FTA

FEDERAL TRANSIT ADMINISTRATION

# Draft Greenhouse Gas Emissions from Transit Projects: Programmatic Assessment

NOVEMBER 2016

FTA Report No. 0097
Federal Transit Administration

**PREPARED BY**
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U.S. Department of Transportation
**Federal Transit Administration**

## COVER PHOTO

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U.S. Department of Transportation
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## Metric Conversion Table

| SYMBOL | WHEN YOU KNOW | MULTIPLY BY | TO FIND | SYMBOL |
|---|---|---|---|---|
| | | **LENGTH** | | |
| **in** | inches | 25.4 | millimeters | mm |
| **ft** | feet | 0.305 | meters | m |
| **yd** | yards | 0.914 | meters | m |
| **mi** | miles | 1.61 | kilometers | km |
| | | **VOLUME** | | |
| **fl oz** | fluid ounces | 29.57 | milliliters | mL |
| **gal** | gallons | 3.785 | liters | L |
| **$ft^3$** | cubic feet | 0.028 | cubic meters | $m^3$ |
| **$yd^3$** | cubic yards | 0.765 | cubic meters | $m^3$ |
| | | NOTE: volumes greater than 1000 L shall be shown in $m^3$ | | |
| | | **MASS** | | |
| **oz** | ounces | 28.35 | grams | g |
| **lb** | pounds | 0.454 | kilograms | kg |
| **T** | short tons (2000 lb) | 0.907 | megagrams (or "metric ton") | Mg (or "t") |
| | | **TEMPERATURE (exact degrees)** | | |
| **$^oF$** | Fahrenheit | 5 (F-32)/9 or (F-32)/1.8 | Celsius | $^oC$ |

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The National Environmental Policy Act (NEPA) requires federal agencies to disclose and analyze the environmental effects of their proposed actions. The Federal Transit Administration (FTA) currently believes that assessing the effects of greenhouse gas (GHG) emissions and climate change for transit projects at a programmatic level is practicable. This programmatic assessment serves to (1) report on whether certain types of proposed transit projects merit detailed analysis of their GHG emissions at the project level and (2) be a source of data and analysis for FTA and its grantees to reference in future environmental documents for projects in which detailed, project-level GHG analysis is not vital.

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## ABSTRACT

The National Environmental Policy Act (NEPA) requires federal agencies to disclose and analyze the environmental effects of their proposed actions. The Federal Transit Administration (FTA) currently believes assessing the effects of greenhouse gas (GHG) emissions and climate change for transit projects at a programmatic level is practicable. This programmatic assessment serves to (1) report on whether certain types of proposed transit projects merit detailed analysis of their GHG emissions at the project level and (2) be a source of data and analysis for FTA and its grantees to reference in future environmental documents for projects where detailed, project-level GHG analysis is not vital.

## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| APTA | American Public Transportation Association |
| BRT | Bus Rapid Transit |
| CEQ | Council on Environmental Quality |
| CIDI | Compression-ignition direct-injection |
| CIG | Capital Improvement Grants Program |
| CNG | Compressed natural gas |
| $CO_2$ | Carbon dioxide |
| CR | Commuter rail |
| DR | Demand response |
| eGRID | Emissions & Generation Resource Integrated Database |
| EPA | Environmental Protection Agency |
| FHWA | Federal Highway Administration |
| FTA | Federal Transit Administration |
| GHG | Greenhouse gas |
| GREET | Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation |
| HR | Heavy rail |
| ICE | Infrastructure Carbon Estimator |
| kWh | Kilowatt hour |
| LNG | Liquefied natural gas |
| LPG | Liquefied petroleum gas |
| LR | Light rail |
| MBTA | Massachusetts Bay Transportation Authority |
| MPO | Metropolitan planning organization |
| MT | Metric ton |
| $MTCO_2e$ | Metric ton of carbon dioxide equivalent |
| NEPA | National Environmental Policy Act |
| NTD | National Transit Database |
| PaLATE | Pavement Lifecycle Assessment Tool |
| SI | Spark-ignition |
| TCRP | Transit Cooperative Research Program |
| TIP | Transportation Improvement Plan |
| TRB | Transportation Research Board |
| USDA | U.S. Department of Agriculture |
| VMT | Vehicle miles traveled |

# EXECUTIVE SUMMARY

The National Environmental Policy Act (NEPA) requires federal agencies to disclose and analyze the environmental effects of their proposed actions. The Federal Transit Administration (FTA) currently considers it practicable to assess the effects of greenhouse gas (GHG) emissions and climate change for transit projects at a programmatic level. This programmatic assessment serves to:

- Report on whether certain types of proposed transit projects merit detailed analysis of their GHG emissions at the project-level.
- Provide a source of data and analysis for FTA and its grantees to reference in future environmental documents for projects in which detailed, project-level GHG analysis would provide only limited information beyond what is collected and considered in this programmatic analysis.

The project team developed and applied a GHG emissions Typology Matrix (Matrix) to estimate partial lifecycle emissions for the construction, operations, and maintenance phases of sample bus rapid transit (BRT), streetcar, light rail, commuter rail, and heavy rail projects. A full lifecycle assessment accounts for the GHG emissions from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. The Matrix represents a lookup table of select emissions factors that allows users to estimate GHG emissions that transit project development generates, less personal vehicle emissions displaced due to transit's "ridership effect" (i.e., shifting drivers from private vehicles). The Matrix offers practitioners a simplified resource for estimating GHG emissions using limited project information.

Results suggest that BRT and streetcar projects generate relatively low levels of GHG emissions primarily due to their low infrastructure needs and low annual transit vehicle miles traveled (VMT). Results for light rail projects suggest that projects with a high ridership effect, regardless of length, alignment, and number of stations, result in a net reduction in GHG emissions. Similarly, commuter rail projects with a high ratio of displaced VMT to transit VMT are expected to result in low or net reductions in GHG emissions. Heavy rail projects also may have this impact, but the sample was too small to draw this conclusion.

In cases in which project characteristics and assumptions are similar to those analyzed here, transit agencies considering BRT, streetcar, light rail, commuter rail, and heavy rail projects may incorporate this programmatic assessment by reference into their NEPA analyses. It is recommended that light, commuter, and heavy rail projects that have characteristics that differ from the sample analyzed here use the Matrix or another locally-recommended approach to make project-specific GHG emissions estimates in their NEPA analyses.

In no case is the use of the Matrix mandatory, and transit agencies should work with FTA Regions to determine whether to conduct project-specific analyses and the best approach for doing so.

SECTION 1

# Introduction

Human activities have elevated atmospheric concentrations of greenhouse gases,[1] particularly carbon dioxide ($CO_2$), to levels unprecedented in at least the last 800,000 years. These emissions, along with emissions from natural substances and processes, are drivers of climate change (Intergovernmental Panel on Climate Change 2014). In the United States, transportation is a leading source of greenhouse gas (GHG) emissions, accounting for the second largest portion of U.S. GHG emissions after electricity production (Environmental Protection Agency 2015). Within the transportation sector in 2014, light-duty vehicles[2] accounted for the majority (61%) of GHG emissions, whereas bus and rail accounted for a comparatively small proportion, 1% and 2%, respectively (EPA 2016a).

The National Environmental Policy Act of 1969, as amended (42 U.S.C. 4321-4327 and 40 C.F.R. Parts 1500-1508) (NEPA), requires federal agencies to evaluate and disclose the environmental effects of their proposed actions. NEPA analyses of GHG emissions and climate change pose difficult challenges in assuring that meaningful analysis is provided. Virtually any human activity, including those that federal agencies fund or permit, can cause emissions of GHGs, yet it is unlikely that any individual project would generate enough GHG emissions to significantly influence global climate change. Instead, a project contributes to the global climate impact incrementally and cumulatively, combining with the emissions from all other sources of GHGs. In August 2016, the Council on Environmental Quality (CEQ) released final guidance for federal agencies on how to consider the impacts of their actions on global climate change in their NEPA reviews (CEQ 2016). The guidance provides a framework for agencies to consider the effects of a proposed action on climate change, as indicated by its estimated GHG emissions. The guidance emphasizes that agency analyses should be commensurate with projected GHG emissions and climate impacts and that they should employ appropriate quantitative or qualitative analytical methods to ensure that useful information is available to inform the public and the decision-making process in distinguishing between alternatives and mitigations.

The CEQ guidance acknowledges that incorporation by reference is of great value in considering GHG emissions or the implications of climate change for the proposed action and its environmental effects. The guidance notes that "an agency may decide that it would be useful and efficient to provide an aggregate

[1] Greenhouse gases include carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. The common unit of measurement for greenhouse gases is metric tons of $CO_2$ equivalent ($MTCO_2e$).

[2] Includes passenger cars and light-duty trucks.

analysis of GHG emissions or climate change effects in a programmatic analysis and then incorporate by reference that analysis into future NEPA reviews" (CEQ 2016). The Federal Transit Administration (FTA) considers it practicable to assess the effects of GHG emissions and climate change for transit projects at a programmatic level.

This programmatic assessment presents results from an analysis to estimate direct and indirect GHG emissions generated from the construction, operations, and maintenance phases of projects across selected transit modes. The findings provide a reference for FTA and its grantees to use in future NEPA documents to describe the effects of proposed transit investments on partial lifecycle GHG emissions.[3] This assessment's results can inform transit project proponents who are considering the implications GHG emissions of future transit investments or who might independently want to evaluate the GHG emissions benefits and cost of such investments.

[3] A full lifecycle assessment accounts for GHG emissions from "cradle to grave—in other words, from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. See the Methodology and Data Limitations sections for information on the phases included in this assessment.

SECTION 2

# Methodology

The project team's analytical approach involved creating a typology matrix of GHG emissions factors[4] and then applying the typology matrix to a sample of transit project scenarios to estimate the GHG emissions generated. Each of these aspects is described below. The assessment focuses on GHG emissions from transit projects in the United States.

## Typology Matrix of GHG Emissions

The project team extensively reviewed literature to understand the state of the practice in quantifying GHG emissions associated with transit projects and to identify and assess existing GHG estimation tools and emissions factors. The literature review included research studies, peer-reviewed practice papers, white papers, and federal funding and oversight programs published primarily between 2005 and 2015.

Generally, the literature acknowledges transit's role in reducing GHG emissions, largely holding that public transportation produces lower GHGs per person trip than personal vehicles (e.g., American Public Transportation Association [APTA] 2014, Chester et al. 2013, Transit Cooperative Research Program [TCRP] 2013, Southworth et al. 2011, FTA 2010, TCRP 2010a, and TCRP 2008). This is especially the case when transit ridership levels are high enough such that more emissions are displaced from private travel than are emitted from transit vehicles themselves or when transit spurs denser land use development patterns (TCRP 2010b, TCRP 2015, Transportation Research Board 2009). A subset of researchers has challenged the degree to which transit systems can offset or displace other transportation system emissions (O'Toole 2008, Greene and Plotkin 2011).

Despite the considerable body of literature regarding transit's GHG emissions role, project-level quantification of transit GHG emissions has been limited. Currently, few state and local governments require the project-level analysis of GHG emissions during the environmental review process. The project team investigated the requirements for completing project level analyses in places in which such requirements *do* exist, as well as more than 120 recent environmental documents for transit projects in these and other locations to understand better

[4] An emission factor is the average GHG emission rate from a given source, relative to units of activity.

where project-specific GHG analyses have occurred, the methods and tools used, and the associated data needs.[5]

The project team then identified a comprehensive list of GHG emission sources for the construction, maintenance, and operation phases of a transit project. The emissions sources were classified by transit mode, vehicle and fuel type, and facility type. The transit modes considered were those reported to FTA's National Transit Database (NTD), the nation's primary resource for information and statistics on American transit systems. For the purposes of this assessment, some NTD transit modes were consolidated into broader categories due to the similarities of their emissions sources. Others were excluded from the analysis due to their low and infrequent receipt of federal funding relative to other modes or the lack of available data regarding their associated GHG emissions (see Table 2-1).[6]

**Table 2-1**

*Consolidated Transit Modes for Programmatic Assessment*

| NTD Modes | Consolidated Mode |
|---|---|
| Heavy Rail (HR) | Heavy Rail (HR) |
| Alaska Railroad<br>Commuter Rail (CR)<br>Hybrid Rail | Commuter Rail (CR) |
| Light Rail (LR) | Light Rail (LR) |
| Streetcar | Streetcar |
| Bus Rapid Transit<br>Commuter Bus<br>Conventional Bus, includes Articulated Bus<br>Trolleybus | Bus Rapid Transit |
| Demand Response (DR), including DR Taxi<br>Vanpool | DR/Vanpool |
| Ferryboat | Excluded |
| Aerial Tramway<br>Cable Car<br>Inclined Plane<br>Jitney<br>Publico<br>Monorail/Automated Guideway or People Mover | Excluded |

The project team used the literature review to identify available tools and data resources to estimate the direct and indirect GHG emissions generated from each of the identified transit GHG emissions sources. Direct GHG emissions are caused by sources that a transit agency owns or controls, typically transit vehicle power, propulsion, and maintenance, and power production or fuel combustion

[5] As of June 2016, California and Massachusetts require project-level GHG emissions quantification for all statewide projects subject to the respective state environmental policy acts. Minnesota, New York, and Washington have requirements that apply only to projects under jurisdiction of select agencies with GHG or climate change analysis policy requirements.

[6] Ferryboats were excluded due to a lack of available data and/or tools regarding their associated GHG emissions.

at transit facilities. Indirect transit GHG emissions are produced by a separate organization as a result of a transit agency's activities, such as the purchase of electricity to power light rail vehicles or facilities or the contracted construction of a transit facility.

A convention of GHG inventory reporting protocols is to categorize GHG emissions by "scope" (Climate Registry 2013, World Resources Institute 2010, EPA 2016):

- **Scope 1 (direct) GHG emissions** include direct emissions from vehicle fleet operations, facilities, and sources under the transit agency's operational control. The decisions a transit agency makes (regarding propulsion technology, for example) can directly influence the annual volume of greenhouse Scope 1 emissions.
- **Scope 2 (indirect) GHG emissions** are emissions from purchased electricity, heating and cooling, and steam that are consumed within the transit agency's organizational boundaries. Although these emissions are the result of a transit agency's activities, the emissions are produced by other emitters, typically power plants.
- **Scope 3 (other) GHG emissions** are indirect emissions not included in Scope 2. Although emissions from these sources are also a result of the transit agency's activities, they are ultimately sources beyond the agency's control, as they reflect the GHG emissions from personal vehicles between residences or other locations to and from transit stations and/or work.

The comprehensive list of transit GHG emissions sources was narrowed to align with the consolidated transit modes and data or tools available to estimate their GHG emissions. Table 2-2 presents the transit emission sources included in this analysis by their scopes.

**Table 2-2** *GHG Emissions Sources Included in Matrix by Scope*

| Emissions Related to | Direct (Scope 1) | Indirect (Scope 2) | Indirect (Scope 3) | Sources Excluded from Matrix[7] |
|---|---|---|---|---|
| Construction | • Tree removal | | • Contracted transitway track, station, and parking construction<br>• Contracted paving of separated rights-of-way<br>• Contracted catenary system construction/ copper | • Construction-induced congestion<br>• Third rail system of electrification<br>• "Other" facilities' construction (administrative buildings, maintenance/storage facilities, intermodal hub, traction substations, etc.).<br>• Transit vehicle manufacture |
| Maintenance | • Routine transitway maintenance<br>• Routine pavement maintenance<br>• Routine vehicle maintenance | | | • Routine station and facility maintenance<br>• Waste disposal |
| Operations | • Operation of transit vehicles fueled by non-electricity fuels<br>• Boiler/furnace combustion for stations and maintenance/ storage facilities.<br>• Operation of non-revenue vehicles fueled by non-electricity fuels | • Purchased electricity for transit vehicles, stations, maintenance/ storage facilities, and parking facilities. | • Transit access trips | • Operation of "other" facilities (i.e., administrative buildings, intermodal hubs, etc.)<br>• Electricity/steam transmission and distribution losses<br>• Refrigerants |
| Displacements | | | • Operation of personal vehicles | • Congestion relief<br>• Transit-oriented development |

The project team used available GHG emissions factors and estimation tools to develop a "GHG Emissions Typology Matrix" (Matrix). The Matrix (Table 2-3) represents a lookup table of select emissions factors that allows users to calculate partial lifecycle GHG emissions estimates by transit mode for the construction, maintenance, and operations phases of transit project development, less personal vehicle emissions displaced due to transit's "ridership effect." It provides scalable estimates for upstream and downstream emissions for each emissions source[8] in that it presents the emissions per unit of each GHG emissions source in terms of metric tons of $CO_2$ equivalent ($MTCO_2eq$).[9] Although the Matrix lacks the precision that may be attainable by using more complex emission models or route-specific ridership estimates, it provides a resource to generate coarse but informative estimates of GHG emissions for a broad range of transit projects. The following section provides more detail about the emission factors included in the Matrix.

[7] These sources were excluded due to a lack of data or tools available to estimate their GHG emissions. Transit vehicle manufacture was excluded due to a lack of data that reflect the diversity of transit vehicle types that transit agencies in the United States use.

[8] See the Methodology section for information on the upstream and downstream emissions associated with each phase.

[9] Carbon stock loss due to removal of trees is presented in the Matrix as metric tons of $CO_2$/ tree, not $CO_2eq$/tree.

**Table 2-3** *Transit GHG Emissions Factor Typology Matrix*

| | Phase | Source | | Upstream | Downstream | $MTCO_2eq$ |
|---|---|---|---|---|---|---|
| HEAVY RAIL | Const. | Track Mile | Underground | 111,262 | 5,085 | /mi |
| | | | Elevated | 3,223 | 717 | /mi |
| | | | At Grade | 580 | 362 | /mi |
| | | Catenary | | 3,161 | - | /mi |
| | | Station | Underground | 143,384 | 1,640 | /facility |
| | | | Elevated | 133,694 | 1,135 | /facility |
| | | | At Grade | 81,764 | 457 | /facility |
| | Maint. | Track Mile | | - | 5 | /mi/yr |
| | | Vehicle | | - | 0.0003 | /mi/yr |
| | Ops. | Vehicle | Electric | 0.0030 | - | /veh-mile |
| | | Station | | - | 0.0117 | /sq-ft/yr |
| | | Maint/ Storage Fac. | Electricity | - | 0.0121 | /sq-ft/yr |
| | | | Heat | - | 0.0018 | /sq-ft/yr |

| | Phase | Source | | Upstream | Downstream | $MTCO_2eq$ |
|---|---|---|---|---|---|---|
| COMMUTER RAIL | Const. | Track Mile | Underground | 111,262 | 5,085 | /mi |
| | | | Elevated | 3,223 | 717 | /mi |
| | | | At Grade | 580 | 362 | /mi |
| | | | Conv./Upgraded | - | - | /mi |
| | | Catenary | | 3,161 | - | /mi |
| | | Station | Underground | 143,384 | 1,640 | /facility |
| | | | Elevated | 133,694 | 1,135 | /facility |
| | | | At Grade | 81,764 | 457 | /facility |
| | Maint. | Track Mile | | - | 5 | /mi/yr |
| | | Vehicle | | - | 0.0010 | /mi/yr |
| | Ops. | Vehicle | Electric | 0.0029 | - | /veh-mile |
| | | | Diesel | 0.0109 | 0.0029 | /veh-mile |
| | | Station | | - | 0.0117 | /sq-ft/yr |
| | | Maint/ Storage Fac. | Electricity | - | 0.0121 | /sq-ft/yr |
| | | | Heat | - | 0.0018 | /sq-ft/yr |

| | Phase | Source | | Upstream | Downstream | $MTCO_2eq$ |
|---|---|---|---|---|---|---|
| LIGHT RAIL | Const. | Track Mile | Underground | 111,262 | 5,085 | /mi |
| | | | Elevated | 2,905 | 310 | /mi |
| | | | At Grade | 310 | 109 | /mi |
| | | | Conv./Upgraded | 310 | 74 | /mi |
| | | Catenary | | 3,161 | - | /mi |
| | | Station | Underground | 35,760 | 1,640 | /facility |
| | | | Elevated | 57,560 | 1,135 | /facility |
| | | | At Grade | 2,527 | 457 | /facility |
| | Maint. | Track Mile | | - | 5 | /mi/yr |
| | | Vehicle | | - | 0.0010 | /mi/yr |
| | Ops. | Vehicle | Electric | 0.0043 | - | /veh-mile |
| | | Station | | - | 0.0117 | /sq-ft/yr |
| | | Maint/ Storage Fac. | Electricity | - | 0.0121 | /sq-ft/yr |
| | | | Heat | - | 0.0018 | /sq-ft/yr |

| | Phase | Source | | Upstream | Downstream | $MTCO_2eq$ |
|---|---|---|---|---|---|---|
| BUS/BUS RAPID TRANSIT | Const. | New BRT Lane/ROW | | 248 | 197 | /mi |
| | | Conv./Upgraded Lane/ROW | | 158 | 70 | /mi |
| | | Trolleybus Catenary | | 902 | - | /mi |
| | | Station | | 2,527 | 9 | /facility |
| | Maint. | Pavement, BRT | | - | 3 | /mi/yr |
| | | Vehicle | | - | 0.00005 | /veh/yr |
| | Ops. | Vehicle | Electric | 0.0017 | 0.0000 | /veh-mile |
| | | | Diesel | 0.0005 | 0.0027 | /veh-mile |
| | | | Biodiesel | 0.0001 | 0.0022 | /veh-mile |
| | | | LNG | 0.0007 | 0.0026 | /veh-mile |
| | | | CNG | 0.0008 | 0.0026 | /veh-mile |
| | | Station | Electricity | - | 0.0117 | /sq-ft/yr |
| | | | Heat | - | 0.0017 | /sq-ft/yr |
| | | Maint/Storage Facility | Electricity | - | 0.0152 | /sq-ft/yr |
| | | | Heat | - | 0.0010 | /sq-ft/yr |

## Table 2-3 (cont'd.) *Transit GHG Emissions Factor Typology Matrix*

| | Phase | Source | | Upstream | Downstream | $MTCO_2eq$ |
|---|---|---|---|---|---|---|
| DR, VANPOOL, DISPLACED AUTOS | Ops. | Vanpool | Diesel | 0.0002 | 0.0011 | /mi |
| | | | Gas | 0.0002 | 0.0010 | /mi |
| | | | Ethanol | -0.0001 | 0.0013 | /mi |
| | | Sedan/Auto | Gas, Ethanol | 0.0001 | 0.0003 | /mi |
| | | | CNG, LPG | 0.0001 | 0.0003 | /mi |
| | | | H (gaseous) | 0.0005 | - | /mi |
| | | | HEV | 0.0001 | 0.0002 | /mi |
| | | | Bio/Diesel | 0.0000 | 0.0003 | /mi |
| | | School Bus | Diesel | 0.0003 | 0.0015 | /mi |
| | | | Biodiesel | 0.0001 | 0.0012 | /mi |
| | | | LPG | 0.0003 | 0.0015 | /mi |
| | | | CNG | 0.0004 | 0.0014 | /mi |
| | | Demand Response Bus | Diesel | 0.0005 | 0.0027 | /mi |
| | | | Biodiesel | 0.0001 | 0.0022 | /mi |
| | | | CNG | 0.0008 | 0.0026 | /mi |

| | Phase | Source | Upstream | Downstream | $MTCO_2eq$ |
|---|---|---|---|---|---|
| PARKING | Const. | Lot | 1 | - | /space |
| | | Garage | 5 | - | /space |
| | Ops. | Lot | - | 0.0001 | /space/yr |
| | | Garage | - | 0.0001 | /space/yr |

| CARBON STORAGE | Upstream | Downstream | $MTCO_2eq$ |
|---|---|---|---|
| C Sequestration Loss Due to Tree Removal | - | 0.8368 | /tree/yr |

## Typology Matrix Data Sources

Table 2-4 lists the data resources used to develop the emissions factors included in the Matrix. The following section describes each of the data resources in depth.

**Table 2-4**

*Typology Matrix Data Sources*

| Phase | Mode | Sources | Data Resource |
|---|---|---|---|
| Construction | Rail[10] | New, at-grade HR, CR, LR track<br>New, elevated HR, CR, LR track<br>New, underground HR, CR, LR track<br>Converted or upgraded existing LR track<br>New, at-grade HR, CR, LR station<br>New, elevated HR, CR LR station<br>New, underground HR, CR, LR station | FHWA ICE |
| | | Rail catenary system | Hanson et al. 2014 |
| | Bus/BRT | BRT new lane or right-of-way<br>BRT converted or upgraded lane<br>New, at-grade station | FHWA ICE |
| | | Trolleybus catenary system | Hanson et al. 2014 |
| | Parking | Surface parking<br>Structured parking | FHWA ICE |
| Maintenance | Rail | HR, CR, LR vehicle | Chester, 2008 |
| | Bus/BRT | HR, CR, LR track | FHWA ICE |
| | | BRT pavement | FHWA ICE |
| Vehicle Operation | Rail | HR electric<br>LR electric<br>CR electric | NTD electricity use and VMT data; EPA eGRID 2012 |
| | | CR diesel and biodiesel | GREET |
| | Bus/BRT | Electric vehicle<br>Diesel vehicle<br>Biodiesel vehicle<br>LNG vehicle<br>CNG vehicle | GREET |
| | DR/Vanpool | Sedans, vans, buses of various fuel types | GREET |
| Facility Operation | Rail | Station electricity<br>Station heating | Energy use data from one transit agency |
| | | Maintenance/storage electricity<br>Maintenance/storage heat | Energy use data from seven transit agencies |
| | Bus/BRT | Station electricity<br>Station heating | Energy use data from one transit agency |
| | | Maintenance/storage electricity<br>Maintenance/storage heat | Energy use data from seven transit agencies |
| | Parking | Surface parking<br>Structured parking | FHWA ICE |
| Carbon Storage | | Carbon sequestration loss due to tree removal | USDA; Zhao and Sander (2015) |

[10] Rail includes heavy rail, commuter rail, light rail, and streetcar.

### *Construction-related Emissions Factors*

In the construction phase of a transit project, upstream emissions are the emissions associated with the extraction, transport, and production of the materials used in the construction of the facilities (e.g., asphalt, concrete, base stone, and steel). Downstream construction emissions are tailpipe emissions resulting from the operation of construction vehicles and equipment. The primary data sources for construction-related GHG emissions factors in the Matrix are the Federal Highway Administration's (FHWA) Infrastructure Carbon Estimator (ICE) and research by Hanson et al. (2014).

FHWA's ICE is a spreadsheet tool that estimates the lifecycle energy and GHG emissions from the construction and maintenance of transportation facilities. ICE's lifecycle emissions include those resulting from the operation of construction vehicle and equipment and the embodied energy and emissions associated with the extraction, transport, and production of the materials (i.e., asphalt, concrete, base stone, and steel) used in the construction of the transportation facilities. The information in ICE is based on a nationwide database of construction bid documents, data collected from state Departments of Transportation, and consultation with transportation engineers and lifecycle analysis experts. ICE use emission factors from the Pavement Lifecycle Assessment Tool (PaLATE).

Hanson et al. (2014) provides a technique to assess the GHG emissions associated with the construction of commuter rail projects, with focus given to the lifecycle emissions associated with materials used to construct track, catenary systems, station platforms, parking facilities, and tunnels and bridges.

### *Maintenance-related Emissions Factors*

Maintenance-phase GHG emissions are all considered downstream emissions. The Matrix includes GHG emission factors for maintenance of track/lane-miles and transit vehicles. The GHG emission factors for track/lane-mile maintenance are based on FHWA's ICE. The ICE tool accounts for direct emissions associated with routine maintenance activities such as snow removal and vegetation management, among other activities. The ICE tool used data from the Los Angeles County Metropolitan Transportation Authority (LACMTA) and the NTD to estimate total fuel use for rail-related maintenance activities.

The Matrix's GHG emission factors for vehicle maintenance are based on research by Chester (2008), which calculated the GHG emissions for vehicle maintenance for buses and rail. GHG emission rates for bus vehicle maintenance are based on a 40-foot bus. Chester provides GHG emission rates for rail vehicle maintenance, which includes routine maintenance (standard upkeep and inspection), cleaning, and flooring replacement, for four types of vehicles: Bay Area Rapid Transit (BART) heavy rail trains, Caltrain commuter rail trains, Muni

light rail trains, and the Massachusetts Bay Transit Authority's (MBTA) Green Line light rail trains. The emissions factors in the Matrix for the heavy rail and commuter rail maintenance are from the Chester report; the emissions factors in the Matrix for light rail vehicle maintenance are an average of the Muni and MBTA light rail vehicle emissions estimates from Chester (2008).

## Operations-related Emissions Factors

***Vehicle Operations***

The Matrix includes upstream and downstream GHG emissions factors for the operation of road- and rail-based transit vehicles across a range of fuel sources. During the operations phase, upstream emissions are associated with the extraction, production, and transportation of the vehicle fuel; downstream emissions are the tailpipe emissions resulting from the operation of a transit vehicle.

Emissions factors for road-based vehicles, including buses, were derived from Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model, 2015 release.

The Matrix's downstream emissions factors for road vehicle operations represent GREET's default "pump-to-wheels"[11] emissions factors for the 2015 simulation year. The Matrix's upstream emissions (well-to-pump)[12] figures for road vehicle operations were derived by subtracting GREET's pump-to-wheels emissions factors from GREET's "well-to-wheels" emissions factors:

*Upstream vehicle operations emissions = GREET well-to-wheels – GREET pump-to-wheels*

The vehicle types in the Matrix use the following GREET vehicle types:

- *Electric bus:* Heavy-Duty, Transit Bus, Electric Vehicle, U.S. mix
- *Diesel bus:* Heavy-Duty, Transit Bus, Compression-ignition direct-injection (CIDI) diesel
- *Biodiesel bus:* Heavy-Duty, Transit Bus, CIDI biodiesel
- *Liquefied natural gas (LNG) bus:* Heavy-Duty, Transit Bus, Spark-ignition (SI) Vehicle LNG
- *Compressed natural gas (CNG) bus:* Heavy-Duty, Transit Bus, SI Vehicle CNG
- *Demand response bus:* Use same as buses above
- *Vanpool diesel:* Light Heavy-Duty Vocational Vehicles with diesel as baseline
- *Vanpool gas:* Medium Heavy-Duty gasoline as baseline

[11] Pump-to-wheel emissions are the operational emissions associated with the vehicle technology (i.e., tail pipe emissions and the energy efficiency of the vehicle).

[12] Well-to-pump emissions are those associated with producing the fuel used in the vehicle.

- *Vanpool ethanol:* Light Heavy Duty, diesel baseline; ethanol as fuel
- *All Sedan/Autos:* Spark-ignition internal combustion engine vehicles, except for biodiesel, which is CIDI internal combustion engine vehicle
- *School bus diesel:* Heavy-Duty, School Bus, CIDI diesel
- *School bus biodiesel:* Heavy-Duty, School Bus, CIDI biodiesel
- *School bus liquefied petroleum gas (LPG):* Heavy-Duty, School Bus, SI Vehicle LPG
- *School bus CNG:* Heavy-Duty, School Bus, SI Vehicle CNG

The Matrix's emissions factors for each rail mode's electric vehicle operations are based on energy consumption rates derived from energy use and transit vehicles mile traveled (VMT) data reported in the NTD[13] and electricity emission rates from the EPA's Emissions & Generation Resource Integrated Database (eGRID) 2012. The following calculations were made for each rail mode:

(1) Total electricity use for years 2010–2014 (kilowatt-hours (kWh) / Total VMT for years 2010–2014 = kWh used per VMT

(2) kWh per VMT * eGRID2012 annual total output emission rate[14] = GHG emissions per VMT

Commuter rail consumes both diesel and electricity; however, NTD does not report VMT by diesel and electricity separately.[15] The VMT of 4 of 24 commuter rail systems nationwide for which NTD has data reported are powered all electrically. For electrically-powered commuter rail, VMT and kWh data from NTD 2014 for the four all-electric commuter rail systems were used to calculate the energy consumption information used in the Matrix's commuter rail electric operations factors. For diesel and biodiesel-powered commuter rail, GREET was used to estimate GHGs following the method described in Appendix A.

### *Facility Operations*

The Matrix includes GHG emission factors for the operation of both rail and bus stations and maintenance and storage facilities. The project team calculated emissions factors for maintenance and storage facilities based on annual electricity and heating usage data that seven transit agencies provided for a variety of their facilities; the estimates for GHG emissions from station electricity are based on data from two subway stations. The project team aggregated the information and estimated the average annual electricity and

[13] The project team analyzed the GREET rail module as an alternative data source for estimating GHG emissions from rail operations. See Appendix A for a description of the analysis.

[14] eGRID annual total output emission rates are available at www.epa.gov/sites/production/files/2015-10/documents/egrid2012_summarytables_0.pdf, last accessed 9/16/16.

[15] Data for one biodiesel-only commuter rail system is reported to the NTD.

heating fuel usage per square foot by facility type.[16] The aggregate average annual electricity data (kWh) and heat data, provided in gallons of heating oil, therms of natural gas, and cubic feet of natural gas, were converted to GHG emissions using the following conversion factors:

1 kWh electricity = 0.000689551 $MTCO_2$ (per EPA)[17]

0.01010 MCF natural gas = 1 kWh electricity[18]

1 therm = 29.3001 kWh electricity

1 gallon residual fuel oil (#6 oil) = 43.9 kWh electricity[19]

### *Parking Emissions*

The Matrix includes GHG emission factors for the construction of structure (garage) and surface parking on a per-space basis using data from FHWA's ICE. ICE's parking emissions include those from the operation of construction vehicle and equipment, and the embodied energy and emissions associated with the extraction, transportation, and production of the materials (i.e., asphalt and base course stone) required to construct parking facilities.

### *Carbon Storage Emissions Factors*

The Matrix includes an emissions factor for the annual, per-tree carbon sequestration[20] loss due to tree removal. The project team referred to data from the U.S. Department of Agriculture (USDA), Novak and Crane (2002), and Zhao and Sander (2015). The Matrix figure was derived as follows:

(1) 0.22801 MT C stored per urban tree based on data from 11 American cities (Novak and Crane 2002, Zhao and Sander 2015)

(2) For every 1 MT C stored annually, approximately 3.67 $MTCO_2$ are sequestered per year (USDA)

(3) 0.22801 MT C stored * 3.67 $MTCO_2$ sequestered per year = 0.8368 $MTCO_2$ sequestered/tree/year

[16] Although cubic footage is the preferred unit of measurement for building size, the project team was limited to the available square footage information.

[17] $CO_2$ only

[18] Energy Information Administration, www.eia.gov/tools/faqs/faq.cfm?id=667&t=8.

[19] www.think-energy.net/energy_units.htm.

[20] Carbon sequestration describes the process by which carbon is removed from the atmosphere and stored in carbon sinks such as oceans, forests, or soils.

The Matrix does not include emissions factors for gains in carbon storage due to tree plantings; however, the U.S. Forest Service offers a Tree Carbon Calculator that allows users to make species-, age-, and diameter-specific estimates.[21]

## *Typology Matrix Data Quality and Limitations*

***Construction-Related Emissions***

**Underground track miles, downstream emissions:** ICE's estimates for downstream emissions resulting from the construction of new underground track miles differ based on (1) where the project is located and (2) whether the track is constructed through hard or soft stone. This is because the analysis for an underground tunnel involves an estimate of electricity used for the operation of a tunnel boring machine.[22] GHG emissions associated with producing electricity vary depending on the fuel(s) used to produce the electricity. Since the fuel mix for electricity production varies geographically across the country, underground tunnel construction emissions vary depending upon where the project is located. Constructing tunnels through hard stone also generally requires more electricity than doing so through soft stone, resulting in relatively elevated emissions. The Matrix's underground track construction emissions factor is based on construction through hard stone in the State of Colorado, corresponding to ICE's most conservative emissions estimate (i.e., generates the greatest amount of GHG emissions).[23]

**Rail and BRT station construction:** Due to wide variability in the size, design, and amenities offered among transit stations, within a transit mode and among different transit modes, it is difficult to create generic assumptions regarding station construction. ICE includes emissions factors for commuter rail stations that are based on the materials required for station structures and platforms, but the tool does not provide details on the transit station design upon which its station construction emissions are based. Other potential data sources for station construction emissions factors exist. For example, Hanson et al. (2014) includes emissions factors for commuter rail stations that are based on the materials required for station platforms. It does not include any additional structures due, according to the authors, in part to the wide variety of potential structures, ranging from bus shelters to large buildings that provide commuters with various amenities, such as heated waiting areas. The Matrix's station construction emissions figures use ICE's emissions estimates in order to include emissions associated with the structure as well as the station platforms.

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[21] The calculator is available at www.fs.usda.gov/ccrc/tools/tree-carbon-calculator-ctcc.

[22] ICE does not include emissions estimates for tunnel blasting.

[23] The conservative estimate is 5,085 $MTCO_2eq$ per track mile. For comparison, the emissions factor associated with new construction of one mile of underground track through soft soil in California, which represents the low-end of the ICE's underground track construction emissions range, is 3,204 $MTCO_2eq$ per track mile.

**Commuter rail emissions:** The Matrix's commuter rail track and commuter rail station construction emissions factors are based on ICE's heavy rail construction estimates. FHWA's ICE tool provides data for heavy and light rail only and does not currently include data specific to commuter rail.

**Catenary:** The Matrix's catenary system construction emissions factors are based on data for commuter rail electrified track from Hanson et al. (2014). The material components for catenary systems in the Matrix's emissions factors for commuter rail and light rail include the emissions associated with the steel and aluminum in the scaffolding and copper in the copper wire. The trolleybus catenary system emissions factors includes the emissions associated with the copper component only as the copper requirements for trolleybus overhead wires are expected to be similar to that for commuter rail. No data regarding the amount of copper in heavy rail's third rail or the GHG emissions associated with that component were readily available and thus are not included in this analysis or in the Matrix. Due to the lack of data it is unknown whether heavy rail's third rail copper component is a considerable source of emissions.

### *Vehicle Operations-related Emissions*

**Electric vehicles:** The emissions factors in the Matrix for electrically powered vehicles use the "U.S. Mix" region from the EPA's eGRID2012, which represents an average value for the country. The U.S. Mix region emission rates overestimate emissions for electrically-powered vehicles in regions with cleaner electricity generation mixes and underestimate emissions for the same in regions where electricity production is less clean. EPA's eGRID also provides GHG emission data at the subregion level, which reflect more region-specific electricity generation. The eGRID subregion electricity emission factors are provided in Appendix B.

**Transit vehicle operations:** GHG emissions factors for transit vehicles are based solely on VMT by vehicle and fuel type and do not account for additional location specific factors such as different fleet mixes, vehicle age distributions, load factors, and speed profiles.

**Fuels for buses, demand response vehicles, and vanpools:** The Matrix does not include a comprehensive accounting of all vehicle fuels for buses, demand response vehicles, and vanpools. Buses operating with gasoline, liquefied propane gas, ethanol, kerosene, and hydrogen were not included in the Matrix because data were not readily available.

### *Facility Operations-related Emissions*

**Facility operations:** Due to the wide variability in transit station and facilities in term of size, design, amenities offered, and operating efficiencies, it is difficult to create generic assumptions regarding their associated electricity and heat

usage. This challenge was compounded by the fact that transit agencies provided the project team with limited data for stations; the current station operation GHG emissions factor is based on only two data points from one transit agency. Furthermore, the electricity and heating figure for rail and bus maintenance and storage facilities are based largely on older buildings. As such, the emission factors for facility operations in the Matrix are likely conservative because new buildings are likely more energy efficient than older buildings. Projects to retrofit or upgrade facilities are expected to improve efficiencies by design.

### *Displaced Emissions*

**Congestion relief and land use effect:** In addition to displacing VMT, transit—especially when met with high ridership—can help reduce congestion and spur more compact, transit-oriented development, thus avoiding GHG emissions that may have otherwise occurred. Mode shift to transit has the potential to displace emissions caused by traffic congestion (APTA 2009). Such congestion relief benefits are achieved through improved operating efficiency of private automobiles, including reducing idling in stop-and-go traffic, promoting shorter trips, or avoiding automobile trips all together. Potentially greater GHG reductions can be achieved through denser development that transit helps to induce. Some researchers believe that this "land use effect" may result in the largest GHG emissions reductions, albeit over a decade or longer timeframe given the relatively slow pace of land development.[24] Therefore, when the congestion relief and land use effect are factored, the total net GHG emissions for each transit mode is expected to be lower than reported here; data were not available to estimate the degree of the additional reductions at a programmatic level.[25]

**Other displaced emissions:** The programmatic analysis does not consider GHG emissions displaced due to a reduced need for highway maintenance or emission reductions associated with displaced personal vehicle ownership as a result of the new transit project.

## Scenario Testing

The project team quantified the GHG emissions from a sample of transit projects to analyze the range of emissions associated with different transit modes and project characteristics (Table 2-5).

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[24] Nahlik and Chester (2014) explored how desired development patterns and behaviors can be integrated with lifecycle cost analysis to more fully understand the benefits and costs of moving people closer to transit.

[25] Regarding the land use effect, TRCP Report 176 offers a calculator for estimating the associated GHG emissions reductions. The calculator could not be applied at a programmatic scale due to its location-specific nature.

**Table 2-5**

*GHG Emissions Sources in Scenario Results by Inclusion Status*

| | Emissions Sources Included | Emissions Sources Excluded |
|---|---|---|
| Construction-related Emissions | • Transitway track construction<br>• Paving of separated rights-of-way<br>• Station construction<br>• Parking construction<br>• Catenary system construction/ copper | • Tree removal |
| Maintenance-related Emissions | • Routine maintenance of transitway<br>• Routine maintenance of pavement<br>• Routine maintenance of vehicles | |
| Operations-related Emissions | • Transit vehicle miles traveled (VMT) | • Boiler/furnace combustion for stations and maintenance/storage facilities<br>• Purchased electricity for stations, maintenance/storage facilities, parking facilities<br>• Transit access trips<br>• Operation of non-revenue vehicles |
| Displaced Emissions | • Personal vehicle VMT | |

The sample included 36 transit projects that applied for funding through the Section 5309 Capital Investment Grants (CIG) Program in fiscal years 2015 through 2018. The sample included 12 bus rapid transit projects, 10 light rail projects, 8 streetcar projects, 4 commuter rail projects, and 2 heavy rail projects. The project team used information provided on the CIG templates for the following project characteristics to quantify the emissions associated with each transit project:

- Length of transitway and type of alignment (at-grade, elevated, below-grade)
- Count of stations and their locations in space (at-grade, elevated, below-grade)
- Count of parking spaces and type (surface or structure)
- Annual VMT by transit mode/technology (the change in annual transit VMT[26] between the build and the no-build scenario) for the forecast year
- Annual personal automobile VMT displaced (the change in annual VMT between the build and the no-build scenario) for the forecast year
- Catenary system construction

Due to a lack of available information for the sample transit projects, the following emission sources were not included in the scenario testing:

- Operation of stations and maintenance/storage facilities
- VMT associated with transit access trips

[26] For rail modes, VMT was reported in terms of total rail passenger car mileage.

- Operation of non-revenue vehicles
- Tree removal

To calculate a project's expected total annual GHG emissions the project team summed each transit project's estimated amortized construction emissions,[27] annual maintenance-related emissions, and annual operations-related emissions minus annual displaced emissions. (See Appendix C for the detailed results.)

### *Scenario Testing Data Quality and Limitations*

The following section outlines the assumptions and methods used to generate GHG emissions estimates for transit projects sample:

- **Amortized construction emissions:** The Matrix's construction GHG emissions emission factors represent the total amount of emissions per unit to complete construction. The project team amortized construction emissions over a 50-year period, which corresponds to the *minimum* useful lifespan of facilities.[28] Using a truncated amortization period for transit scenarios or example projects would increase the total annual GHG emissions reported for the project.
- **Track and catenary construction emissions:** The project team used mileage figures for rail transit projects as presented in the CIG templates. The project team then relied on information in projects' environmental documents to determine whether catenary overhead systems would be used to supply the electricity to power the respective transit vehicles. All sample streetcar and light rail projects were found to use a catenary system. The project team assumed the catenary systems would be overhead for the project's entire length.
- **BRT construction:** The Matrix includes emissions associated with constructing a new BRT lane and right-of-way and for converting or upgrading a lane. All BRT projects analyzed were assumed to be new fixed-guideway BRT lanes and thus involve pavement construction.
- **Annual VMT forecasts:** Using travel forecasts and transit operating plans, project sponsors provide FTA with estimated annual transit and automobile VMT for no-build[29] and build[30] scenarios for the current year and a horizon

[27] The short-term construction emissions are divided over the life of a project to develop annual construction-related emissions estimates.

[28] FTA Circular 5010.1D Chapter IV. 3.f.(2)(e).

[29] The no-build scenario for the current year is the existing transportation system excluding the proposed transit project. The horizon year no-build is the existing transportation system plus transportation investments committed in the Transportation Improvement Plan (TIP) or the metropolitan planning organizations' (MPO's) fiscally-constrained long range transportation plan excluding the proposed transit project.

[30] The current year build scenario reflects the transit project's opening year service plan. The future build scenario is the existing transportation system plus transportation investments committed in the TIP or the MPO's fiscally constrained long-range transportation plan plus the proposed transit project.

year (which is optional). For this analysis, when a CIG project template included both a current and horizon-year forecast, the horizon-year data were used. Except for one instance of a light rail project, BRT was the only transit mode that did not provide horizon-year data.

- **Electric vehicles:** The scenario analysis used the emission factors for the U.S. Mix region from EPA's eGRID2012. The electricity emission rates used in this analysis do not account for an overall "greening" of electricity production that is likely to occur in the future.
- **Displaced emissions:** The scenario testing analysis assumes that all of the displaced automobile VMT is from gasoline-fueled sedans. The automobile fleet is expected to shift toward cleaner vehicles over time concurrently with a "greening" of electricity production. As personal vehicles produce fewer emissions, the VMT displacement benefit of transit may also be reduced.
-

SECTION

3

# Results

The annual GHG emissions that the sample transit projects are estimated to generate range from a reduction of approximately 40,000 $MTCO_2eq$ to an increase of 11,000 $MTCO_2eq$ (Figure 3-1). More than 70% (26 of 36) of the sample transit projects are expected to have annual GHG emissions less than 1,000 $MTCO_2eq$. A total of 14 of those projects are expected to result in a net reduction in GHG emissions annually. One of the 31 sample transit projects, a commuter rail project, is estimated to have annual GHG emissions over 10,000 $MTCO_2eq$.

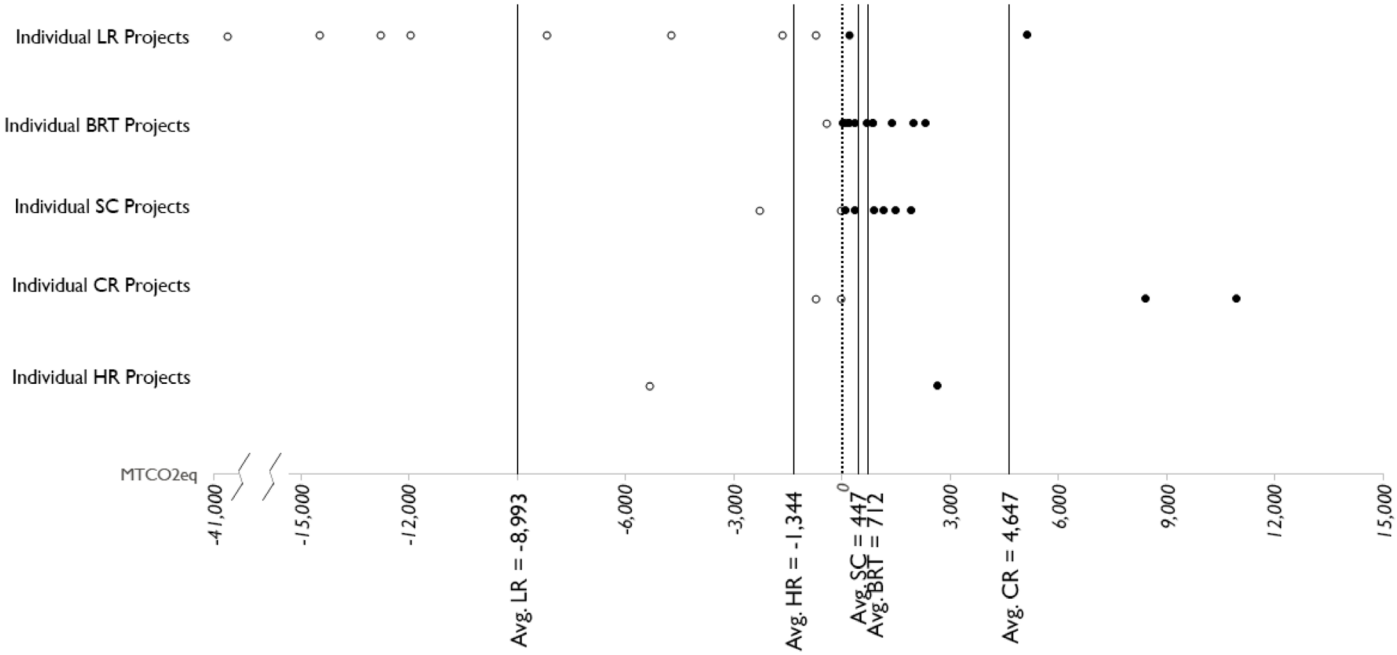



**Figure 3-1** *Total GHG emissions by transit project analyzed*

## Bus Rapid Transit Sample Results

BRT is a fixed-route bus mode in which the majority of the line operates in a separated right-of way. The BRT vehicles are roadway vehicles powered by diesel, gasoline, battery, or alternative fuel engines contained within the vehicle.

Annual GHG emissions from BRT projects sample (n=12) averaged approximately 710 ± 830 $MTCO_2eq$. All of the BRT projects analyzed resulted in total annual GHG emissions of less than 2,400 $MTCO_2eq$ per year; one project resulted in an overall reduction in annual GHG emissions.

The majority of the GHG emissions generated from the BRT projects in the sample are estimated to be operations-related downstream emissions (e.g., the tailpipe emissions), followed by construction-related upstream emissions (e.g., the emissions associated with the extraction, transport, and production of the materials used in the construction of the facilities) (Figure 3-2). In terms of operations, the BRT projects included diesel-, hybrid-, and CNG-powered vehicles. The projects were also predominately at-grade with relatively low transit VMT. Although the BRT projects analyzed were expected to displace emissions through a reduction in personal vehicle VMT, their expected displaced GHG emissions were typically lower than the GHG emissions volumes they were expected to generate.

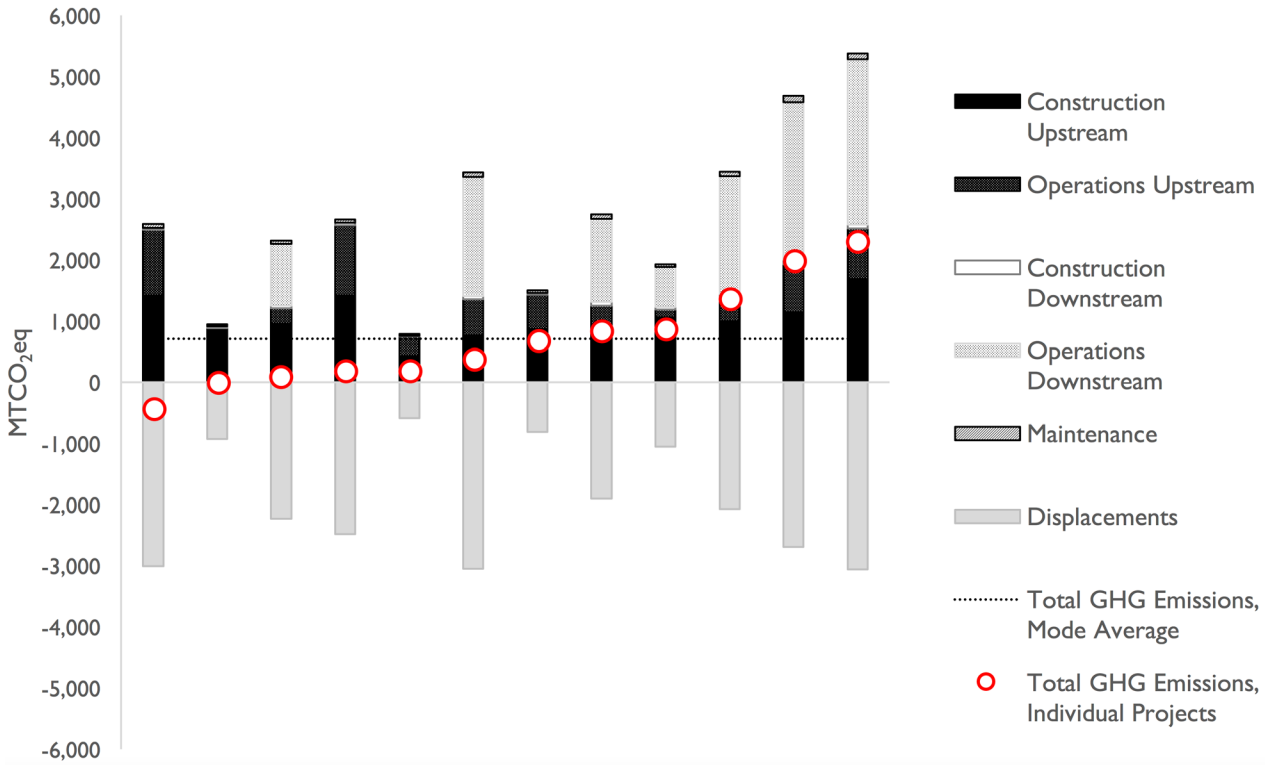



**Figure 3-2** *GHG Emissions from sample BRT projects by project phase*

# Streetcar Sample Results

Streetcar is a mode of rail transit that operates predominantly on streets in mixed traffic. This service typically operates with single-car trains powered by overhead catenaries.

Annual GHG emissions from the sample of streetcar projects analyzed (n=8) averaged approximately 450 ± 1,300 $MTCO_2eq$. Each of the streetcar projects analyzed was expected to have net GHG emissions of less than 2,000 $MTCO_2eq$ annually (Figure 3-3).

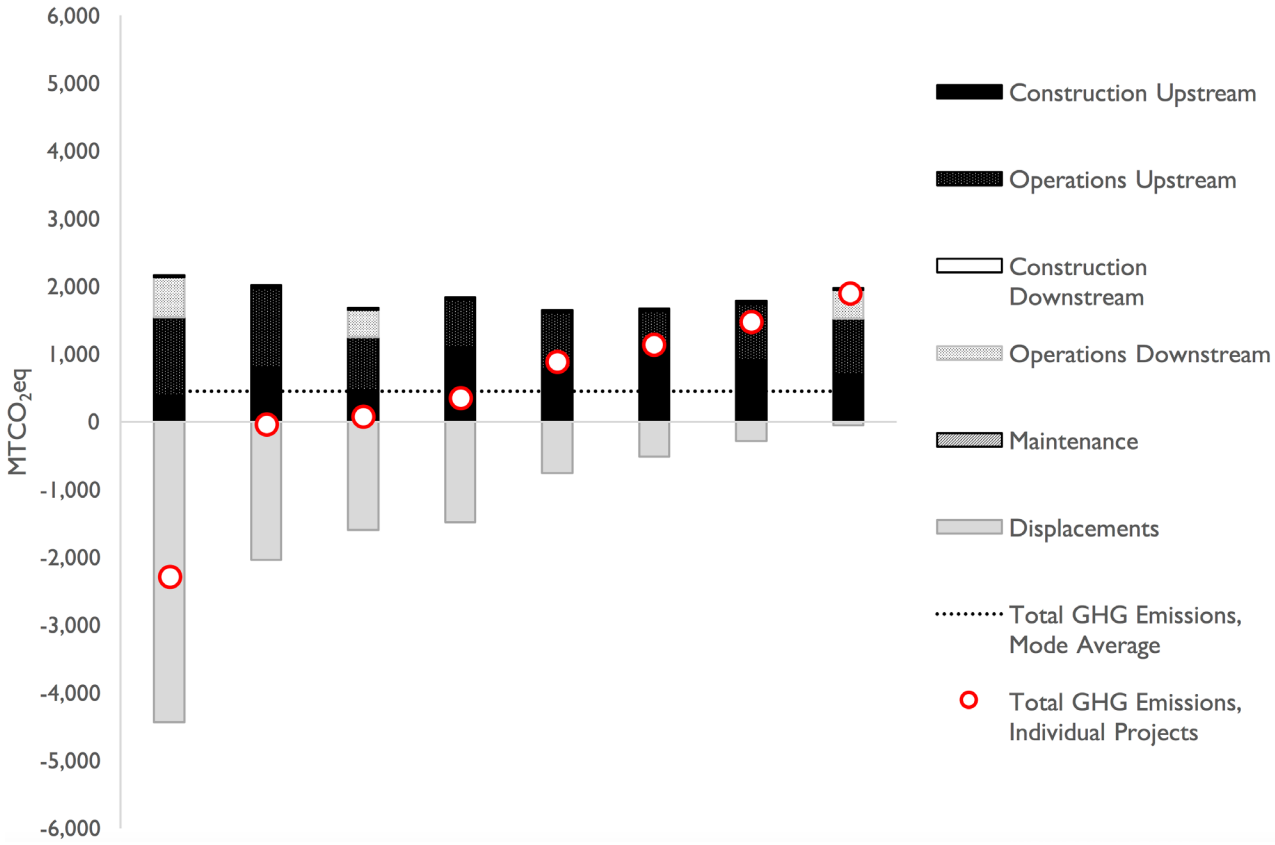



**Figure 3-3** *GHG emissions from sample streetcar projects by project phase*

The streetcar projects in the sample were predominately at-grade with relatively low transit VMT. The majority of the GHG emissions generated from the sample streetcar projects are expected to be from operations-related upstream emissions (e.g., emissions associated with the production and generation of the purchased electricity used to power the streetcar vehicles). For this reason, the net volume of annual GHG emissions from streetcar projects largely depends

on the fuel source used for electricity generation (see later section for more discussion regarding the impact of the electricity generation mix on GHG emissions). Although the streetcar projects analyzed were expected to displace emissions through a reduction in personal vehicle VMT, the annual volume of their displaced emissions were typically less than the annual volume of GHG emissions streetcar projects were estimated to generate.

## Light Rail Sample Results

Light rail is a mode of transit service operating passenger rail cars singly (or in short, usually two-car or three-car trains) on fixed rails in right-of-way that often is separated from other traffic for part or much of the way. Light rail vehicles are typically driven electrically with power being drawn from an overhead catenaries.

Annual GHG emissions from the sample of light rail projects (n=10) averaged approximately -9,000 ± 12,800 MTCO2eq; estimated emissions ranged from a reduction of 41,000 $MTCO_2eq$ per year to an increase of 5,000 $MTCO_2eq$ per year (Figure 3-4).

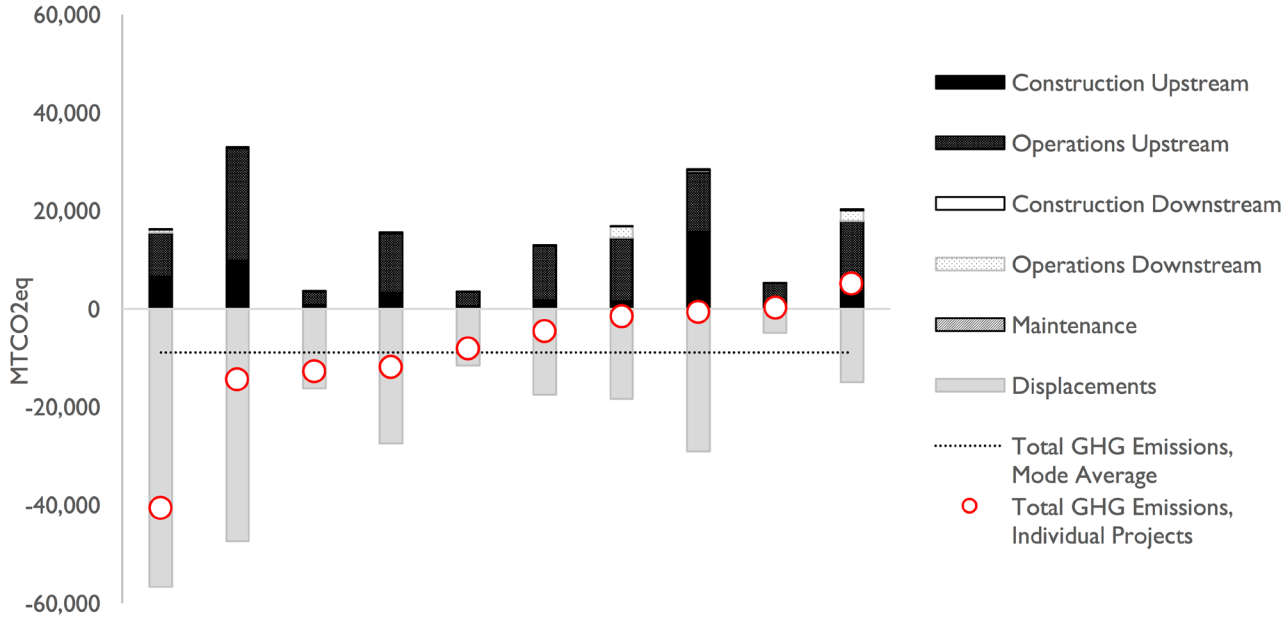



**Figure 3-4** *GHG emissions from light rail projects by project phase*

The light rail projects in the sample varied in length, track alignment, and number of stations; though all had relatively high rates of displaced personal vehicle VMT as compared to transit VMT. The majority of GHG emissions that light rail projects are expected to generate are operations-related upstream emissions (e.g., emissions associated with the production and generation of the purchased

electricity used to power the light rail vehicles). For this reason, the net volume of annual GHG emissions from light rail projects largely depend on the fuel source used for electricity generation (see later section for more discussion regarding the impact of the electricity generation mix on GHG emissions).

Each of the light rail projects analyzed was expected to displace emissions through a reduction in personal vehicle VMT. In 80% of the projects (8 of 10), the light rail project displaced more emissions than it generated on an annual basis.

## Commuter Rail Sample Results

Commuter rail is a mode of transit service characterized by an electric or diesel-propelled railway for urban passenger train service consisting of local short distance travel operating between a central city and adjacent suburbs. The sample analyzed here consists solely of diesel-powered commuter rail service.

Annual GHG emissions from the sample of commuter rail projects (n=4) averaged approximately 4,600 ± 5,900 $MTCO_2eq$; estimated emissions ranged from a reduction of 470 $MTCO_2eq$ per year to an increase of 10,700 $MTCO_2eq$ per year. The majority of the GHG emissions that commuter rail projects generate are expected to be from construction-related upstream emissions (the emissions are the emissions associated with the extraction, transport, and production of the materials used in the construction of the facilities) and operations-related upstream emissions (e.g., the emissions are associated with the extraction, production, and transportation of the vehicle fuel) (Figure 3-5).

The commuter rail projects in the sample varied in length, track alignment, number of stations, and rates of displaced personal vehicle VMT as compared to transit VMT. The two projects in the sample that resulted in a reduction in GHG emissions had high rates of displaced personal vehicle VMT as compared to transit VMT.

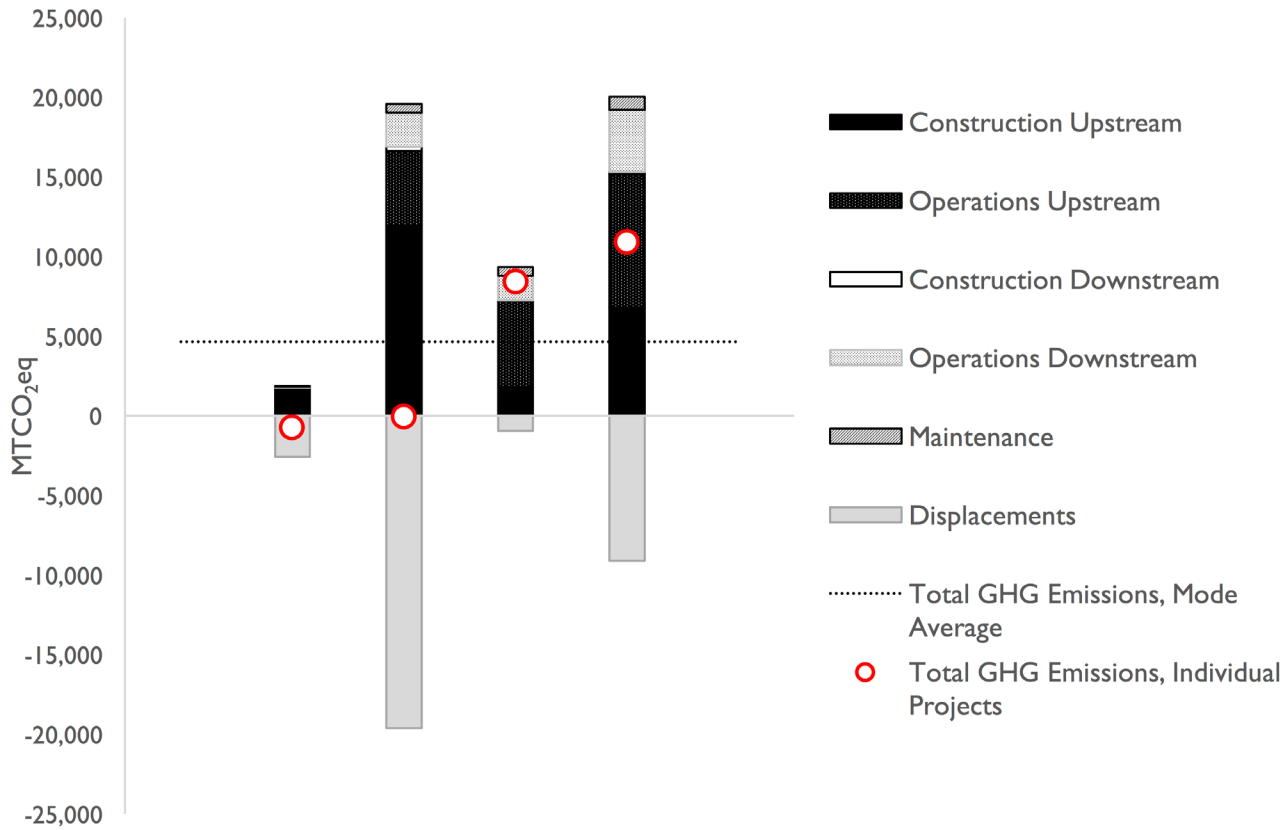



**Figure 3-5** *GHG emissions from commuter rail projects by project phase*

# Heavy Rail Sample Results

Heavy rail is a mode of transit service (also called metro or subway) operating on an electric railway with the capacity for a heavy volume of traffic. It is characterized by high speed and rapid acceleration passenger rail cars operating singly or in multi-car trains on fixed rails and separated rights-of-way. Heavy rail passenger cars are driven by electric power taken from overhead lines or third rails.

The sample of heavy rail projects (n=2) was too small to make meaningful overall GHG emissions estimates for heavy rail projects. However, the volume of greenhouse emissions for each project phase is likely indicative of typical heavy rail projects. The majority of GHG emissions that heavy rail projects are expected to generate are construction-related upstream emissions (e.g., the emissions associated with the extraction, transport, and production of the materials used in the construction of the facilities).

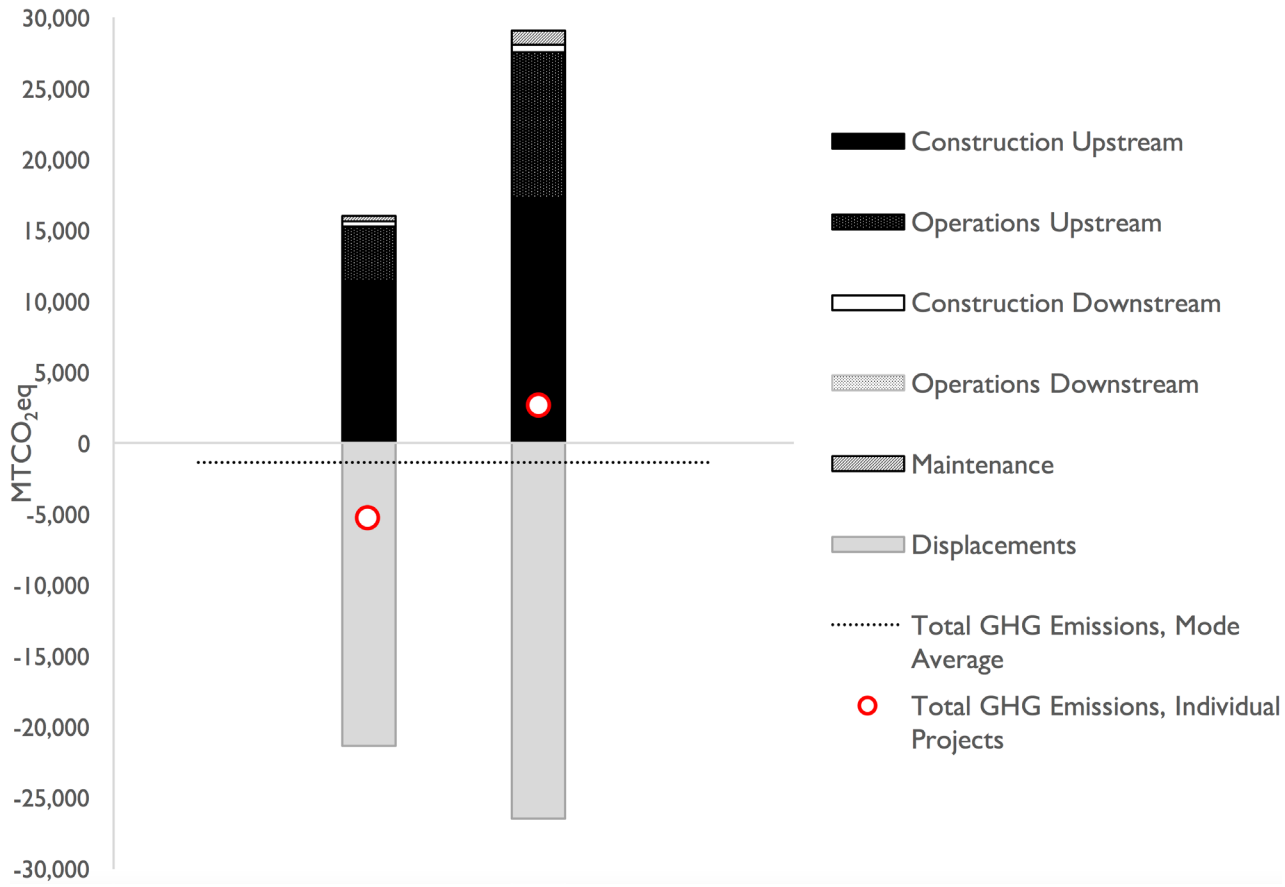



**Figure 3-6** *GHG emissions from heavy rail projects by project phase*

# Impact of Electricity Source on Results

In the United States, electricity is generated using a variety of energy resources, including coal, natural gas, nuclear power, and renewable energy. The GHGs emitted by electricity use depend on the fuel source used to generate it (i.e., the electricity mix). The estimated net GHG difference between a transit project powered by cleaner energy sources and the same project powered by electricity with a less renewable environmental profile is substantial.

Figure 3-7 illustrates the differences in the GHG emissions associated with an example light rail project across different eGRID subregions. The impact of the electricity generation mix on the example light rail project's GHG emissions is relevant to the operation of any electrically-powered transit mode.

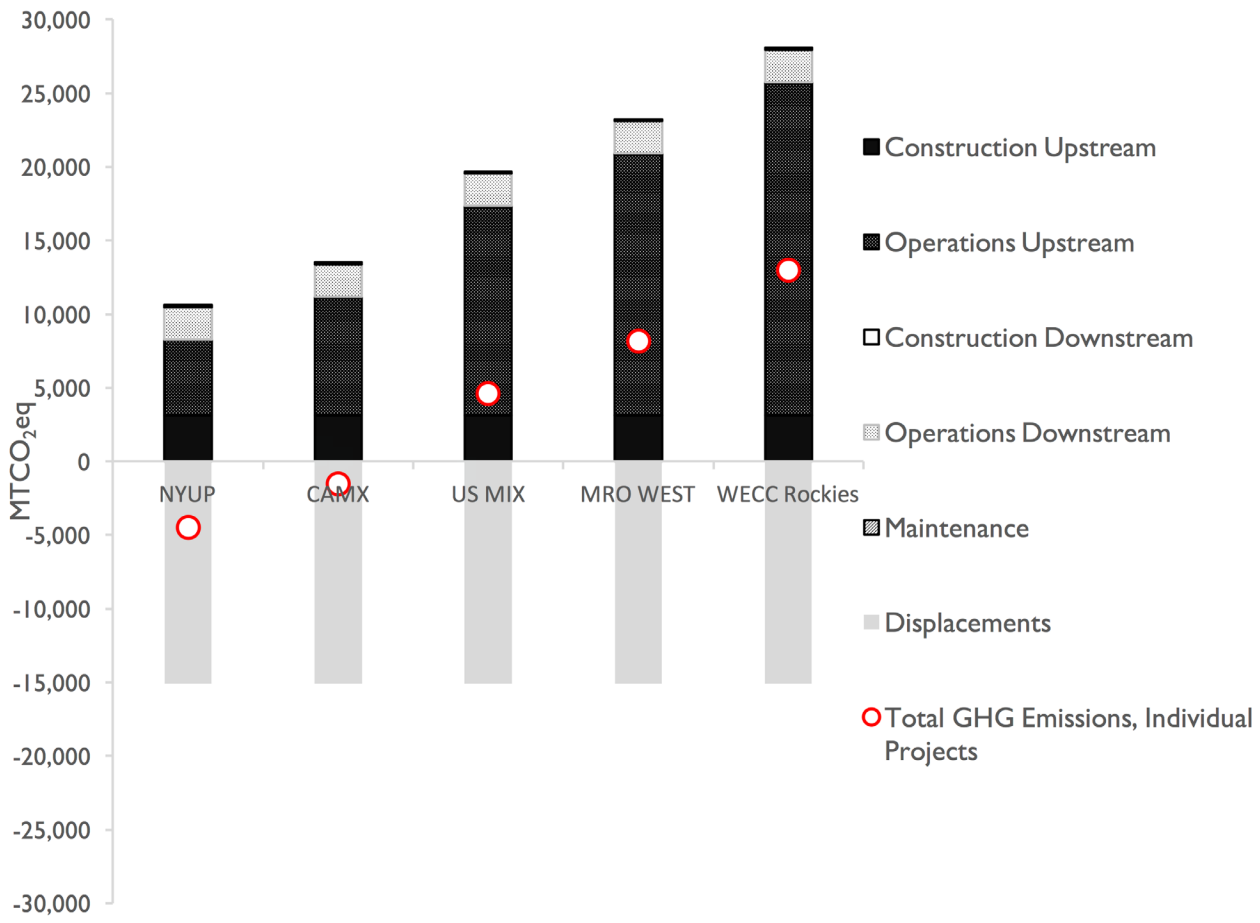



**Figure 3-7** *Total GHG emissions for light rail project from sample with highest emissions using different electricity generation mixes*

## Results Factoring Ridership

The results presented above use GHG emissions per VMT as the metric to measure vehicle operations-related GHG emissions. APTA's *Recommended Practice for Quantifying GHG emissions from Transit* outlines other metrics to measure a transit project's emissions, including emissions for revenue vehicle hour, which measures operation efficiency, and emissions per passenger- or per seat mile, which takes into account service productivity.[31] The latter metric provides insight into how the GHG emissions on a per-passenger basis changes based on change in ridership and load factors.

For illustrative purposes, the project team analyzed the estimated GHG emissions from the sample transit projects, recasting results to account for

[31] Service productivity refers to the number of riders served by the transit mode/route.

passenger loads for each mode. To do so, the project team divided estimated GHG emissions for each project in the sample by average loads for each mode. For example, according to NTD data, from 2011 to 2014 all commuter rail service nationally operated at 17% capacity, or 36 passengers, assuming a vehicle size of 211. The estimated GHGs generated by each commuter rail project were then divided by 36, whereas displaced GHG emissions from personal vehicles were divided by 1.67 to correct for typical auto occupancies. Displaced GHG emissions were subtracted from generated GHG emissions to obtain a total annual GHG emissions estimate that factors ridership. This approach was repeated for each mode. See Table 3-1.

**Table 3-1**

*Estimated Annual GHG Emissions Factoring Ridership and Auto Occupancy*

| Mode | Typical Vehicle Capacity (people) | Average Vehicle Load, 2011–2014 (people, rate) | Annual GHG Emissions Factoring Ridership and Auto Occupancy ($MTCO_2e$) | Annual GHG Emissions, Original Estimate ($MTCO_2e$) |
|---|---|---|---|---|
| CR | 211 | 36 (17%) | -4,400 | 4,600 |
| LR | 180 | 25 (14%) | -14,000 | -9,000 |
| BRT | 86 | 19 (22%) | -580 | 710 |
| Streetcar | 82 | 18 (22%) | -690 | 450 |

*Sources:* NTD for estimated transit mode capacities; FHWA 2009 National Household Travel Survey for auto occupancy; APTA *2016 Fact Book* for historical passenger loads.

Considering annual GHG emissions in this manner provides another lens through which the benefits of transit may be assessed. As transit vehicle load rates increase, the relative GHG benefits of a transit project can increase, and its "payback period," or point in time when emissions displaced or avoided offset emissions generated during construction, can occur sooner.

SECTION 4

# Conclusions

Transit projects generate GHG emissions during their construction, operations, and maintenance phases and can displace emissions by reducing personal vehicle emissions due to transit's "ridership effect." The conservative analysis here provides insight into the potential effects of proposed actions on climate change as indicated by estimated net GHG emissions. The analysis concludes that on average, BRT and streetcar projects are expected to generate relatively low levels of GHG emissions primarily due to their low infrastructure needs and low annual transit VMT. Results for light rail projects suggest that projects with a high ridership effect, regardless of length, alignment, and number of stations, are expected to result in a net reduction in GHG emissions. Similarly, commuter rail projects with a high ratio of displaced VMT to transit VMT may also be expected to result in low or net reductions in GHG emissions. Heavy rail projects also may have this impact, but the sample was too small to draw this conclusion.

From a programmatic vantage, in cases where project characteristics and assumptions are similar to those analyzed here, transit agencies that are considering BRT, streetcar, light rail, commuter rail, and heavy rail projects may incorporate this programmatic assessment by reference into their NEPA reviews. Mode-specific recommendations for doing so are:

- **BRT projects:** BRT projects generate relatively low levels of GHG emissions primarily due to their lower infrastructure needs and low annual transit VMT. The BRT projects in the sample were predominately at-grade with high ratios of displaced personal vehicle VMT as compared to transit VMT. BRT projects that share these characteristics are expected to have similar GHG emissions levels as those estimated for the BRT sample. Calculating project-specific GHG emissions for BRT projects is expected to provide only limited information beyond the information collected and considered in this programmatic analysis. Therefore, it is recommended that NEPA reviews for individual BRT projects incorporate this programmatic assessment by reference.
- **Streetcar projects:** Streetcar projects generate relatively low levels of GHG emissions primarily due to their lower infrastructure needs and low annual transit VMT. The streetcar projects in the sample were predominately at-grade with relatively low transit VMT as compared to displaced personal vehicle VMT. Streetcar projects that share these characteristics are expected to have similar GHG emissions levels as those estimated for the streetcar sample. Calculating project-specific GHG emissions for streetcar projects is expected to provide only limited information beyond the information

collected and considered in this programmatic analysis. Therefore, it is recommended that NEPA reviews for individual streetcar projects incorporate the analysis presented in this programmatic assessment by reference.

- **Light rail projects:** Light rail projects with a high proportion of displaced VMT to annual transit VMT, regardless of length, alignment, and number of stations, are expected to result in a net reduction in GHG emissions. Light rail projects with this characteristic are expected to have similar GHG emissions levels as those estimated for the light rail sample. Calculating project-specific GHG emissions for such light rail projects is expected to provide only limited information beyond the information collected and considered in this programmatic analysis. Therefore, it is recommended that NEPA reviews for individual light rail projects incorporate the analysis presented in this programmatic assessment by reference. However, in cases were a light rail project is expected to have a lower ratio of displaced VMT to annual transit VMT, then conducting a project-specific analysis using the Matrix or another locally recommended approach may be appropriate.
- **Commuter rail projects:** The commuter rail projects in the sample varied in length, track alignment, number of stations, and ratio of transit VMT to displaced personal vehicle VMT. The commuter rail projects that had a high ratio of displaced VMT to annual transit VMT resulted in a net reduction in GHG emissions. Due to the limited number of projects in the commuter rail sample, it is recommended that commuter rail projects that have characteristics that differ from the sample analyzed here (see Appendix C) use the Matrix or another locally recommended approach to make project-specific greenhouse emissions estimates in their NEPA analyses.
- **Heavy rail projects:** Due to the limited number of projects in the heavy rail sample, it is recommended that heavy rail projects that have characteristics that differ from the sample analyzed here (see Appendix C) use the Matrix or another locally recommended approach to make project-specific greenhouse emissions estimates in their NEPA analyses.

In no case is the use of the Matrix to estimate GHGs mandatory. Transit agencies should work with FTA Regions to determine whether to conduct project-specific analyses and the best approach for doing so. State and local requirements for greenhouse analysis may exist that influence the type of analysis that is conducted as part of the NEPA review of a project.

## Mitigation Strategies

Regardless of mode, transit agencies have adopted or are considering various strategies supplementary to the transit systems themselves to mitigate or offset their GHG emissions. Researchers have reasoned that strategies that promote transit to reduce GHG emissions should focus on improving the efficiency of current systems and promoting the most efficient systems (Greene and Plotkin 2011). This notion is echoed in TCRP Synthesis 84 (2010), which references a

case study where a net increase in GHG emissions from transit was observed. The report notes that opportunities for GHG emissions reductions exist through increased ridership on existing service or through a restructuring of service to focus on more heavily used routes.

Strategies that transit agencies have adopted to mitigate or offset GHG emissions have generally included planting trees, using new technology and low-carbon energy sources, making operational improvements, and implementing policies that result in behavior change (Table 4-1).

**Table 4-1**

*Example Transit Agency GHG Emissions Mitigation Strategies and Tactics*

| Tactic | Strategy |
|---|---|
| Technology Efficiency Improvements | • Cleaner engine use (e.g., installation of exhaust-after-treatment traps in vehicles) |
| | • Use of flywheels to capture and store energy |
| | • Use of engine fuel injectors |
| | • Use of automatic engine start-stop idle-reduction systems |
| | • Lighting upgrades to light-emitting diode bulbs |
| | • Halon replacement with lower emitting fire suppression systems (one transit agency has estimate lifetime $CO_2$ savings to be 27,000+ tons. |
| | • Upgrade to low NOx boilers |
| | • Use of on-board railcar energy storage units that release previously stored electrical energy upon acceleration |
| | • Use of stationary fuel cells |
| | • Installation of renewable energy technologies |
| | • Conversion of fossil fuel fleet to alternative fuel vehicles |
| Operational Improvements | • Enhancement of vehicle maintenance practices |
| | • Use of remote controlled third-rail heating systems |
| Policy Implementation and Behavior Change | • Congestion pricing |
| | • Traffic management |
| | • Allowance for flexible work schedules and teleworking |
| | • Active lifestyle encouragement |
| | • Transit subsidy |
| | • Land use and zoning decisions to reward transit in dense areas or to promote future dense development |

Hardy et al. (2013) and LA Metro (ICF 2010) have compared the cost-effectiveness of these and additional transit strategies intended to reduce greenhouse gases. LA Metro findings are illustrated in Table 4-2.

**Table 4-2**

*Summary of GHG Emissions Reduction Cost-Effectiveness and Maximum Annual Emission Reduction of Various Transit Tactics Considered by LA Metro*

| GHG Benefit | Cost Savings/Cost Neutral | Moderate Cost ($300–$900 per ton) | High Cost (> $1,000 per ton) |
|---|---|---|---|
| Large (> 10,000 $MTCO_2e$/yr) | • Ridesharing/transit programs for employers<br>• Transit-oriented development<br>• Vanpool subsidy<br>• On-board railcar energy storage | | • Expand rail and BRT systems<br>• Wayside energy storage substation |
| Moderate (1,000–10,000 $MTCO_2e$/yr) | • 45-foot composite buses<br>• Facility lighting efficiency | • Metro transit subsidy | • Bicycle paths along transit corridors<br>• Gasoline-electric hybrid buses |
| Small (< 1,000 $MTCO_2e$/yr) | • Tunnel lighting retrofit<br>• Hybrid non-revenue cars<br>• Recycled water for bus washing<br>• Low-water sanitary fixtures | • Solar panels<br>• Bike-to-transit commuter incentives | • Hybrid non-revenue light trucks |

*Source:* Adapted from ICF International (2010)

## GLOSSARY

**Bus** – A mode of transit service characterized by roadway vehicles powered by diesel, gasoline, battery, or alternative fuel engines contained within the vehicle. Vehicles operate on streets and roadways in fixed-route or other regular service.

**Bus Rapid Transit** – service that includes features that emulate the services provided by rail fixed guideway transit systems including defined stations, traffic signal priority (TSP) for public transportation vehicles, and short headway bidirectional services for a substantial part of weekdays and weekend days.

**Carbon dioxide equivalent** – A unit of measurement that can be used to compare the emissions of various GHGs based on how long they stay in the atmosphere and how much heat they can trap. For example, over a period of 100 years, 1 pound of methane will trap as much heat as 21 pounds of carbon dioxide. Thus, 1 pound of methane is equal to 21 pounds of carbon dioxide equivalents.

**Catenary** – A system of overhead wires used to supply electricity to a locomotive, streetcar, or light rail vehicle which is equipped with a pantograph.

**Commuter rail** – A mode of transit service characterized by an electric or diesel propelled railway for urban passenger train service consisting of local short distance travel operating between a central city and adjacent suburbs. Service must be operated on a regular basis by or under contract with a transit operator for the purpose of transporting passengers within urbanized areas, or between urbanized areas and outlying areas. Such rail service, using either locomotive hauled or self-propelled railroad passenger cars, is generally characterized by multi-trip tickets, specific station to station fares, railroad employment practices and usually only one or two stations in the central business district. Intercity rail service is excluded, except for that portion of such service that is operated by or under contract with a public transit agency for predominantly commuter services. Most service is provided on routes of current or former freight railroads.

**Displaced vehicle miles traveled** – The miles of private automobile travel that are avoided through a mode shift from private automobiles to transit.

**Downstream emissions** – Emissions from activities that occur "downstream" from the proposed action, such the combustion of fossil fuels

**Emission factor** – A representative value that relates the quantity of GHG emissions released to the atmosphere with an activity associated with the release of those emissions.

**Greenhouse gas (GHG)** – Natural or manmade gases that trap heat in the atmosphere and contribute to the greenhouse effect. The primary greenhouse gases emitted by the transportation sector are carbon dioxide ($CO_2$), nitrous oxide ($N_2O$), methane ($CH_4$), and hydrofluorocarbons (HFC).

**Heavy rail** – A mode of transit service (also called metro or subway) operating on an electric railway with the capacity for a heavy volume of traffic. It is characterized by high speed and rapid acceleration passenger rail cars operating singly or in multi-car trains on fixed rails; separate rights-of-way from which all other vehicular and foot traffic are excluded; sophisticated signaling, and high platform loading.

**Lifecycle assessment** – A technique to assess the environmental impacts associated with all stages of a product or service from cradle to grave. A full lifecycle assessment accounts for the GHG emissions from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling.

**Light rail** – A mode of transit service operating passenger rail cars singly (or in short, usually two-car or three-car, trains) on fixed rails in right-of-way that is often separated from other traffic for part or much of the way. Light rail vehicles are typically driven electrically with power being drawn from an overhead electric line via a trolley or a pantograph; driven by an operator on board the vehicle; and may have either high platform loading or low level boarding using steps.

**Miles of track** – A measure of the amount of track operated by rail transit systems where each track is counted separately regardless of the number of tracks on a right-of-way.

**National Environmental Policy Act (NEPA)** – The primary law governing the Federal Transit Administration's environmental protection process. The National Environmental Policy Act establishes protection of the environment as a national priority and mandates that environmental impacts must be considered before any federal action likely to significantly affect the environment is undertaken.

**Ridership effect** – Describes the effect that transit has on shifting drivers out of private vehicles and onto transit.

**Streetcar** – A mode of rail transit service that operates entire routes predominantly on streets in mixed-traffic. This service typically operates with single-car trains powered by overhead catenaries and with frequent stops.

**Transit vehicle miles traveled** – The miles a transit vehicle (bus, light rail, commuter or heavy rail vehicle) travels while in service.

**Upstream emissions** – Emissions from activities that occur "upstream" of the proposed action, such the extraction of fossil fuels.

APPENDIX

# A

# GREET Rail Module Analysis

The GREET Model, 2015 release, includes a rail module that provides emissions data for four classes of passenger rail: intercity, commuter, light, and heavy rail.[32] The project team analyzed the GREET rail module as an alternative data source for estimating GHG emissions from electrically-powered operations for commuter, light, and heavy rail. The emissions factors reported in GREET for electrically-powered rail operations are considerably higher than factors derived using other sources, including EPA's eGRID 2012 emission rates (see Table A-1). The project team ultimately opted for the approach described earlier (herein "NTD/eGRID") due to discrepancies between GREET-derived results and those from other estimation approaches described in the literature.

GREET's rail module presents emissions factors in grams/passenger-mile. The project team converted these units into units compatible with this analysis as follows:

(1) GREET GHGs (g/pass-mile) by rail mode * NTD's 2014 passenger miles by rail mode = total 2014 operations GHGs by mode)

(2) Total 2014 operations GHGs by mode ÷ NTD's 2014 transit VMT = GHGs/vehicle-mile

**Table A-1**

*Comparison of Derived Rail Operations Emissions Multipliers, $MTCO_2eq$/VEHICLE-MILE*

| | GREET-derived | NTD/eGRID-derived (US Mix) |
|---|---|---|
| HR | 0.1150 | 0.0030 |
| LR | 0.0161 | 0.0043 |
| CR | 0.0123 | 0.0055 |

GHGs/vehicle-mile were then multiplied against the operation (VMT) of electrically-powered rail vehicles from the sample of projects. See Table A-2.

[32] See Han et al. 2014 for more information on data sources and calculation methodology for each rail class, https://greet.es.anl.gov/publication-rail-module,

**Table A-2**

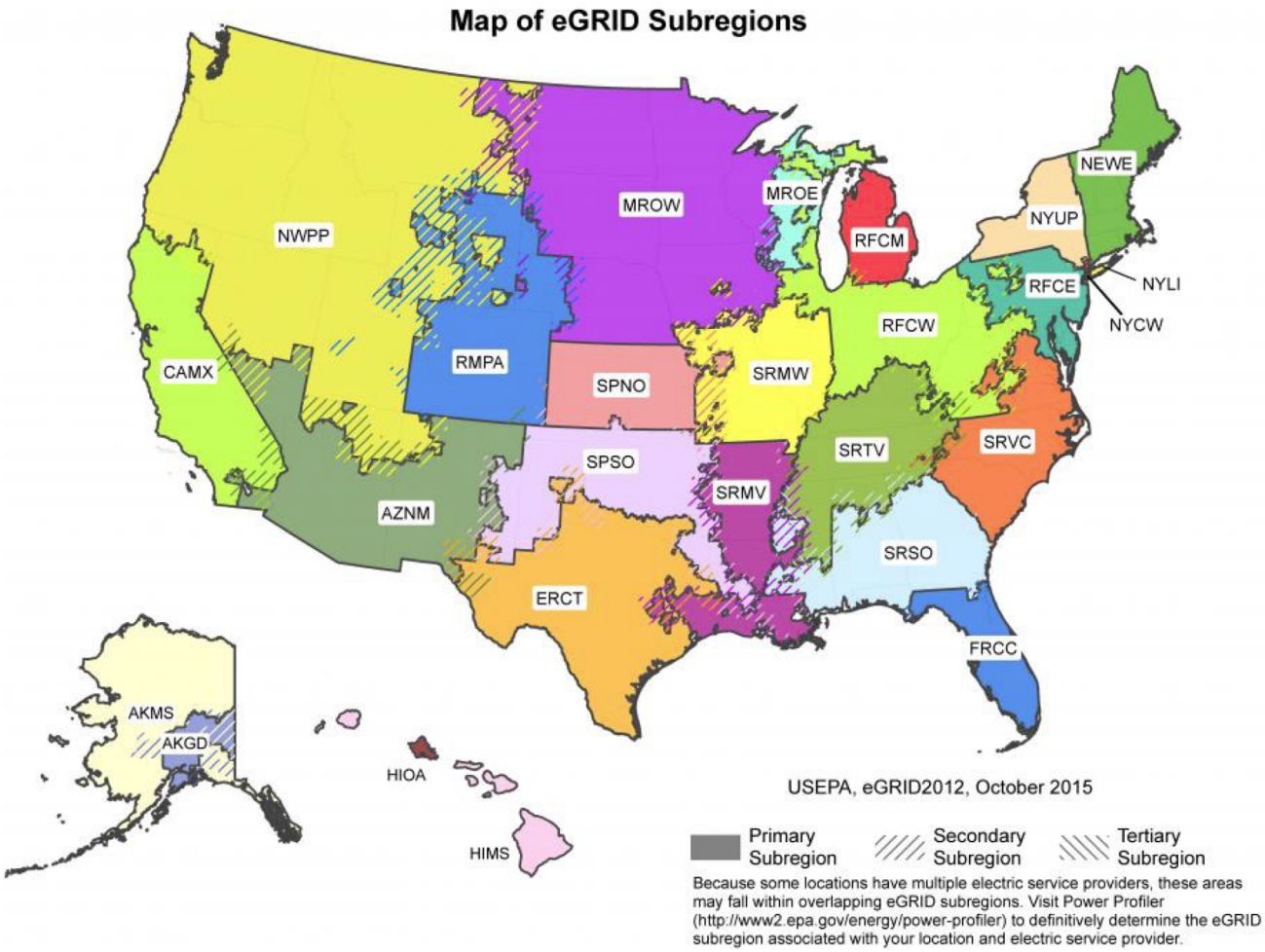
*Estimated GHG Emissions from Operation of Sample Rail Transit Projects*

| | MTCO$_2$eq as Estimated via | | | MTCO$_2$eq as Estimated via | | | MTCO$_2$eq as Estimated via | |
|---|---|---|---|---|---|---|---|---|
| *Rail Mode* | *GREET Rail Module* | *NTD/ eGRID* | *Rail Mode* | *GREET Rail Module* | *NTD/ eGRID* | *Rail Mode* | *GREET Rail Module* | *NTD/ eGRID* |
| Streetcar | 2,000 | 530 | LR | 10,100 | 2,700 | HR | 14,900 | 3,900 |
| Streetcar | 2,500 | 700 | LR | 10,700 | 2,800 | HR | 39,300 | 10,300 |
| Streetcar | 2,600 | 700 | LR | 16,400 | 4,400 | | | |
| Streetcar | 2,600 | 700 | LR | 32,300 | 8,600 | | | |
| Streetcar | 3,100 | 800 | LR | 40,400 | 11,000 | | | |
| Streetcar | 3,100 | 800 | LR | 41,600 | 11,100 | | | |
| Streetcar | 3,700 | 1,000 | LR | 44,600 | 11,900 | | | |
| Streetcar | 4,400 | 1,200 | LR | 45,400 | 12,100 | | | |
| | | | LR | 52,100 | 13,900 | | | |
| | | | LR | 85,300 | 22,800 | | | |

APPENDIX

# B

# Electric Rail Vehicle Operations Emission Factors by eGrid Subregions



| Stream Source | Up | Down | Up | Down | Up | Down | Up | Down | Up | Down |
|---|---|---|---|---|---|---|---|---|---|---|
| | **U.S.** | | **NYUP** | | **AKMS** | | **NEWE** | | **CAMX** | |
| Heavy Rail Electric | 0.0030 | - | 0.0011 | - | 0.0013 | - | 0.0017 | - | 0.0017 | - |
| Commuter Rail Electric | 0.0029 | - | 0.0010 | - | 0.0012 | - | 0.0016 | - | 0.0016 | - |
| Light Rail Electric | 0.0043 | - | 0.0015 | - | 0.0018 | - | 0.0024 | - | 0.0024 | - |
| | **NYCW** | | **RFCE** | | **SRVC** | | **SRMV** | | **FRCC** | |
| Heavy Rail Electric | 0.0018 | - | 0.0023 | - | 0.0025 | - | 0.0028 | - | 0.0030 | - |
| Commuter Rail Electric | 0.0018 | - | 0.0022 | - | 0.0024 | - | 0.0027 | - | 0.0029 | - |
| Light Rail Electric | 0.0026 | - | 0.0032 | - | 0.0035 | - | 0.0040 | - | 0.0042 | - |
| | **SRSO** | | **AZNM** | | **HIMS** | | **NYLI** | | **AKGD** | |
| Heavy Rail Electric | 0.0030 | - | 0.0030 | - | 0.0032 | - | 0.0032 | - | 0.0033 | - |
| Commuter Rail Electric | 0.0029 | - | 0.0029 | - | 0.0030 | - | 0.0031 | - | 0.0032 | - |
| Light Rail Electric | 0.0043 | - | 0.0043 | - | 0.0045 | - | 0.0045 | - | 0.0048 | - |
| | **RFCW** | | **MROW** | | **MROE** | | **SPSO** | | **RFCM** | |
| Heavy Rail Electric | 0.0036 | - | 0.0037 | - | 0.0040 | - | 0.0040 | - | 0.0041 | - |
| Commuter Rail Electric | 0.0035 | - | 0.0036 | - | 0.0039 | - | 0.0039 | - | 0.0040 | - |
| Light Rail Electric | 0.0052 | - | 0.0054 | - | 0.0057 | - | 0.0058 | - | 0.0059 | - |
| | **SRMW** | | **SPNO** | | **RMPA** | | **NWPP** | | **ERCT** | |
| Heavy Rail Electric | 0.0045 | - | 0.0045 | - | 0.0048 | - | 0.0018 | - | 0.0030 | - |
| Commuter Rail Electric | 0.0043 | - | 0.0044 | - | 0.0046 | - | 0.0017 | - | 0.0029 | - |
| Light Rail Electric | 0.0064 | - | 0.0065 | - | 0.0059 | - | 0.0025 | - | 0.0043 | - |
| | **SRTV** | | **HIOA** | | | | | | | |
| Heavy Rail Electric | 0.0035 | - | 0.0041 | - | | | | | | |
| Commuter Rail Electric | 0.0034 | - | 0.0040 | - | | | | | | |
| Light Rail Electric | 0.0050 | - | 0.0059 | - | | | | | | |

*Note: All data in $MTCO_2eq/mile$*

APPENDIX

# C

# Transit Scenario Emissions Analysis Results

| | TRANSITWAY MILEAGE | | | # STATIONS | | | # PARKING SPACES | | ANNUAL TRANSIT VMT | | | | | | ANNUAL DISPLACED VMT | | | | GHG Emissions ($MTCO_2e$) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | | Construction (Amortized 50 yrs) | | Maint. | Operations | | Displaced Emissions | Total Annual Emissions |
| MODE | ABOVE | BELOW | AT-GRADE | ABOVE | BELOW | AT-GRADE | SURFACE | STRUCTURED | CNG BUS | HYBRID BUS | DIESEL BUS | LIGHT RAIL | DIESEL COM. RAIL | HR ELECTRIC | DIESEL BUS | HYBRID BUS | CNG BUS | AUTO | Upstream | Down | Down | Upstream | Down | | |
| BRT | | | 8.5 | | | 27 | 275 | | | 625,000 | | | | | 340,000 | | | 4,699,000 | 1,400 | 40 | 50 | 1,100 | - | 3,000 | (420) |
| BRT | | | 5.9 | | | 17 | | | | 2,000 | | | | | 2,000 | | | 2,250,000 | 900 | 30 | 20 | - | - | 900 | 10 |
| BRT | | | 10.5 | | | 18 | | | 28,000 | 22,000 | 354,000 | | | | | | | 5,442,000 | 1,000 | 40 | 50 | 300 | 1,000 | 2,200 | 90 |
| BRT | | | 8.5 | | | 27 | 250 | | | 671,000 | | | | | 414,000 | | | 2,829,000 | 1,400 | 40 | 60 | 1,200 | - | 2,500 | 190 |
| BRT | | | 3.1 | | | 8 | | | | 189,000 | | | | | | 64,000 | | 1,156,000 | 400 | 10 | 20 | 300 | - | 600 | 200 |
| BRT | | | 13.3 | | | 14 | | | 742,000 | | | | | | 730,000 | | | 1,744,000 | 800 | 50 | 70 | 600 | 1,900 | 3,100 | 370 |
| BRT | | | 7.1 | | | 16 | 1490 | | | 327,000 | | | | | 158,000 | | | 751,000 | 900 | 30 | 40 | 600 | - | 800 | 700 |
| BRT | | | 16.8 | | | 15 | 250 | | 517,000 | | | | | | | | | 4,649,000 | 800 | 70 | 70 | 400 | 1,400 | 1,900 | 850 |
| BRT | | | 8.8 | | | 20 | 98 | | | | 249,000 | | | | | | | 2,580,000 | 1,100 | 40 | 40 | 100 | 700 | 1,100 | 870 |
| BRT | | | 12.3 | | | 18 | 1355 | | | | 726,000 | | | | | | | 5,053,000 | 1,000 | 50 | 70 | 400 | 1,900 | 2,100 | 1,380 |
| BRT | | | 18.5 | | | 21 | | | 985,000 | | | | | | 837,000 | | | 35,000 | 1,200 | 80 | 100 | 800 | 2,600 | 2,700 | 1,990 |
| BRT | | | 15.6 | | | 32 | 186 | | 1,033,000 | | | | | | 724,000 | | | 1,808,000 | 1,700 | 70 | 90 | 800 | 2,700 | 3,100 | 2,320 |
| Streetcar | | | 2.5 | | | 4 | | | 228,000 | | | 228,000 | | | | | | 10,855,000 | 400 | 10 | 30 | 1,200 | 600 | 4,400 | (2,280) |
| Streetcar | 0.1 | | 4.1 | | | 10 | 50 | | | | | 274,000 | | | | | | 4,982,000 | 800 | 10 | 20 | 1,200 | - | 2,000 | (20) |
| Streetcar | | | 2.4 | | | 6 | | | 153,000 | | | 153,000 | | | | | | 3,899,000 | 500 | 10 | 20 | 800 | 400 | 1,600 | 80 |
| Streetcar | | | 4.3 | | | 16 | | | | | | 162,000 | | | | | | 3,622,000 | 1,100 | 10 | 20 | 700 | - | 1,500 | 350 |
| Streetcar | 0.4 | | 2.5 | | | 11 | | | | | | 194,000 | | | 89,000 | | | 1,144,000 | 800 | 10 | 20 | 800 | - | 800 | 890 |
| Streetcar | | | 5.8 | | | 11 | | 1350 | | | | 123,000 | | | 114,000 | | | 369,000 | 1,100 | 10 | 30 | 500 | - | 500 | 1,150 |
| Streetcar | | | 3.0 | | | 14 | | | | | | 193,000 | | | | | | 682,000 | 900 | 10 | 20 | 800 | - | 300 | 1,490 |
| Streetcar | 0.1 | | 2.8 | | | 10 | | | 160,000 | | | 160,000 | | | | | | 127,000 | 700 | 10 | 20 | 800 | 400 | 50 | 1,920 |
| LR | | 1.9 | | | 3 | | | | 214,000 | | | 2,004,000 | | | | | | 138,744,000 | 6,500 | 230 | 40 | 8,800 | 600 | 56,700 | (40,640) |
| LR | 6.2 | 2.0 | 0.3 | 3 | 1 | | 250 | 2650 | | | | 5,300,000 | | | 370,000 | | | 113,108,000 | 9,800 | 270 | 110 | 22,800 | - | 47,400 | (14,490) |
| LR | 1.1 | | 1.8 | | | 5 | 604 | 2900 | | | | 626,000 | | | | | | 39,947,000 | 500 | 10 | 20 | 2,700 | - | 16,300 | (13,090) |
| LR | 0.7 | 0.6 | 9.7 | | | 21 | | | | | | 2,822,000 | | | 153,000 | 35,000 | 73,000 | 65,228,000 | 3,200 | 90 | 90 | 12,100 | - | 27,500 | (11,970) |
| LR | 0.3 | | 2.0 | | | 3 | 75 | 2025 | | | | 663,000 | | | 48,000 | | | 27,997,000 | 400 | 10 | 20 | 2,800 | - | 11,600 | (8,350) |
| LR | 11.0 | - | 12.4 | | | 1 | 240 | 1480 | 16,000 | 132,000 | | 2,494,000 | | | | | | 43,045,000 | 1,700 | 40 | 100 | 11,000 | - | 17,600 | (4,750) |
| LR | 4.0 | 0.04 | 6.9 | | | 9 | 650 | 520 | 841,000 | 118,000 | 20,000 | 2,771,000 | | | | | | 45,123,000 | 1,800 | 50 | 130 | 12,800 | 2,300 | 18,500 | (1,420) |
| LR | 0.7 | 4.7 | 8.7 | | 5 | 14 | 1675 | | | 455,000 | | 2,586,000 | | | | | | 71,152,000 | 15,800 | 570 | 120 | 11,900 | - | 29,100 | (680) |
| LR | 1.0 | | 3.7 | | | 7 | 180 | | | | | 1,022,000 | | | | | | 12,189,000 | 900 | 20 | 40 | 4,400 | - | 5,000 | 400 |
| LR | 3.0 | 0.5 | 11.0 | | | 16 | 1847 | 640 | | 132,000 | 824,000 | 3,236,000 | | | | | | 36,895,000 | 3,100 | 100 | 150 | 14,600 | 2,200 | 15,100 | 5,050 |
| CR | | | 2.1 | | | 1 | | | | | | | 11,000 | | 60,000 | | | 5,819,000 | 1,900 | 20 | 20 | 100 | 30 | 2,600 | (470) |
| CR | 2.6 | 0.01 | 24.6 | | | 7 | 1779 | | 368,000 | | | | 402,000 | | | | | 47,930,000 | 11,900 | 280 | 540 | 4,700 | 2,100 | 19,600 | (110) |
| CR | | | 12.3 | | | 1 | 113-293 | | | | 34,000 | | 494,000 | | | | | 2,272,000 | 1,800 | 100 | 540 | 5,400 | 1,500 | 900 | 8,410 |
| CR | | | 17.2 | | | 4 | 1272 | | | | 650,000 | | 739,000 | | | | | 22,249,000 | 6,600 | 160 | 840 | 8,400 | 3,900 | 9,100 | 10,760 |
| HR | | 2.6 | | | 2 | | | | | | | | | 1,299,000 | | | | 52,191,000 | 11,400 | 320 | 390 | 3,900 | - | 21,300 | (5,330) |
| HR | | 3.9 | | | 3 | | | | | | | | | 3,419,000 | | | | 64,673,000 | 17,300 | 500 | 1,010 | 10,300 | - | 26,500 | 2,640 |

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