-specific population forecasts. In this way, total U.S. VMT growth is consistent with AEO forecasts, but state-level VMT forecasts reflect projected state-specific population trends.

the base year and the latest horizon year, and must be broken out by the four vehicle categories (noted in the previous bullet).

- **Vehicle Electrification Baseline** – This represents the zero-emissions vehicle (ZEV) forecast used for baseline projections.[2] Users are prompted to select one of the following options for the baseline vehicle electrification forecast scenario:

  - **AEO Baseline**: A baseline vehicle electrification forecast from the 2023 AEO Reference Case. This is a conservative forecast projecting that approximately 10 percent of light-duty vehicles (stock) and less than 1 percent of trucks (stock) will be zero-emissions by 2050. Users in states that do not have any policies in place to require or incentivize ZEVs, that are observing relatively slow adoption of ZEVs, or that otherwise wish to be as conservative as possible about vehicle electrification projections, may wish to use this forecast.

  - **ACCII**: Vehicle electrification forecast which models the statewide adoption of rules emulating California's Advanced Clean Cars II (ACCII) rule.[3] This is an ambitious electrification forecast for light-duty vehicles, based on zero-emission vehicle (ZEV) projections from the California Air Resources Board (see Section 3.1.1, 'On-Road Mobile Sources'), which assumes that over 90 percent of light-duty vehicles will be zero-emissions by 2050. States that have adopted a clean cars rule consistent with ACCII (but not a clean trucks rule) and/or expect the targets to be fully achieved within their jurisdiction may wish to use this forecast.

  - **ACCII + ACT**: Vehicle electrification forecast which models the statewide adoption of rules emulating California's Advanced Clean Cars II and Advanced Clean Trucks rules.[4] This is an ambitious electrification forecast for all on-road vehicles, based on ZEV projections from the California Air Resources Board (CARB) which assume that over 90 percent of light-duty vehicles, half of medium-duty trucks, and one-quarter of heavy-duty trucks will be zero-emissions by 2050. States that have adopted a clean cars rule consistent with ACCII and a clean trucks rule, and/or expect the targets to be fully achieved within their jurisdiction, may wish to use this forecast.

  - **Custom**: If the tool user would like to instead use a custom electrification forecast for the state, the user will select the *Custom* option. Tool users will then go to the **Advanced** tab, which will direct them to enter a custom electrification forecast in the *Advanced 1* table. The forecast must be entered between the base year and the latest horizon year, and must be broken out to the four vehicle categories: Passenger Cars, Light-duty Passenger Trucks, Medium-duty Trucks, and Heavy-duty Trucks. The numbers entered for the forecast must represent vehicle stock percentages (not vehicle sales percentages). States may wish to use a custom forecast if they have not adopted ACC or ACT rules, but have reason to believe that ZEV market penetration will be higher than the AEO projections, because of other state and/or federal incentives and/or because of favorable market conditions for ZEVs in their state.

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[2] The "vehicle electrification" forecasts may include any ZEV technology for the purpose of estimating direct (tailpipe) emissions. However, TEA-CART will not properly estimate upstream emissions associated with ZEV technologies other than battery-electric vehicles, including hydrogen fuel-cell vehicles.

[3] In June 2025, Congress passed, and President Trump signed, a joint resolution rescinding California's authority to implement this regulation. The legality of this action is being challenged and is currently unresolved.

[4] Id.

- **Electricity Grid Emissions Net-Zero Year** – If the selected state has policies in place to decarbonize its electricity grid by a certain year (by 2050 or earlier), users can select the horizon year for a zero-emissions grid (see Section 3.1, 'Greenhouse Gas Inventory' for sources).

- **Include Rail Emission** – The user may include emissions from passenger rail and freight rail in the Baseline emissions forecast by selecting "Yes" from the dropdown menu. Otherwise, these off-road emissions will be excluded from the Baseline.

2.2.2 'Projects' Tab

In the **Projects** tab, tool users are prompted to enter project-level information across a series of project categories for which they would like to estimate the emissions impacts. The **Projects** tab accepts inputs in the form of quantities of infrastructure or service provided. Alternatively, the user can use the **Budget** tab (see Section 2.2.3, ''Budget' Tab') to enter a total budget and share of allocation of that budget across project types.

Within each project category, users must enter the relevant project data input in the units specified in the *Unit* column. As a reminder, when entering data, users should:

- Double-click a table to enter data.
- Press CTRL + ENTER to finish entering data. (Note, your cursor must be in a cell, inside a table, for this to work).
- Enter data for one table at a time.
- To clear entered data for a given table, click the "Reset Projects" button to the right of the table.
- Remember to click "Download User Inputs," to periodically save your work.

The **Projects** tab includes columns for each of the horizon years of the analysis. When inputting project data under a given horizon year, it is essential to understand two important rules of data entry:

- First, all entered projects are assumed to be "constructed" or "in operation" by the year of the column where they are input (horizon year). For example, if the user inputs 2 miles of bike lanes in the column for the first Horizon Year (e.g., 2025), it is assumed those bicycle lanes are fully constructed by 2025.

- Second, project inputs from one year are automatically coded to "carry over" into future years. In other words, the entry for the first Horizon Year represents the total new project implementation up to and including that year, and the entry for any subsequent Horizon Year represents the total new project implementation in the year(s) since the previous Horizon Year. The sum of the entries for each Horizon Year is equal to the total project implementation between the Base Year and the furthest Horizon Year. (For reference, TEA-CART calculates cumulative values of each project type in each horizon year. See Section 2.3.5, ''Cumulative Project Totals' Tab)

To clarify this concept, consider the two examples below.

Figure 1 shows an example of a user estimating the effects of new shared-use paths. The first row shows 2 miles of Core (i.e., a high-density urban core area type) shared-use paths being built in 2025. No additional data is entered for 2030 nor 2035. Therefore, since the 2 miles of Core shared-use paths in 2025 "carry over" into future years, it is assumed there will still be a total of 2 miles of Core shared-use paths in 2030 and 2035.

Alternatively, in the second row, two miles of Urban shared-use paths are built in 2025. However, a value of 3.0 is entered in 2030, representing 3 *additional miles* of shared-use paths. Because the 2 miles from 2025 carry over, this input represents a total of *5 miles* of Urban shared-use paths by 2030.

Figure 1: Sample Project Input Data for Shared-Use Paths

Area Type	Facility Type	Unit	2025	2030	2035
Core	New shared-use path	New lane-miles	2	0	0
Urban	New shared-use path	New lane-miles	2	3	0

Figure 2 shows a different example of a user estimating the impacts of transit fleet electrification. In this example, the user has tested the impacts of converting urban diesel buses to electric buses, with 10 vehicles converted by 2025, an *additional* 20 buses converted by 2030, and an *additional* 30 buses converted by 2035. Taken together, using this set of inputs, TEA-CART will estimate the effect of converting a *total* of 10 buses by 2025, 30 buses by 2030, and 60 buses by 2035. In such an example, it is assumed that once a fossil fuel vehicle is replaced with an electric vehicle, future replacement vehicles will assume the new technology type (i.e., new electric buses will not be replaced with fossil fuel buses at the end of their life span).

Figure 2: Sample Project Input Data for Transit Fleet Electrification

Area Type	Fuel Type	Transit Mode	Unit	2025	2030	2035
Urban	Diesel	Bus	Vehicles replaced	10	20	30

2.2.3 'Budget' Tab

This tab provides an alternative to the **Project** tab for entering project inputs. The user first enters:

- The start year of funding.
- The total number of years covered by the funding.
- The total amount of funding over that period, in millions of dollars (note – this is cumulative funding over the period, not average annual funding). Since the default cost dollar value year is 2024, the user may wish to convert future funding into 2024 dollars for consistency, or alternatively, to adjust cost values to represent an expected future year unit cost. For a multi-year horizon, the midpoint year of the funding horizon could be used to convert future dollars to 2024 dollars. One option is to use the historical rate of change of the National Highway Construction Cost Index (NHCCI)[5] as the expected future rate of

[5] https://www.fhwa.dot.gov/policy/otps/nhcci/

inflation. The user may wish to be consistent with the assumptions built into funding forecasts for the agency's capital program. Consider the following example:

- The analysis horizon is five years (2026 through 2030).
- The user wishes to evaluate a total budget of $100 million per year (in nominal dollars) over this period.
- The NHCCI increased by a factor of 1.76 between first quarter 2015 and first quarter 2025, equivalent to a compound annual growth rate of 5.8 percent.
- Converting the midpoint year (2028) to 2024 dollars would equate to an average annual funding level of $100 million / (1.058)^4 = $80 million annually expressed in 2024 dollars.

- The share of that budget that is allocated to any of the carbon reduction strategies included in the tool. If this share is set to less than 100 percent, then any non-allocated budget is not modeled by the tool. In other words, it is assumed that the non-allocated budget is directed towards activities that neither increase nor decrease VMT or GHG emissions. If any projects are expected to have a non-zero effect on emissions but TEA-CART does not have a corresponding entry option, users may choose to use supplemental tools to get a more complete picture of the emissions implications of a capital plan.

The user then scrolls down to "Budget 1," Budget 2," etc. and enters the share of total funding that is directed towards each type of project. The "Funding Summary" table at the top of this tab shows both the share (% allocated) and dollar value of funding for each strategy type. The Funding Summary table cannot be edited directly.

Important note: Once the **Budget** inputs have been entered, the user has to click on the "Fill Project Tab with Budget Inputs" option in order to generate outputs.

It is also important to note that the tool converts budget inputs to project quantities using average or typical unit project costs. This conversion will not be accurate for projects that have substantially different unit costs than average. That might include, for example, a highway expansion or a shared-use path involving a long bridge span for which costs per unit length might be orders of magnitude higher than a typical highway cost per lane-mile or shared-use cost per mile.

2.2.4 'Costs' Tab

The **Costs** tab provides information on the cost inputs for the various project categories. Users can double-click on the different fields to overwrite the default values with any custom values provided by the user. In order to restore values back to the default values, users should click the "Reset Costs" button in the top right corner of the table.

Note that when the user chooses to provide budget inputs rather than project quantities, the unit cost assumptions will affect the estimates of VMT and emissions reductions. That is because the tool uses unit costs to translate total dollar values into quantities of infrastructure or services, which are then used to estimate emission reductions. When providing dollar value inputs, users should be especially careful to review the default unit cost assumptions and update these as appropriate for their own jurisdiction. Using unit costs that are too low will result in an overestimate of the amount of infrastructure or service added, and therefore the emissions impacts. Conversely, using unit costs that are too high will result in an underestimate of emissions impacts. Users should be especially careful when their program includes projects with extremely high costs compared to average values for that type of project.

If a user is entering project quantities rather than budget inputs, the emissions results will not be affected by the unit cost estimates, but the cost-effectiveness estimates will be affected.

Note that default costs included in the tool are expressed in 2024 dollars. The user may wish to enter custom costs in 2024 dollars for consistency with default values, or use a different dollar year of their choosing for all cost inputs. The dollar year of unit costs should be consistent with the dollar year in which funding levels are provided. See section 2.2.3, above, for further guidance on adjusting costs for future inflation.

Also note there are no unit cost inputs for transit service cuts *Projects* | *16* because service cuts would reduce costs and therefore cost-effectiveness is not defined.

2.2.5 'Assumptions' Tab

The **Assumptions** tab provides information on the input assumptions for the various project categories. These inputs affect the GHG impact and effectiveness of each strategy category. Examples include average trip lengths by mode and average traffic volumes by road type. Users can double-click on the different fields to overwrite the default values with any custom values provided by the user. To restore values back to the default values, click the "Reset Assumptions" button in the top right corner of the table.

2.2.6 'Scenarios' Tab

The **Scenarios** tab provides the different possible strategies provided in the TEA-CART analysis. Users can select the desired combination of strategies to be used as forecast "scenarios." The resulting output can be used to compare up to two scenarios, each of which can include one or more of the project strategies provided.

2.2.7 'Advanced' Tab

The **Advanced** tab (far right under the **Inputs** tab) allows users to input advanced custom assumptions for the baseline forecast. Custom inputs can be specified for EV adoption (vehicle stock by year), VMT by vehicle type and year, public transit fuel technology fractions, passenger rail energy source, various freight rail parameters, construction and maintenance emissions, and fuel apportionments (share of plug-in hybrid vehicles driven on electricity). Note that the construction and maintenance emissions option (set to zero as the default) allows the user to enter a single unit emissions value for all construction and maintenance of their programmed projects (this emissions estimate would be obtained using another method, such as the Federal Highway Administration Infrastructure Carbon Estimator).

2.3 Outputs

2.3.1 'Baseline GHG Forecast' Tab

In the **Baseline GHG Forecast** tab, a baseline GHG inventory and forecast is reported based on the information provided in the **Inputs** tabs.

Emissions are reported for the Base Year and Horizon Year(s) across the various surface transportation emission categories.

2.3.2 'Scenario Summary' Tab

In the **Scenario Summary** tab, scenario-level outputs are reported for greenhouse gas emissions (metric tons of carbon dioxide equivalent), VMT, local pollution including oxides of nitrogen (NO_x) and fine particulates ($PM_{2.5}$), and daily active trips[6]. The specific output is selected by the user via a drop-down menu.

To save outputs from your analysis, click the "Download Output Tables" on the left side panel of the tool.

2.3.3 'Strategy Summary' Tab

In the **Strategy Summary** tab, strategy-level outputs are reported for greenhouse gas emissions (metric tons of carbon dioxide equivalent), VMT, local pollution including NO_x and $PM_{2.5}$, and daily active trips. The specific output is selected by the user via a drop-down menu.

2.3.4 'Cost-Effectiveness' Tab

In the **Cost-Effectiveness** tab, users can review the cost-effectiveness of each strategy, as measured by change in annual output of indicator (e.g., metric tons GHG) per $1 million of investment. All cells with the "***" label indicate that a strategy is expected to reduce greenhouse gas emissions *and* save money. All cost-effectiveness information is calculated based on values entered in the **Baseline**, **Costs** and **Assumptions Inputs** tabs (user-provided inputs in the **Projects** or **Budget** tabs do not affect cost effectiveness). Cost-effectiveness is calculated as the change in annual emissions in the first horizon year divided by the average annual cost of the strategy.

2.3.5 'Cumulative Project Totals' Tab

In the **Cumulative Project Totals** tab, information in the tables represents the cumulative total quantity of each project or service type implemented by each horizon year, based on user inputs in the **Projects** tab.

2.4 Quick Reference Guide for Tool Inputs

Table 2-1 summarizes the inputs that a user can enter and/or modify in the tool's **Inputs** tabs, for each of the listed strategies or parameters.

Inputs for transit service cuts can only be provided when using the tool in the **Projects** mode, and not in the **Budget** mode.

Additionally, there are no cost input tables for *Costs 4* (transit fleet electrification) or *Costs 17* (transit service cuts). Costs related to transit electrification can be found in *Costs 2* (i.e., with other transit vehicle costs).

[6] Local pollutants are sourced on a per-mile basis for different vehicle and fuel types from the U.S.DOT (2024), which sources these emission rates from MOVES4. Emission rates from year 2021 are reduced in future years in proportion to the change in average fuel economy of the fleet. Note that emission rates may vary locally and by evaluation year. For more precise estimates of local pollutants, users may wish to apply emission factors for the horizon year based on MOVES runs (or EMFAC in California) using the latest available inputs for the location being analyzed.

Transit service cuts result in cost savings and therefore the cost-effectiveness of this action is not defined. Costs related to transit service cuts cannot be updated by the user.

Table 2-1: Cross-referencing Strategies and Parameters with Input Tabs

Table No.	Strategy / Parameter	Projects	Budget	Costs
1	**Bicycle & Pedestrian Lane Miles of New Infrastructure**	✓	✓	✓
2	**Transit: Increased Fixed Route Service**	✓	✓	✓
3	**Transit: Increased Demand Response Service**	✓	✓	✓
4	**Transit: Fleet Electrification**	✓	✓	
5	**Public Transportation: Bus Priority Treatment**	✓	✓	✓
6	**Public Transportation: Rail**	✓	✓	✓
7	**Travel Demand Management (TDM)**	✓	✓	✓
8	**Micromobility**	✓	✓	✓
9	**Traffic Operations - Intersection Improvements**	✓	✓	✓
10	**Medium- and Heavy-Duty Vehicle (MHDV) Replacement**	✓	✓	✓
11	**Park-and-Ride Projects**	✓	✓	✓
12	**Charging Infrastructure and EV Incentives**	✓	✓	✓
13	**Freight Intermodal Facilities**	✓	✓	✓
14	**Roadway Expansion**	✓	✓	✓
15	**Roadway Resurfacing**	✓	✓	✓
16	**Land Use**	✓	✓	✓
17	**Transit Service Cuts**	✓		
18	**Fuel Price**			✓

3.0 Methodology

3.1 Greenhouse Gas Inventory

The first functionality of the tool is to construct a baseline greenhouse gas inventory and forecast using a few key data inputs and variables. The tool estimates emissions for the following subsectors of transportation activity:

- On-road mobile sources including light-duty vehicles, medium-duty and heavy-duty trucks, and buses other than public transit buses.
- On-road public transit buses.
- Passenger rail (including urban and intercity rail).
- Freight rail.

The tool does not include aviation, marine, or off-road sources other than passenger and freight rail.

Table 3-1 provides fuel emission factors and other conversion factors that are used for all emissions source (vehicle) types. Consistent with practices in many states where biofuels are assumed to result in zero emissions from the transportation sector, the emission factors exclude the biofuel portion of the fuel blend (based on national average blend rates).

Table 3-1: Global Fuel and Energy Parameters

Variable	Source	Values	Methodology Notes
Conventional fuel emission factors	U.S. Environmental Protection Agency (U.S. EPA, 2023a)	Gasoline (kg CO_2/gal) – 7.94 Diesel (kg CO_2/gal) – 9.40 CNG (kg CO_2/cubic foot) – 0.0544	Gasoline and diesel are exclusive of blended biofuels (at national average blend)
Upstream emission factors – fossil fuels	Argonne National Laboratory, GREET v2021	Gasoline – 0.24 Diesel – 0.21 CNG – 0.29	Values applied as a multiplier on direct emissions rate
Electricity emission factors	U.S. EPA – eGRID (U.S. EPA, 2023b)	Data sourced at the state level, measured in grams per megawatt-hour (g/MWh)	NA
kWh per gallon gasoline equivalent	Calculated from BTU/gal and kWh/BTU	34.0	NA
gallon diesel per gallon gasoline equiv.	USDOE (2023c)	0.893	NA
cubic feet CNG per gallon gasoline equivalent	USDOE (2023c)	123.6	NA
BTU per kWH	Physical constant	3,414	NA
BTU per gallon gasoline	USDOE (2023c)	116,000	Low heating value
BTU per gallon diesel	USDOE (2023c)	128,500	Low heating value

Variable	Source	Values	Methodology Notes
CNG to diesel energy efficiency ratio	CARB (2020)	0.9	NA

3.1.1 On-Road Mobile Sources

Table 3-2 provides the key variables and sources, as well as methodological notes for the emissions forecast for on-road mobile sources.

Table 3-2: On-Road Mobile Sources Emissions: Sources and Methodology

Variable	Source	Methodology Notes
Vehicle fuel economy	AEO 2023 Reference Case (U.S. Department of Energy (DOE), 2023a)	Broken out by vehicle type and fuel type • Vehicle types include: passenger car, light-duty truck, medium-duty truck, heavy-duty truck • Fuel types include gasoline, diesel, electric
Vehicle-miles traveled	Federal Highway Administration (FHWA) Highway Statistics (FHWA, 2019), 2023 AEO (U.S. DOE, 2023a), Weldon Cooper Center	Default VMT by state is projected starting with base-year VMT by state from FHWA's 2019 Highway Statistics, with growth rates based on state-specific population forecasts adjusted so that the sum of state VMT matches the U.S. VMT projected growth from the 2023 AEO Reference Case s
Vehicle technology fractions	2023 AEO (U.S. DOE, 2023a); California Air Resources Board (CARB)[7]	Vehicle technology fraction forecasts are broken out by vehicle type; default forecasts provided by U.S. DOE 2023 AEO; policy scenario forecasts provided by CARB

For each vehicle type-fuel type combination, emissions are calculated as:

*Annual emissions = vehicle miles traveled * emission rate*

Where:

*Emission rate (g/mi) = emission factor (kg/gal) / fuel economy (mi/gal) * 1,000*

OR

*Emission rate (g/mi) = emission factor (g/MWh) * kWh/mi / 1,000*

Emissions from all vehicle type-fuel type combinations are then summed to calculate total emissions. Since buses are captured in FHWA VMT estimates, emissions from on-road public transit (calculated separately) are subtracted out of the "on-road mobile sources" total to avoid double-counting.

[7] California Air Resources Board. Modeling estimates for Advanced Clean Cars II and Advanced Clean Trucks obtained through email correspondence, 2023.

3.1.2 On-road Public Transit

Table 3-3 provides the key variables and sources, as well as methodological notes for the emissions forecast for on-road public transit sources.

Table 3-3: On-Road Public Transit Emissions: Sources and Methodology

Variable	Source	Methodology Notes
Transit vehicle revenue miles	Federal Transit Administration (FTA) – National Transit Database (NTD) (FTA, 2019)	State-level data, broken out by service type (fixed-route, demand response) and area type (urban, rural)
Transit vehicle fuel economy	FTA NTD 2019 (FTA, 2019), National Renewable Energy Laboratory (NREL, 2018)	Conventional fuel economy reported by vehicle type and fuel type from FTA; electric vehicle fuel economy provided by NREL
Conventional and electricity fuel emission factors	See Table 3-2	NA

3.1.3 Passenger Rail

Table 3-4 provides the key variables and sources, as well as methodological notes for the emissions forecast for passenger rail sources.

Table 3-4: Passenger Rail Emissions: Sources and Methodology

Variable	Source	Methodology Notes
Passenger miles	FTA NTD 2019 (FTA, 2019)	Broken out by service type (light rail, heavy rail, commuter rail)
Energy intensity	Oak Ridge National Laboratory (Oak Ridge, 2022)	Measured in British thermal units (Btu) per ton-mile; broken out by service type (light rail, heavy rail, commuter rail)
Conventional and electricity fuel emission factors	See Table 3-2	NA

3.1.4 Freight Rail

Table 3-5 provides the key variables and sources, as well as methodological notes for the emissions forecast for freight rail sources.

Table 3-5: Freight Rail Emissions: Sources and Methodology

Variable	Source	Methodology Notes
Freight ton-miles	FHWA Freight Analysis Framework (FHWA FAF5)	NA
Energy intensity	Oak Ridge (2022)	Measured in BTU per ton-mile
Conventional fuel emission factors	See Table 3-2	NA

3.2 Strategy Analysis

TEA-CART estimates the greenhouse gas and other impacts of various types of projects typically funded through a capital program, relative to the baseline forecast emissions projected by the tool. The following sections describe the key variables, equations, and data sources for each strategy.

Each strategy is evaluated independently, and potential interactive effects among strategies are not considered. However, the selected baseline assumptions may affect the estimates of strategy effectiveness. For example, a higher electrification forecast will lead to lower absolute levels of emission reductions from VMT reduction strategies. This is because while VMT reductions are independent of the degree of electrification, the vehicle emission rate (grams per mile) will be lower at higher levels of electrification, and therefore the total emissions reduction from a given amount of VMT reduction will be smaller. Similarly, the benefits of transit service increases will be affected by the assumptions regarding baseline public transit fuel technology fractions (which may be edited in the **Advanced** tab under the **Inputs** tab).

Note that when inputs are provided as dollar values (e.g., in the **Budget** tab) rather than quantities of projects, the cost assumptions will affect the estimates of VMT and emissions reductions. That is because the tool uses unit costs to translate total dollar values into quantities of infrastructure or services, which are then used to estimate emission reductions. When providing dollar value inputs, users should be especially careful to review the default unit cost assumptions and update these as appropriate for their own jurisdiction. Also, the user may wish to exclude or separately evaluate projects with extremely high unit costs (e.g., a bridge project that includes added lanes). See Section 2.2.3,'‘Budget’ Tab’, and Section 2.2.4, ‘‘Costs’ Tab’, for a discussion of appropriate dollar value inputs.

3.2.1 Bicycle and Pedestrian Facilities

TEA-CART estimates the GHG impact of increased bicycle and pedestrian facilities based on the change in emissions resulting from displaced VMT. The tool prompts users to input the number of new facility miles of infrastructure broken out by two dimensions:

- Facility type: Six options including: shared use path (off-street); bicycle lane (on-street, not separated from traffic); separated bike lane (physically separated and protected from traffic using curbs, bollards, flexible posts, etc.); sidewalk; Complete Streets treatment (bicycle lanes and pedestrian improvements); and widened shoulders. Bicycle lane-miles represent <u>two-way miles</u>, e.g., a 1-mile segment of bidirectional road with bike lanes serving both directions would be entered in TEA-CART as 1 new mile of bike lane. For facilities providing only one direction of service, enter half of the total mileage of the new facility.

- Area type: Four options including core, urban, suburban, or rural, based on population density (preferably at the census tract or block group level), with the categories shown in Table 3-6.

Table 3-6: Area Type Categories for Bicycle and Pedestrian Facilities

Area Type	Population Density (persons per square mile)
Core	>10,000
Urban	4,000 – 10,000
Suburban	500 – 4,000
Rural	<500

Emissions are calculated per the following equation, with Table 3-7 providing the sources and methodological notes for the key variables in the calculations. The annualization factor, average trip length, and prior drive mode shares may be changed under *Assumptions 1* of the **Assumptions** tab.

*Change in emissions = new facility miles * new daily users per facility mile * annualization factor * average trip length * prior drive mode share * light-duty vehicle emission rate*

Table 3-7: Strategy Analysis Data Sources: Bicycle and Pedestrian

Variable	Source/Value	Methodology Notes
New daily active travel users per facility mile	Varies by facility type and area type	See Section 3.4.1
Annualization factor	365	Assumption that the estimates of average daily users per facility mile are based on annual data
Average trip length	2017 National Household Travel Survey (NHTS) (McGuckin and Fucci, 2018) - 0.7 mi for walk, 2.3 mi for bike	Reported separately for walking trips and cycling trips
Prior drive mode share	Varies from 47% to 75% by area type	See Section 3.4.2
Light-duty vehicle emission rate	See Table 3-2	NA

3.2.2 Transit: Increased Fixed Route Service

TEA-CART estimates the GHG impact of increased fixed-route transit service, which is defined as buses operated along a prescribed route according to a fixed schedule. TEA-CART considers both the increased emissions from the provision of the new service and the displaced emissions resulting from increased ridership and decreased VMT.

The tool prompts users to input the number of new vehicles operated in maximum service (VOMS). For bus service, these inputs are broken out by area type (urban or rural) and fuel type of the vehicle (diesel, CNG, or electric). “Urban” and “rural” area types are defined consistent with National Transit Database reporting which classifies transit providers as either urban or rural based on whether or not they serve a Census-defined urbanized area (UZA). Emissions are calculated using the following equation, with Table 3-8 providing the sources and methodological notes for the key variables in the calculations. Load factors, prior drive mode shares, vehicle revenue-miles (VRM) per vehicle, and fuel economy may be changed under *Assumptions* 2 of the **Assumptions** tab. Note – if the user would like to evaluate a planned change in VRM rather than a change in VOMs, they can divide the total planned change in VRM by the average VRM per vehicle to estimate the number of VOMs to enter into TEA-CART.

*Change in emissions = # of VOMS * VRM per vehicle * transit vehicle fuel economy * fuel emission factor – change in automobile VMT * light-duty vehicle emission rate * land use multiplier [if selected]*

Where,

*Change in automobile VMT = # of VOMS * VRM per vehicle * load factor * prior drive mode share*

TEA-CART also provides an option to apply the “land use multiplier” to transit investment. This multiplier represents total VMT reduction, including reductions related to more efficient land use patterns supported by transit, relative to the direct VMT reduction from increased transit ridership. NASEM (2021) found a median value of the land use multiplier of 6.03 across all transit agencies studied. These effects, to the extent they are observed, will be indirect and likely to emerge over longer time horizons. If the user selects the “apply land use multiplier” option on the **Baseline** tab, the change in automobile VMT is multiplied by 6.03. Please note that this feature may result in double counting of transit-related VMT reductions if the user also includes ‘Land Use” related projects under the **Projects** tab (e.g., mixed-use transit-oriented development).

Table 3-8: Strategy Analysis Data Sources: Transit Service

Variable	Source/Value	Methodology Notes
VRM per vehicle	FTA NTD 2019 (FTA, 2019)	Broken out by state and area type (urban, rural)
Transit vehicle fuel economy	FTA NTD 2019 (FTA, 2019)	State-specific average fuel economy reported
Transit load factor	FTA NTD 2019 (FTA, 2019)	State-specific value calculated as passenger-miles per vehicle-mile
Prior drive mode share	Varies from 47% to 75% by area type	See Section 3.4.2
Land use multiplier	6.03 per NASEM (2021)	National average
Fuel emission factors	See Table 3-2	NA
Light-duty vehicle emission rate	See Table 3-2	NA

When quantities of transit service are input, the cost-effectiveness estimate considers both capital and operating costs. However, when budget inputs are provided, only the capital cost (e.g., new vehicles needed to operate increased service) is included since operating costs are typically funded through agency operating budgets.

3.2.3 Transit: Increased Demand Response Service

TEA-CART estimates the GHG impact of increased demand response transit service, defined as non-fixed route services that are initiated by customers and require advanced scheduling, such as vehicles provided by public entities, nonprofits, and private providers. These inputs are broken out by area type (urban or rural) and fuel type of the vehicle (gasoline, CNG, or electric). “Urban” and “rural” area types are defined consistent with National Transit Database reporting which classifies transit providers as either urban or rural. The methodology and data sources are the same as for *Transit: Increased Fixed Route Service* as described in

Section 3.2.2. Default values of VRM per vehicle, fuel economy, and load factors are state averages specific to the Demand Response (DR) mode reported in the National Transit Database.

3.2.4 Fleet Electrification

TEA-CART estimates the GHG impact of transit fleet electrification by computing the change in emissions from the replacement of a conventional fuel transit vehicle with an electric transit vehicle. The tool prompts users to input the number of conventional fuel vehicles that will be electrified, broken out by the fuel type of the replaced vehicle (diesel, gas or CNG, or electric), the area type where the service is provided (urban or rural), and the transit mode (bus or demand response). "Urban" and "rural" area types are defined consistent with National Transit Database reporting which classifies transit providers as either urban or rural. Emissions are calculated using the following equation, with Table 3-9 providing the sources and methodological notes for the key variables in the calculations. The miles per vehicle and fuel economy assumptions may be changed under *Assumptions* 2 of the **Assumptions** tab.

*Change in emissions = # of vehicles * VRM per vehicle * (conventional fuel transit vehicle fuel economy * fuel emission factor – electric transit vehicle fuel economy * electricity emissions factor)*

Table 3-9: Strategy Analysis Data Sources: Transit Fleet Electrification

Variable	Source	Methodology Notes
Vehicle revenue-miles per vehicle	FTA NTD 2019 (FTA, 2019)	Broken out by state and area type (urban, rural)
Transit vehicle fuel economy	FTA NTD 2019 (FTA, 2019)	State-specific average fuel economy reported
Fuel and electricity emission factors	See Table 3-2	NA

TEA-CART assumes that any new vehicle is again replaced by the new technology type at the end of its life cycle. Per-vehicle costs are one-time costs, and future replacements are not assumed to incur any additional incremental costs.

Cautionary note: users should be mindful of the scale of the current vehicle stock of the fleet in the state being analyzed (to avoid electrifying more vehicles than exist in the current stock).

3.2.5 Public Transportation: Bus Priority Treatment

TEA-CART estimates the impacts of bus priority treatments that reduce travel time and improve reliability for transit riders along a corridor. Examples of priority treatments include transit signal priority, queue jump lanes, and bulb-outs at bus stops to reduce delays from pulling into traffic. The tool considers the emissions benefits of travelers shifting from driving to transit as a result of the service improvements.

The user must enter the street-miles to which the priority treatments are applied. Additionally, in *Assumptions 2* under the **Assumptions** tab, the user can change the default values for the number of routes to which treatments are applied (i.e., routes using the affected streets), the number of daily buses per route, and the percent of route-hours on these routes assuming to materially benefit from the treatments. For example, the user might estimate that only peak-period operations benefit and that off-peak bus travel times might be similar with or without the treatments. Here, the user can also change default values in the tool for the percent travel time change on the affected route and the ridership elasticity (percent change in riders with respect to a percent change in travel times). Emissions are calculated using the following equation, with Table 3-10 providing the sources and methodological notes for the key variables in the calculations.

*Change in emissions = miles of bus priority treatment * # of routes covered * # of daily buses per route * % hours affected * annualization factor * load factor * % travel time improvement * ridership elasticity with respect to travel time * prior drive mode share * light-duty vehicle emission rate*

Table 3-10: Strategy Analysis Data Sources: Bus Priority Treatment

Variable	Source/Value	Methodology Notes
Annualization factor	250	Assumes weekday benefits only
Transit load factor	FTA NTD 2019 (FTA, 2019)	State-specific value calculated as passenger-miles per vehicle-mile
% travel time improvement	10%	Based on data from TCRP Synthesis 83 (Danaher, 2010)
Ridership elasticity with respect to travel time	-0.4	See Evans, et al (2004)
Prior drive mode share	Varies from 47% to 75% by area type	See Section 3.4.2
Light-duty vehicle emission rate	See Table 3-2	NA

3.2.6 Public Transportation: Rail

TEA-CART estimates the GHG impact of increased rail service, include service on light rail or streetcar lines, heavy rail, and commuter rail. The methodology and data sources are the same as for *Transit: Increased Fixed Route Service* as described in Section 3.2.2, with users entering the total number of vehicles added in maximum service. For rail service, these inputs are broken out by the type of service (electric light rail/street car, electric heavy rail, or diesel or electric commuter rail). Default values of VRM per vehicle, Energy use per vehicle, and load factors are state averages specific to the rail modes reported in the National Transit Database. Note that the costs and cost-effectiveness only account for vehicle capital and operating costs, i.e., increases in service levels on existing rail facilities. Capital costs associated with new or extended rail lines are not considered. When the tool is used with budget inputs, only the capital cost (e.g., new vehicles needed to operate increased service) is included since operating costs are typically funded through agency operating budgets.

3.2.7 Travel Demand Management

TEA-CART estimates the GHG impact of employer-sponsored travel demand management (TDM) programs by computing the change in emissions resulting from reduced work-related VMT. Specifically, the tool prompts users to enter the total number of employees that will be covered through the funded TDM programs. TDM programs are designed to shift travel demand and change traveler behavior, with the goal of reducing single-occupancy vehicle travel and encouraging the use of public transit, walking, biking, teleworking, and ridesharing.

Emissions for TDM are calculated per the following equation:

*Change in emissions = # of covered employees * % change in work VMT for covered employees * average work trip length * workday annualization factor * light-duty vehicle emissions rate*

Table 3-11 provides the sources and methodological notes for the key variables in the calculations. The average work trip length, annualization factor, and % change in work VMT may be changed under *Assumptions* 3 of the **Assumptions** tab.

Table 3-11: Strategy Analysis Data Sources: Travel Demand Management

Variable	Source/Value	Methodology Notes
Average work trip length (one-way mi)	12.7	FHWA (2018)
Workday annualization factor	250	= 50 weeks * 5 days/week
% change in work VMT for covered employees	5%	U.S. DOT (2010), p. 5-75, 5% reduction in SOV mode share; Boarnet (2014) as cited in California Air Pollution Control Officers Association (CAPCOA, 2021), 4-6% VMT reduction
Light-duty vehicle emission rate	See Table 3-2	NA

3.2.8 Micromobility

TEA-CART estimates the GHG impact of micromobility investments by measuring the change in VMT resulting from electric bicycle or “e-bike” subsidies that reimburse part of the cost of purchasing an e-bike. Specifically, the tool prompts users to input the total number of e-bikes that will be subsidized in the capital program. Emissions are calculated per the following equation, with Table 3-12 providing the sources and methodological notes for the key variables in the calculations. The average trip length, bike trips per week, prior drive mode share, and subsidy share per e-bike may be changed under *Assumptions 4* of the **Assumptions** tab.

*Change in emissions = # of e-bikes subsidized * (trips per bike per week / 7) * annualization factor * average bike trip length * prior drive mode share * light-duty vehicle emission rate*

Table 3-12: Strategy Analysis Data Sources: Micromobility

Variable	Source/Value	Methodology Notes
Average trip length	9.3	MacArthur et al (2018): Table 3-12, average for e-bike trips that replace automobile trips
Prior drive mode share	28%	MacArthur et al (2018): 28% said they were motivated to purchase an e-bike to replace car trips
Trips per bike per week	5.7	MacArthur et al (2018): Figure 3.6. 49% of e-bike owners ride e-bikes daily, 42% ride weekly; assume "daily" means 5 days per week
Annualization factor	365	Users in areas with a high degree of seasonal variation in e-bike use may want to reduce this factor
Subsidy per e-bike (% of cost)	50%	Assumption
Light-duty vehicle emission rate	See Table 3-2	NA

3.2.9 Traffic Operations

TEA-CART estimates the GHG impact of traffic operations strategies for two strategies: arterial signal re-timings and roundabout conversions. Carbon emission changes related to arterial signal re-timings depend on two offsetting effects: reduced delay from congestion (resulting in emission reduction), and induced travel resulting from higher travel speeds (resulting in higher emissions). The tool prompts users to input the number of signals to be re-timed or the number of intersections converted to roundabouts. Emissions are calculated using the following equation, with Table 3-13 providing the sources and methodological notes for the key variables in the calculations.

Arterial signal re-timing:

*Change in emissions = # of retimed signals * (% change in travel time * elasticity of VMT w/r/t change in travel time * annual average daily traffic (AADT) – reduced hours delay per vehicle * emissions per hour of delay * VMT)*

Where:

*Reduced hours of delay per vehicle [calculated for a sample 1-mile corridor with 2 signals] = - (1 / baseline travel speed) + (1 / (baseline travel speed * (1 + % travel time change))*

Roundabouts:

*Change in emissions = # of roundabouts * AADT * reduced* CO_2 *per vehicle*

The AADT, travel speed, and travel time elasticities may be changed under *Assumptions 5* of the **Assumptions** tab. The default assumptions for AADT and speed are different for urban vs. rural areas. Those area types are defined based on Census definitions of urban vs. rural areas[8] and are consistent with state classifications used for reporting traffic data to FHWA for publication in Highway Statistics.

Table 3-13: Strategy Analysis Data Sources: Traffic Operations

Variable	Source	Methodology Notes
Annual average daily traffic	Highway Statistics (FHWA, 2019)	State average data by facility type (highway, arterial) and area type (urban, rural)
Baseline travel speed	43 miles per hour (mph) based on National Highway Traffic Safety Administration (NHTSA) (MacArthur, 2015)	For principal urban arterial
Elasticity of VMT with respect to travel time	-0.30 based on [U.K.] Highways Agency (1997), Barr (2000)	[U.K.] Highways Agency (1997) recommended a value of -0.20 to -0.33 for "urban areas with low modal competition, or interurban"; Barr (2000) provided a range of -0.3 to -0.5
Re-timing impact: corridor travel time change (%)	12% based on U.S. DOT (2010)	U.S. DOT (2010), p. 4-24: travel time reductions of 8-25% possible for preset signals, or 8-41% for actuated signals

[8] See: https://www.census.gov/programs-surveys/geography/guidance/geo-areas/urban-rural.html

Variable	Source	Methodology Notes
Emissions per hour of delay	Derived from Texas A&M Transportation Institute (TTI, 2021) study	Based on estimates of delay-induced fuel consumption of 0.40 gal/hr (cars) or 1.7 ga/hr (heavy trucks) derived from TTI (2021), adjusted for future years based on ratio of future year to TTI study year average fuel efficiency from AEO
Roundabout CO_2e reduced per vehicle	0.067 kg CO_2/vehicle based on Hu *et al* (2014)	Study data was adjusted to account for increasing fuel efficiency by reducing the study value (0.085 average for two intersections) by the ratio of 2012 to 2025 light-duty vehicle average fuel economy from AEO

3.2.10 Medium- and Heavy-Duty Vehicle Replacement

TEA-CART estimates the GHG impact of medium- and heavy-duty vehicle (MHDV) replacement based on the change in emissions from the replacement of conventional fuel trucks with electric trucks.[9] (Public transit MHDVs are covered separately under the "Transit Electrification" strategy.) The tool prompts users to input the number of conventional fuel vehicles that will be electrified broken out by the fuel type of the replaced vehicle (diesel or gasoline). TEA-CART always assumes that any new electrified vehicles are additional to the ZEV stocks projected in the baseline. Emissions are calculated using the following equation, with Table 3-14 providing the sources and methodological notes for the key variables in the calculations. The annual miles per vehicle may be changed under *Assumptions 6* of the **Assumptions** tab.

*Change in emissions = # of vehicles * miles per vehicle * (conventional fuel vehicle emission rate – electric vehicle emission rate)*

Table 3-14: Strategy Analysis Data Sources: MHDV Replacement

Variable	Source	Methodology Notes
Miles per vehicle	Calculated by vehicle type based on selected VMT forecast divided by vehicle stock	NA
Vehicle emission rates	See Table 3-2	NA

TEA-CART assumes that any new vehicle is again replaced by the new technology type at the end of its life cycle. Per-vehicle costs are one-time costs, and future replacements are not assumed to incur any additional incremental costs.

Cautionary note: users should be mindful of the scale of the current vehicle stock of the fleet in the state being analyzed (to avoid electrifying more vehicles than exist in the current stock).

[9] Other ZEV technologies including hydrogen fuel-cell vehicles may be modeled using this strategy for impacts on direct (tailpipe) emissions. However, upstream emissions (electricity and/or fuel-cycle) will not be correctly reported for ZEVs other than battery-electric vehicles.

3.2.11 Park-and-Ride Projects

TEA-CART estimates the GHG impact of the construction of park-and-ride facilities. A park-and-ride space allows private transport users to park their vehicles at a large parking space and continue their commute via public transport or shared ride. The tool prompts users to input the number of new park-and-ride spaces that will be constructed. The change in emissions is based on the reduced VMT as a result of increased transit or high-occupancy vehicle usage.[10] Emissions are calculated per the following equation:

*Change in emissions = # of spaces * utilization * average work trip length * workday annualization factor * light-duty vehicle emissions rate*

Table 3-15 provides the sources and methodological notes for the key variables in the calculations. It is assumed that park-and-ride expansion increases utilization of existing services; if new transit services are added in conjunction with a park-and-ride facility, they should be evaluated as a new transit service project. The park-and-ride utilization rate may be changed under *Assumptions 7* of the **Assumptions** tab, while the average work trip length and annualization factor may be changed under *Assumptions 3* of the **Assumptions** tab (TDM parameters).

Table 3-15: Strategy Analysis Data Sources: Park-and-Ride

Variable	Source/Value	Methodology Notes
Average work trip length	MacArthur et. Al (2018)	NA
Workday annualization factor	250	= 50 weeks * 5 days/week
Park-and-ride utilization rate	25%	Sample assumption - no literature consensus for this value, tool users recommended to use local expertise for custom value
Light-duty vehicle emission rate	See Table 3-2	NA

Note – Some park-and-ride facilities could have secondary effects on emissions if they preclude alternative forms of development such as transit-oriented development projects. TEA-CART is not intended to evaluate tradeoffs between park-and-ride facilities vs. potential alternative land uses. The user should be aware of any such tradeoffs that might occur in their project context and consider alternative evaluation methods.

3.2.12 EV Charging Infrastructure

TEA-CART estimates the GHG impact of the provision of EV charging infrastructure (additional charging ports to supply electric power for recharging electric vehicles) based on the change in emissions from the increased adoption of electric vehicles as a result of increased infrastructure availability. Note that if the jurisdiction being evaluated has adopted Advanced Clean Cars and/or Advanced Clean Trucks rules requiring manufacturers to sell increasing numbers of ZEVs, provision of EV charging infrastructure may simply help attain compliance with those required ZEV levels rather than incentivizing additional ZEVs beyond the ACC2 or ACT forecast levels. Due to lack of data, TEA-CART does not model interactions

[10] This analysis does not account for circumstances in which a park-and-ride facility may be competing with other land-uses that could achieve greater VMT reductions – such as dense, transit-oriented development.

between baseline ZEV forecasts and the impacts of infrastructure, and all benefits reported by the tool are incremental to the baseline.

The tool prompts users to input the number of new public charging ports, broken out by the power of the charger (level 2 or fast-charge) as well as the use case (general public or dedicated truck/bus). Emissions are calculated using the following equation:

*Change in emissions = # of chargers * elasticity of # of vehicle sales with respect to # of ports * miles per vehicle * (electric vehicle emission rate – conventional fuel vehicle emission rate)*

Table 3-16 provides the sources and methodological notes for the key variables in the calculations. The new sales per charging port can be changed in *Assumptions 8* of the **Assumptions** tab.

Table 3-16: Strategy Analysis Data Sources: EV Charging Infrastructure

Variable	Source/Value	Methodology Notes
# of new EV sales per new charging port	1 LDV per Level 2, 5 LDV per public DCFC, 2 MHDV per truck/bus DCFC	See Section 3.4.3
Miles per vehicle	Calculated by vehicle type based on selected VMT forecast divided by vehicle stock	NA
Vehicle emission rates	See Table 3-2	NA

3.2.13 EV Purchase Incentives

TEA-CART estimates the GHG impact of EV purchase incentives based on the change in emissions from the increased adoption of electric vehicles as a result of incentives for vehicle purchase. Note that if the jurisdiction being evaluated has adopted Advanced Clean Cars and/or Advanced Clean Trucks, or any other rules requiring manufacturers to sell increasing numbers of ZEVs, provision of EV purchase incentives may simply help attain compliance with those required ZEV levels rather than incentivizing additional ZEVs beyond the ACC2 or ACT forecast levels. Due to lack of data, TEA-CART does not model interactions between baseline ZEV forecasts and the impacts of purchase incentives, and all benefits reported by the tool are assumed to be additional, incrementally to the baseline.

The tool prompts users to input the total dollar value of incentives offered for purchase of light-duty EVs. (Incentives for new medium and heavy vehicles may be considered using the “Medium- and Heavy-duty Vehicle Replacement” strategy.) Emissions are calculated using the following equation:

*Change in emissions = total dollar value of incentives offered / incentive $ per new EV * miles per vehicle * (electric vehicle emission rate – conventional fuel vehicle emission rate)*

Table 3-17 provides the sources and methodological notes for the key variables in the calculations. The source of the assumed incentive value needed to induce one new EV purchase is based on modeling using the National Energy Modeling System – the model that underpins the U.S. Department of Energy Annual Energy Outlook forecasts – as documented in Section 3.4.3, ‘Light-Duty Electric Vehicles’.

Cautionary note: users should be mindful of the scale of the current vehicle stock of the fleet in the state being analyzed (to avoid electrifying more vehicles than exist in the current stock).

Table 3-17: Strategy Analysis Data Sources: EV Purchase Incentives

Variable	Source/Value	Methodology Notes
Incentive $ per new EV	Varies by year - $8,500 in 2025, declining to $3,100 in 2030	See Section 3.4.3
Miles per vehicle	Calculated by vehicle type based on selected VMT forecast divided by vehicle stock	NA
Vehicle emission rates	See Table 3-2	NA

3.2.14 Freight Intermodal Facilities

TEA-CART estimates the GHG impact of 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.

TEA-CART estimates freight intermodal effectiveness based on cost-effectiveness data (changes in truck VMT and rail ton-miles per capital dollar). Emissions are calculated as follows, with sources and notes provided in Table 3-18. The change in annual truck VMT and rail-miles per $ million can be changed under *Advanced 5* of the **Advanced** tab.

*Change in emissions = investment ($millions) * change in truck VMT per $million * truck emissions rate + change in rail ton-miles per $million * rail emissions rate*

Table 3-18: Strategy Analysis Data Sources: Freight Intermodal

Variable	Source/Value	Methodology Notes
Change in annual truck VMT per $million	-72,100	See Section 3.4.6
Change in annual rail ton-miles per $million	1,020,000	See Section 3.4.6
Truck emission rates	See Table 3-2	NA
Rail emission rates	See Table 3-5	NA

3.2.15 Roadway Expansion

TEA-CART estimates the GHG impact of roadway expansion based on both the decreased emissions from reduced delay as well as increased emissions resulting from induced travel demand. The tool prompts users to input the number of new lane-miles of roadway, broken out by the facility type of the roadway (freeway or arterial), as well as the area type of the facility (urban or rural). “Urban” and “rural” area types are based on Census definitions as used as the basis for Highway Statistics reporting. Emissions are calculated per the following equation, with Table 3-19 providing the sources and methodological notes for the key variables in the calculations. Traffic and emissions are calculated separately for light-duty and medium- and heavy-duty vehicles. The VMT per lane mile, travel speed, % trucks, and travel time elasticities may be changed under *Assumptions 5* of the **Assumptions** tab.

*Change in emissions = (# of lane miles * VMT per lane-mile * Elasticity of VMT w/r/t lane-miles * on-road vehicle emission rate) – (# of lane miles * VMT per lane-mile * hours of delay reduced per VMT * emissions per hours of delay)*

Table 3-19: Strategy Analysis Data Sources: Roadway Expansion

Variable	Source/Value	Methodology Notes
VMT per lane-mile	FHWA Highway Statistics 2019 (FHWA, 2019)	State average data by facility type (highway, arterial) and area type (urban, rural)
% trucks	FHWA Highway Statistics 2019 (FHWA, 2019)	State average data by facility type
Travel speed	71-72 mph for freeways, 43 mph for urban arterials, 60 mph for rural arterials	See NHTSA (2015)
Elasticity of VMT with respect to lane-miles	1.0 for freeways, 0.75 for arterials	See Volker and Handy (2022)
Hours of delay reduced per VMT[a]	See Section 3.4.5	NA
Emissions per hour of delay	See Section 3.4.5	NA
Vehicle emission rates	See Table 3-2	NA

[a]This parameter is not stating a relationship between increased VMT and reduced travel delay. Rather, it is representing how much delay is reduced for each vehicle-mile traversing the capacity expansion project.

Note that if the tool is used with budget inputs, the assumed cost per mile will affect how many lane-miles are provided for a given budget. The default costs per mile are likely to underestimate actual costs in certain settings such as densely built urban areas or mountainous terrain, or for certain types of projects such as major bridge projects. Unit costs may also vary based on factors such as prevailing wage rates and climate. The user should look closely at the unit costs if using the tool in budget mode and make adjustments as needed for local conditions.

3.2.16 Roadway Resurfacing

TEA-CART estimates the emissions benefits of roadway resurfacing based on lane-miles of roadway resurfaced. Emissions benefits result from reduced surface roughness and decreased rolling resistance, as well as improved travel speeds.[11]

Emissions are calculated per the following equation, with Table 3-20 providing the sources and methodological notes for the key variables in the calculations. Section 3.4.4 provides additional information on the key assumptions for this strategy.

[11] Users may use discretion regarding the extent to which some or all of the resurfacing projects in a capital program are additional, for the purposes of a TEA-CART analysis. Since roadway resurfacing is a routine capital investment – i.e., part of good asset management – some users may choose to only use TEA-CART to account for resurfacing projects that are above and beyond historical levels of investment.

*Change in emissions = # of lane-miles resurfaced * GHG benefit per lane-mile resurfaced*

Table 3-20: Strategy Analysis Data Sources: Roadway Resurfacing

Variable	Source/Value	Methodology Notes
GHG benefit per lane-mile resurfaced	8.2 kg per year per lane-mile resurfaced (2032)	See Section 3.4.4 for details and underlying data

3.2.17 Land Use

TEA-CART estimates emissions reductions from more compact and transit-oriented, walkable development. Land use strategies can reduce emissions from driving by placing destinations closer together and in environments more conducive to transit and non-motorized travel, thereby reducing vehicle-trips and trip lengths. Please note that including Land Use projects in the analysis may result in double counting of transit-related VMT reductions if the user also chooses "Apply Land Use Multiplier to Transit Investment," which is available in the **Baseline** tab.

The user can provide land use inputs in the following two ways:

(1) dollar value of incentives for development in walkable, transit-oriented development (TOD) areas (i.e., development in transportation-efficient locations with lower levels of VMT per capita), and/or

(2) acres rezoned for higher densities or mixed-use TOD . For rezoning, it is assumed that development occurs within the horizon year timeframe consistent with the rezoned acreage. The rezoning feature is only available when using the tool in the **Projects** mode.

Emissions are calculated per the following equations. For the dollar value input, the equation is:

*Change in emissions = ($ invested / $ per household shifted) * # of persons per household * (suburban VMT per capita – urban VMT per capita) * vehicle emissions rate*

For inputs of residential acres rezoned to higher density, the equation is:

*Change in emissions = # of rezoned acres * new density * (new density / old density) * VMT per household * elasticity of VMT with respect to density * vehicle emissions rate*

For inputs of commercial acres rezoned to higher density (increased job density), the equation is:

*Change in emissions = # of rezoned acres * # of employees per acre * annualization factor * one-way work trip length * 2 * elasticity of VMT with respect to job density * vehicle emissions rate*

The estimate for rezoning to mixed-use TOD combines the methods for increased residential and job densities into a single estimate. The equation is:

*Change in emissions = (# of rezoned acres * new residential density * (new / old residential density) * VMT per household * elasticity of VMT with respect to density) + (# of rezoned acres * # of employees per acre * annualization factor * one-way work trip length * 2 * elasticity of VMT with respect to job density) * vehicle emissions rate*

Table 3-21 provides the sources and methodological notes for the key variables in the calculations. The default values of these variables may be changed under *Assumptions 9* of the **Assumptions** tab.

Table 3-21: Strategy Analysis Data Sources: Land Use

Variable	Source/Value	Methodology Notes
$ Per Household Shifted	25,000	See Section 3.4.7
Persons per Household	2.5	U.S. average, 2019 – 2023, per U.S. Census (2025)
VMT Per Capita: Suburban	10,553	Cambridge Systematics (CS, 2023), Table 4-12, corresponding to population density of 500 to 4,000 persons per square mile
VMT Per Capita: Urban	7,646	CS (2023), Table 4-12, corresponding to population density of 4,000 to 10,000 persons per square mile
Suburban Density (units/ac)	9	Typical per CAPCOA (2021)
Urban Density (units/ac)	18	Doubling of typical (suburban) density
TOD Density - higher (units/ac)	25	Minimum density level that achieves a “high” rating on Federal Transit Administration benchmarks for New Starts projects (FTA, 2025)
TOD Density - lower (units/ac)	15	Minimum density level that achieves a “medium-high” rating on Federal Transit Administration benchmarks for New Starts projects (FTA, 2025)
Elasticity of VMT w/r/t residential density	-0.22	Stevens (2016), as cited in CAPCOA (2021)
Elasticity of VMT w/r/t job density	-0.07	Stevens (2016), as cited in CAPCOA (2021)
VMT per Household	19,642	FHWA (2018)
Average work trip length (one-way mi)	12.7	FHWA (2018)
Work Annualization	250	Assumption
Employees per acre	145	43,560 square feet per acre / 300 square feet per employee (CAPCOA, 2021) – calculated at 1.0 floor area ratio (FAR)
Vehicle emission rates	See Table 3-2	NA

3.2.18 Transit Service Cuts

TEA-CART estimates emissions changes that could result from funding cuts to transit service. Reductions in transit service could increase emissions if former transit users shift to driving. There will also be some offsetting emission reductions from transit vehicle operations, if current transit operations are powered by fossil fuels or if electricity generation emissions are considered.

The user provides inputs in the form of the percent reduction in vehicle revenue-miles. The emissions impact is calculated using the same equation and key parameters as for the *Transit: Increased Fixed Route Service* strategy, as described in Section 3.2.2, ‘Transit: Increased Fixed Route Service’. However, the key user input is a reduction in VRM (negative value) rather than an increase (positive value). The equation is:

*Change in emissions = # of VOMS * VRM per vehicle * transit vehicle fuel economy * fuel emission factor – change in automobile VMT * light-duty vehicle emission rate * land use multiplier [if selected]*

Where,

*Change in automobile VMT = # of VOMS * VRM per vehicle * load factor * prior drive mode share*

3.3 Cost-Effectiveness

TEA-CART estimates the cost-effectiveness of each strategy, calculated as *annual greenhouse gas changes per annualized cost to the public sector*. For most strategies, only capital costs are included. For added transit service, operating costs are included as well as capital costs (considering vehicles to support the added service but not any infrastructure improvements). TDM costs are program operating costs. Revenues or cost reductions such as tolls, fares, and vehicle operating cost savings for EVs are also not included. Table 3-22 provides the sources for the various cost estimates. All costs were updated from source year dollars to 2024 dollars based on the consumer price index, using the U.S. Bureau of Labor Statistics Consumer Price Index Calculator.[12]

Table 3-22: Strategy Cost Sources and Methodology

Cost Item	Unit	Source
Bicycle and pedestrian infrastructure[13]	Per facility mile	FHWA (2014)
On-road public transit - capital	Per vehicle	American Public Transportation Association (APTA, 2019)
On-road public transit – operating & maintenance	Per VRM	FTA (2019)
On-road public transit - fuel	Per VRM	FTA (2019)
Rail - capital	Per vehicle	CS (2023)
Rail - operating & maintenance	Per VRM	FTA (2019)
Rail - fuel	Per VRM	FTA (2019)
TDM program	Per covered employee	CS (2023)
E-bike costs	Per e-bike	REI (2025)
Retimed signals	Per retimed signal	U.S. DOT (2007)
Roundabouts	Per roundabout	FHWA (2013)
Medium- and heavy-duty truck - capital	Per vehicle	NREL (2021)
Transit vehicle replacement – capital	Per vehicle	APTA 2019)
Transit priority treatment	Per mile	Cesme, Roisman, and Miller (2018)
Park and ride	Per space	Coastal Region MPO (2014)

[12] https://www.bls.gov/data/inflation_calculator.htm

[13] Additional maintenance costs are assumed to be 10% of capital costs annually.

Cost Item	Unit	Source
EV charging infrastructure	Per port	International Council on Clean Transportation (ICCT, 2019)
EV purchase	Per vehicle	See Section 3.4.3
Roadway expansion	Per lane mile	Florida DOT (2024)
Roadway resurfacing	Per lane mile	Florida DOT (2024)
Fuel	Per gallon	AAA Gas Prices (AAA, 2025)

3.4 Additional Documentation of Key Assumptions

This section provides additional explanation of how key assumptions were derived when they were not directly sourced from another study or data source as referenced above, but instead were derived from multiple data sources. Unless noted, these discussions and the referenced data are adapted from the Transportation Investment Strategy Tool (CS, 2023).

3.4.1 New Daily Active Travel Users Per Facility Mile

Walking

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” that describe the quality of the pedestrian environment based on factors such as sidewalk completeness, street crossings, topography, etc.

Sample projects were evaluated using an approach similar to the approach in the Massachusetts Department of Transportation CMAQ Project Worksheet for Complete Streets. Key assumptions and sample calculations are shown in Table 3-23.

Table 3-23: Pedestrian Investment Key Assumptions and Sample Calculations

Parameter	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	Miles
Service Area Radius for Walking (RW):	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	Sq. Miles
Population Density of Neighborhoods Served (PD):	15,000	7,500	2,000	500	Persons/Sq. Mile
Population Served by Facility for Walking (PW): PD * SAW = PW	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	Trips

Parameter	Core	Urban	Suburban	Rural	Units
Baseline Walk Mode Share in Service Area (MSW):[a]	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%	Percent
New Walk Trips (WT): PW * T * MSW * WI = WT	798	247	13	2	1-Way Trips/Day
Average Walk Trip Length (LW):[c]	0.7	0.7	0.7	0.7	Miles
New Daily Walk Miles of Travel (BWM):	559	173	9	1	Miles per Day
Prior Drive Mode Share of New Walk Trips (MSD):[d]	47%	59%	60%	75%	Percent
VMT Reduced per Day (VMTR): BWM * MSD = VMTR	264	103	5	1	Miles per Day
VMTR * Operating Days Per Year	96,387	37,421	1,945	397	VMTR Per Year

[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 values described in Section 3.4.2.

Bicycling

There are few studies that measure or cite impacts in terms of bicycle-miles of travel (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 3-24 shows four independent estimates of new BMT per new facility-mile:

- Line (1) is based on a regression model developed for Los Angeles County, CA relating 2009 American Community Survey 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 Transportation and Climate Initiative (TCI) region investment method, documented in CS (2015), 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 3-25. 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.[14] The details of the elasticity calculation are shown in Table 3-26.

- 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 3-24 to the "core/high urban" area type.

Table 3-24: Scenarios of New Bicycle-Miles Traveled per New Facility-Mile

Source	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 3-25: Assumptions for Sample Regional Bike Investment Analysis[a]

Parameter	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:[b]					
% by Place Type:	9%	10%	20%	36%	25%
Expenditure by 2032 ($M) [c]	$218	$250	$470	$860	$591
% of Build-Out Achieved by 2032:	100%	100%	36%	35%	4%
Impacts (2032):					
New bike facility-miles	1,800	2,067	2,785	12,037	1,154

[14] 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.

Parameter	Core	High Urban	Medium Urban	Suburban	Rural
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]This analysis was originally developed for the Transportation and Climate Initiative (TCI) region of northeast and mid-Atlantic states (see CS, 2023).
[b]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. 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).
[c]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 3-26: Sample Elasticity Scenario Applied to a 1-Square Mile Census Tract

Parameter	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%.

TEA-CART also assumes different 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 3-27, 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 3-24, lines (2), (3), and (4). For example, 150 new cyclists per day (bike lanes, core area type) 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.

Table 3-27: Estimated New Utilitarian Cyclists Per Day Per Mile by Area Type and Facility Type

Facility Type	Core	Urban	Suburban	Rural
Bike lanes	150	80	25	5
At-grade protected lanes/bike boulevard	203	108	34	-
Grade-separated protected lanes	257	137	43	-
Shared-use paths	327	174	55	11

3.4.2 Prior Drive Mode Share (Walk, Bike, Transit)[15]

"Prior drive mode share" is defined as the fraction of transit riders, walkers, or bicyclists who would have driven if the transit, walk, or bike 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 that can vary greatly depending upon the type of service provided, the geographic context, and the travel markets 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 new users would have been distributed among other modes in proportion to the fraction of travelers using those other modes. Prior drive mode share can then be estimated from travel surveys. The 2009 National Household Travel Survey indicates that approximately 60 to 70 percent of trips not taken by transit were taken by driving, considering trips for all purposes. State-level data show modest variation across the Northeast and Mid-Atlantic region; it is 50 percent in the fully urban District of Columbia, about 60 percent in New York State (reflecting the influence of New York City), and close to 70 percent in all other states (Table 3-28).

Table 3-28: 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%

[15] The research in this section draws heavily from sources for the northeast and mid-Atlantic states as it was originally performed for this region. If users have locally-specific data from a source such as a transit rider survey, they may wish to update the prior drive mode share assumptions.

State	% Trips by Driving as Share of all Non-Transit Trips
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 (U.S. DOT, 2009). Calculated as total private vehicle trips divided by total person-trips by modes other than transit.

Journey-to-work data from the 2014 ACS (U.S. Census, 2025b), which was based on five-year 2010-2014 data, was also reviewed to similarly examine the distribution of trips by mode by urbanized area (UZA) size for UZAs in the Northeast and Mid-Atlantic region. Table 3-29 shows the “prior drive mode share” as well as the percent of 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 3-29: 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 3-30.

Table 3-30: 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

Mode	Percent of Work Modes	Percent of School Modes	Work + School Weighted
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 Bus Rapid Transit project).[16] 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 of 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 (TCRP, 2005b).

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 TEA-CART, 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

[16] Unpublished data, submitted to Federal Transit Administration as part of the New Starts/Small Starts funding application for the Woodhaven BRT project.

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%.

3.4.3 Light-Duty Electric Vehicles

TEA-CART can model the impacts of both charging infrastructure investment and EV purchase incentives on EV uptake and emissions.

Effects of Charging Infrastructure

EV charging infrastructure is evaluated based on the number of new vehicles incentivized per new unit of charging infrastructure or per dollar spent on charging infrastructure. Effectiveness of new public infrastructure at incentivizing EV sales and use was estimated based on four studies.

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

When applying an elasticity value, the number of new EVs per new charging port depends upon the ratio of the existing number of EVs to charging ports. This elasticity was applied to U.S. data on the number of charging ports, charging locations, and sales for 2021, as shown in Table 3-31. A 10 percent increase in charging ports and locations would mean 3,174 new locations with 10,681 new ports. An 8 percent increase in annual sales would mean an additional 48,640 vehicles sold. This results in 15.3 new vehicles per new charging location, or 4.6 new vehicles per new port. At the average cost of about $36,000 per port, this results in an incentive cost of $7,800 per new vehicle assuming the port is fully funded with public investment.

Table 3-31 Estimated U.S. EV Charge Points, Locations, Registrations, and Sales (2021)

Parameter	Value	Source
Public and private EV charging ports	106,814	U.S. DOE - Alternative Fuels Data Center (AFDC), accessed 11/21/2022 (U.S. DOE, 2023c)
Public and private EV charging locations	31,738	AFDC, 11/21/2022
Light-duty EV registrations	1,109,000	AFDC, 11/21/2022
EVs per port	10.4	Calculated
EVs per location	34.9	Calculated
Light-duty EV sales	608,000	https://www.energy.gov/energysaver/articles/new-plug-electric-vehicle-sales-united-states-nearly-doubled-2020-2021

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

Applying the port elasticity to U.S. data, a 10 percent increase in the number of ports as of 2021 would be 10,681 new ports, compared to a 1.4 percent increase in registrations = 15,526 new registrations, for a ratio of 1.5 new EV registrations per new port. At the same average cost as used above, the incentive cost is about $24,600 per new EV.

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

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

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

Using a straight average of all the values estimated above provides an average value of 5.6 new EVs per new charging port, at a subsidy of $6,400 per new EV. Note that the National Electric Vehicle Infrastructure (NEVI) Program required stations capable of providing charge at a power level of at least 150 kW. These are likely to be more expensive on average than those considered in the above-referenced studies, which may include DCFC with power levels as low as 50 kW, suggesting the use of a conservative value. A value of 5 new EVs per DCFC port was selected as the default for the tool.

Lower-power Level 2 chargers are capable of providing “top-up” charges for EVs en-route, or full charges for overnight or all-day charging at worksites. It is assumed in the tool that one public Level 2 charger will support one incremental new light-duty EV, based on the Sommer and Vance (2021) finding that one DCFC charger was about five times as influential as a Level 2 charger.

For dedicated truck and bus chargers, it is assumed that each depot charger would be able to support two vehicles each on an overnight charging schedule. This was found to be typical in a recent MHDV electrification study for the State of Maine (CS 2024).[17] Lower-power (50 kW) chargers would be appropriate for shorter-range medium-duty vehicles such as box trucks and school buses. Higher-power (350 kW) chargers would be appropriate for longer-range, heavier vehicles such as transit buses and tractor-trailers running regional delivery cycles.

Table 3-32 summarizes the default assumptions for new EVs per charging port built into TEA-CART.

Table 3-32: Assumptions for New EVs per Charger

Charger Type	New EVs per Charger	EV Types Supported
Level 2: General public	1.0	Light-duty
DCFC (50kw): General public	5.0	Light-duty
DCFC (150kw): General public	5.0	Light-duty
DCFC: Dedicated truck/bus (50kw)	2.0	Medium-duty
DCFC: Dedicated truck/bus (350kw)	2.0	Heavy-duty

EV Purchase Incentives

The user input for this strategy is in the form of dollars invested in EV incentives. As with the EV infrastructure strategy, the effectiveness of EV incentives at increasing the market share of EVs was evaluated based on review of research. The tool does not distinguish among different types of incentives (e.g., point-of-sale rebates, post-purchase rebates, tax credits) or among incentives that may be targeted to different income groups, due to lack of data.[18]

In the Transportation Investment Strategy Tool (CS, 2023), the effectiveness of EV incentives was based on modeling using the National Energy Modeling System (NEMS), conducted by OnLocation in August 2021 for a Reference Case and for a case representing extension of the federal EV tax credit through 2040 and a lifting of the cap on EV tax credits per vehicle manufacturer. The difference in EV sales, stock, and VMT between the two scenarios was used to estimate an impact factor in terms of new EV sales, stock, or VMT per dollar of incentive. The incentive value per new EV sale varied over time, starting at over $14,000 in 2024, dropping to $7,006 in 2025, decreasing further to $3,181 in 2030, and to $2,110 in 2035 (all in 2020 dollars).

Allcott et al (2024) evaluated the effects of the U.S. Inflation Reduction Act (IRA). They estimate that relative to a scenario with no EV credits, the IRA spent $23,000 of government revenue per incremental EV registration. Relative to pre-IRA policy with phaseout, the IRA spent $32,000 per incremental EV registration. Given a credit value of $7,500, these statistics imply that 23 percent to 33 percent of EV credits are additional.

[17] See Appendix G, Table G.4.

[18] Research suggests that rebates are twice as effective as tax credits in to motivating consumers, and point-of-sale incentives can be an order of magnitude more effective. See: ICCT (2016), Principles for Effective Electric Vehicle Incentive Design.

Sheldon and Dua (2024) estimate vehicle choice models for 23 countries using 2011-2019 sales data and using counterfactual simulations to assess the cost-effectiveness of EV incentives. They find that incentives cost between $14,857 and $62,443 per additional EV sold. In the U.S., the value is approximately $25,000. However, cost-effectiveness improves substantially when factoring in medium-run effects, i.e., when the increase in EV sales in one year as a result of a subsidy in turn spurs faster EV adoption in 12 subsequent years. Accounting for effects up to three years forward, the subsidy per EV in the U.S. ranges from $10,386 to $13,058 based on 2013 – 2016 data. Also, the cost per additional EV has been flat or decreasing in most countries.

Xing, Leard, and Li (2021) estimate the impact of Federal tax credits on EV sales using data from 2014. With $726 million spent on tax credits in 2014, and a modeled sales impact of 31,501 vehicles removing the credit, this (subsidy) provides a cost of $23,047 per new EV. Over time the subsidy is expected to provide greater impacts as the price of EVs drops and more of the incremental cost is covered by the subsidy. About 70 percent of the credits were obtained by households that would have bought an EV without the credits. This study covered plug-in hybrids as well as full EVs.

DeShazo, Sheldon, and Carson (2017) estimate the impact of California’s incentives of $1,500 to $2,500 per EV. They find that the incidence of free riding by consumers who would have purchased EVs in the absence of a rebate means that policy cost per *induced* EV purchase is around $30,000. Vehicle price caps improve the cost-effectiveness of the program.

The empirical studies generally find higher costs per EV than the NEMS modeling. However, most are based on pre-2020 data, and most suggest (at least theoretically) that future cost-effectiveness is likely to improve. The NEMS model is also based on older data.

Consideration was given to using the midpoint of the Sheldon and Dua (2024) medium-range value from 2013-2016 ($11,722) and deflating it in future years based on the ratio of EV to internal combustion engine (ICE) vehicle cost. However, some sources are now projecting cost parity between light-duty EVs and ICE vehicles by 2030 or earlier (see ICCT, 2022c). Another source notes that the average EV price in 2020 was 42 percent higher than an ICE vehicle, declining to 16 percent higher in 2024, but the price premium appears to have stabilized, although this source does not project future trends.[19] With cost parity, modeling might suggest incentives are not needed (although they may still be needed for some consumers to make up for performance differences such as lower range or load capacity or limited charging infrastructure).

The TEA-CART default values of incentive per incremental EV were set at the values estimated from the NEMS modeling, with the sole adjustment being to increase these values 21 percent to convert 2020 to 2024 dollars based on the change in consumer price index. NEMS indicates relatively high incentives needed in the early 2020s in line with the literature, but decreasing rapidly in the mid-2020s, which might be expected given observed and projected decreases in battery and EV costs. The continuation of a modest incentive requirement to 2030 and beyond is a conservative assumption considering that even if EVs reach cost parity, incentives may still be required for many consumers to overcome concerns such as limited range and charging infrastructure costs; and also that not every dollar spent on EV incentives will result in a new EV on the road since some incentives will go to people who would have bought an EV anyway. The values used (in 2024 dollars) are shown in Table 3-33.

[19] https://caredge.com/guides/average-price-of-an-electric-car-2024

Table 3-33: Incentive Value per Incremental New EV

2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
$17,725	$8,477	$5,416	$4,606	$4,060	$3,544	$3,114	$2,840	$2,727	$2,574	$2,439	$2,369

3.4.4 Roadway Resurfacing

The user input for this strategy is lane-miles of roadway resurfaced. A transportation agency should be able to estimate this for a capital program based on projects tagged as resurfacing projects, along with the length of the project and number of lanes associated with the roadway segment.

TEA-CART assumes that resurfacing projects of various types can be collectively identified and assigned an average cost per lane-mile; and that the average benefit of these projects is comparable to the benefits estimated in the underlying data and methods described below. Any additional emissions benefits of resurfacing programs could vary across states and programming horizons depending upon current and baseline future state of repair of a state's highway system, local materials and climate conditions, etc.

Time savings and vehicle operating 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 cost data from the study were used to estimate changes in fuel consumption and emissions per unit of investment based on unit fuel prices and emissions as a function of delay.

The Mississippi study estimated a cumulative reduction in vehicle operating costs of $79.5 billion from the "adequate funding" scenario. Assuming the operating cost savings are mainly reduced fuel use at a cost of $3.18 per gallon, spread over a 25-year period this would be an annual fuel savings of 1,000 million gallons, or a reduction of 8,100 metric tons CO_2 at 8.1 kg CO_2 per gallon.[20] With $323 million in annual incremental investment for the "adequate" vs "expected" funding scenarios, and an average cost per lane-mile resurfaced of $429,359 (see below), about 991 lane-miles would be resurfaced annually under the program. Dividing the CO_2 reductions by annual lane-miles provides an estimated reduction of 8.2 tonnes per year per cumulative lane-mile resurfaced.

In TEA-CART, this value is further adjusted in each analysis year based on the average GHG emissions rate of the vehicle fleet (weighted average of light-duty and heavy-duty vehicles) relative to 2032. This is a dynamic adjustment keyed to user-selected or user-input electrification assumptions. For example, if the average emissions rate in 2045 was half the average emissions rate in 2032, the benefits of resurfacing would be 4.1 kg per year per lane-mile resurfaced.

The Florida Department of Transportation (Florida DOT, 2024) provides average costs per mile for various project types, based on modeling, as shown in Table 3-34. The average cost across project types is about $429,000 per lane-mile. There is a modest variation of about +/-10 percent across project types.

[20] The value of 8.1 kg CO_2 per gallon accounts for ethanol blending where many states' accounting protocols do not include biofuels in greenhouse gas estimates.

Table 3-34: Cost per Mile Estimates for Resurfacing

Project Description	Cost/mile	Lanes	Cost/lane-mile
Mill and Resurface 2 Lane Urban Road with 4' Bike Lanes: U12	$911,866	2	$455,933
Mill and Resurface 3 Lane Urban Road with Center Turn Lane and 4' Bike Lanes: U13	$1,186,249	3	$395,416
Mill and Resurface 4 Lane Undivided Urban Roadway with 4' Bike Lanes: U14	$1,606,864	4	$401,716
Mill and Resurface 4 Lane Divided Urban Roadway with 4' Bike Lanes: U15	$1,882,576	4	$470,644
Mill and Resurface 5 Lane Urban Roadway with Center Turn Lane and 4' Bike Lanes: U16	$1,888,808	5	$377,762
Mill and Resurface 6 Lane Divided Urban Arterial with 4' Bike Lanes: U17	$2,736,124	6	$456,021
Mill and Resurface 1 Additional Lane Urban Arterial: U18	$448,025	1	$448,025
Average			**$429,359**

3.4.5 Congestion Relief

The analysis of roadway expansion requires estimates of emissions reduction associated with reduced vehicle travel delay (increased speeds).

In TEA-CART, delay savings (minutes saved per base VMT) are estimated based on CS modeling of a hypothetical freeway widening project in Virginia (CS, 2022). The value is 0.20 minutes per VMT at the modeled demand elasticity of 0.67, which corresponds to a 3 mph average speed increase compared with a base speed of 30 mph. The delay savings are scaled to be zero at an induced demand elasticity of 1.0, and to increase in inverse proportion to the elasticity. For example, at an elasticity of 0 (no induced travel), there would be an average of 0.61 minutes of delay saved per VMT. Note that research suggests that long-run elasticities (i.e., the travel response to capacity increases at least five to 10 years after the improvement) are greater than short-run elasticities (e.g., one to two years after the improvement) since the capacity expansion can induce additional changes in behavior (such as shifting employment locations or land use changes) that take some time to materialize (Volker and Handy, 2022). This means that congestion relief may initially show emissions benefits but these benefits may erode over time as the emissions from additional traffic grow, and also as the delay reduction benefits are reduced. In TEA-CART it is assumed that elasticities are **long-run elasticities**. If TEA-CART is being used to evaluate a project within a short time after completion, the user may wish to enter a lower elasticity value.

Fuel savings are then estimated based on a value of 0.44 gallons fuel saved per hour of delay saved, as calculated from data presented in the Texas A&M Transportation Institute 2021 Urban Mobility Report (TTI, 2021). This value is adjusted to future year values based on the ratio of evaluation year to 2021 average fuel economy from the U.S. DOE 2023 AEO.

3.4.6 Effects of Freight Intermodal Investment

TEA-CART estimates freight intermodal effectiveness based on cost-effectiveness data (changes in truck VMT and rail ton-miles per capital dollar) taken from a variety of studies in various locations. The variation across studies and 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; different types of projects in different contexts may also have very different benefits. For example, the following range of cost-effectiveness was identified:

- Low: based on Connecticut and Massachusetts freight studies and a few individual Northeast and Mid-Atlantic region project evaluations – 40 tons GHG per $million.
- Medium: based on a nationwide analysis in CS (2009) – 140 tons GHG per $million.
- High: based on the Mid-Atlantic Rail Operations Study (I-95 Corridor Coalition, 2009) – 1,165 tons GHG per $million.

Since emission rates change over time, it was considered preferable to identify changes in freight volumes moved per unit of investment and then convert to emissions. Changes in annual truck-miles and rail ton-miles per cumulative dollar of investment were identified from these studies either directly, or based on the GHG reductions. For example, the Mid-Atlantic Rail Operations Study provided estimates of changes in truck VMT (600,000 annual truck VMT reduced per $million) and rail ton-miles (8.5 million rail ton-miles increased per $million).

In TEA-CART, changes in truck VMT and rail ton-miles are projected for future years based on cumulative spending and the cost-effectiveness estimated from the project studies. Emissions changes are then estimated based on fuel consumption and emission rates per truck-mile or rail ton-mile consistent with the baseline projections. Table 3-35 shows the freight intermodal project data used to inform the cost-effectiveness estimates for this strategy.

The default values included in TEA-CART ("use this value" in Table 3-35) were developed as follows. First, the value of 140 annual tons per capital $million from the nationwide analysis ("Moving Cooler") was taken as a moderate estimate of emissions reduction cost-effectiveness, considering the range of estimates shown in the various studies. Since Moving Cooler did not report data to estimate a change in truck VMT or rail ton-miles per dollar, these values were estimated based on the ratio of VMT and ton-mile cost-effectiveness to emissions cost-effectiveness in the Mid-Atlantic Rail Operations Study ("MAROps"), which was conducted in the same timeframe and, similar to Moving Cooler, evaluated a broad program of investments rather than just a single project or state. For illustration, 72,000 annual truck VMT/capital $M = 597,500 * (140 / 1,165); 1,021,000 annual rail ton-mi/capital $M = 8,489,500 * (140 / 1,165).

Table 3-35: 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 et al (2013). (5) Grant et al. (2008). (6) I-95 Corridor Coalition (2009).

3.4.7 Effects of Land Use Incentives

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. Based on these data sources, a value of $25,000 per shifted household was assumed in TEA-CART. This review was originally conducted in 2022 and documented in CS (2023).

Atlanta Regional Commission - Livable Centers Initiative (LCI)

Program data:

- Planning and transportation project grants to support smart growth in designated "livable centers."
- $184M in grants awarded 2000-2014.
- $221M total expenditure assuming a 20 percent local match.
- 76,000 new housing units in LCI communities (+ 90 million square feet commercial space).
- $221M / 76,000 = **$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 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 percent 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 TEA-CART since some of the program costs cover the affordability component.

California Transit-Oriented Development 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.
- $271M / 6,158 = **$44,000** per new housing unit.

Comments on program:

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

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