



F E D E R A L T R A N S I T A D M I N I S T R A T I O N

Greenhouse Gas Emissions from Transit Projects: Programmatic Assessment

JANUARY 2017

FTA Report No. 0097
Federal Transit Administration

PREPARED BY

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FTA Office of Environmental Programs



U.S. Department of Transportation
Federal Transit Administration

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1200 New Jersey Avenue, SE
Washington, DC 20590

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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
ft³	cubic feet	0.028	cubic meters	m ³
yd³	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)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

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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
REET	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.

Introduction

Human activities have elevated atmospheric concentrations of greenhouse gases,¹ particularly carbon dioxide (CO₂), 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 vehicles² 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 CO₂ equivalent (MTCO₂e).

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 factors⁴ 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 Commuter Rail (CR) Hybrid Rail	Commuter Rail (CR)
Light Rail (LR)	Light Rail (LR)
Streetcar	Streetcar
Bus Rapid Transit Commuter Bus Conventional Bus, includes Articulated Bus Trolleybus	Bus Rapid Transit
Demand Response (DR), including DR Taxi Vanpool	DR/Vanpool
Ferryboat Aerial Tramway Cable Car Inclined Plane Jitney Publico Monorail/Automated Guideway or People Mover	Excluded
	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 - Contracted paving of separated rights-of-way - Contracted catenary system construction/copper	- Construction-induced congestion - Third rail system of electrification “Other” facilities’ construction (administrative buildings, maintenance/storage facilities, intermodal hub, traction substations, etc.). - Transit vehicle manufacture
Maintenance	- Routine transitway maintenance - Routine pavement maintenance - Routine vehicle maintenance			- Routine station and facility maintenance - Waste disposal
Operations	- Operation of transit vehicles fueled by non-electricity fuels - Boiler/furnace combustion for stations and maintenance/storage facilities. - 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.) - Electricity/steam transmission and distribution losses - Refrigerants
Displacements			Operation of personal vehicles	- Congestion relief - 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 source⁸ in that it presents the emissions per unit of each GHG emissions source in terms of metric tons of CO₂ equivalent (MTCO₂eq).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 CO₂/tree, not CO₂eq/tree.

Table 2-3 Transit GHG Emissions Factor Typology Matrix

HEAVY RAIL	Phase	Source		Upstream	Downstream	MTCO ₂ eq
	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

COMMUTER RAIL	Phase	Source		Upstream	Downstream	MTCO ₂ eq
	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

LIGHT RAIL	Phase	Source		Upstream	Downstream	MTCO ₂ eq
	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

BUS/BUS RAPID TRANSIT	Phase	Source		Upstream	Downstream	MTCO ₂ eq
	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*

DR, VANPOOL, DISPLACED AUTOS	Phase	Source	Upstream	Downstream	MTCO ₂ eq	
	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

PARKING	Phase	Source	Upstream	Downstream	MTCO ₂ eq
	Const.	Lot	1	-	/space
		Garage	5	-	/space
	Ops.	Lot	-	0.0001	/space/yr
		Garage	-	0.0001	/space/yr

CARBON STORAGE	Upstream	Downstream	MTCO ₂ eq
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 New, elevated HR, CR, LR track New, underground HR, CR, LR track Converted or upgraded existing LR track New, at-grade HR, CR, LR station New, elevated HR, CR LR station New, underground HR, CR, LR station	FHWA ICE
		Rail catenary system	Hanson et al. 2014
	Bus/BRT	BRT new lane or right-of-way BRT converted or upgraded lane New, at-grade station	FHWA ICE
		Trolleybus catenary system	Hanson et al. 2014
	Parking	Surface parking 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 LR electric CR electric	NTD electricity use and VMT data; EPA eGRID 2012
		CR diesel and biodiesel	REET
	Bus/BRT	Electric vehicle Diesel vehicle Biodiesel vehicle LNG vehicle CNG vehicle	REET
	DR/Vanpool	Sedans, vans, buses of various fuel types	REET
Facility Operation	Rail	Station electricity Station heating	Energy use data from one transit agency
		Maintenance/storage electricity Maintenance/storage heat	Energy use data from seven transit agencies
	Bus/BRT	Station electricity Station heating	Energy use data from one transit agency
		Maintenance/storage electricity Maintenance/storage heat	Energy use data from seven transit agencies
	Parking	Surface parking 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:

$$\text{Upstream vehicle operations emissions} = \text{GREET well-to-wheels} - \text{GREET pump-to-wheels}$$

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 NTD¹³ 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 rate¹⁴ = 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:

$$1 \text{ kWh electricity} = 0.000689551 \text{ MTCO}_2 \text{ (per EPA)}^{17}$$

$$0.01010 \text{ MCF natural gas} = 1 \text{ kWh electricity}^{18}$$

$$1 \text{ therm} = 29.3001 \text{ kWh electricity}$$

$$1 \text{ gallon residual fuel oil (\#6 oil)} = 43.9 \text{ kWh electricity}^{19}$$

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 sequestration²⁰ 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 MTCO₂ are sequestered per year (USDA)
- (3) 0.22801 MT C stored * 3.67 MTCO₂ sequestered per year = 0.8368 MTCO₂ 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 CO₂ 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.

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 MTCO₂eq 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 MTCO₂eq 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).

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 • Paving of separated rights-of-way • Station construction • Parking construction • Catenary system construction/copper	• Tree removal
Maintenance-related Emissions	• Routine maintenance of transitway • Routine maintenance of pavement • Routine maintenance of vehicles	
Operations-related Emissions	• Transit vehicle miles traveled (VMT)	• Boiler/furnace combustion for stations and maintenance/storage facilities • Purchased electricity for stations, maintenance/storage facilities, parking facilities • Transit access trips • Operation of non-revenue vehicles
Displaced Emissions	• Personal vehicle VMT • Transit 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 VMT²⁶ between the build and the no-build scenario) for the forecast year
- Annual personal automobile VMT and Transit 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-build²⁹ and build³⁰ 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.ID 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 MTCO₂eq to an increase of 11,000 MTCO₂eq (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 MTCO₂eq. 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 MTCO₂eq.

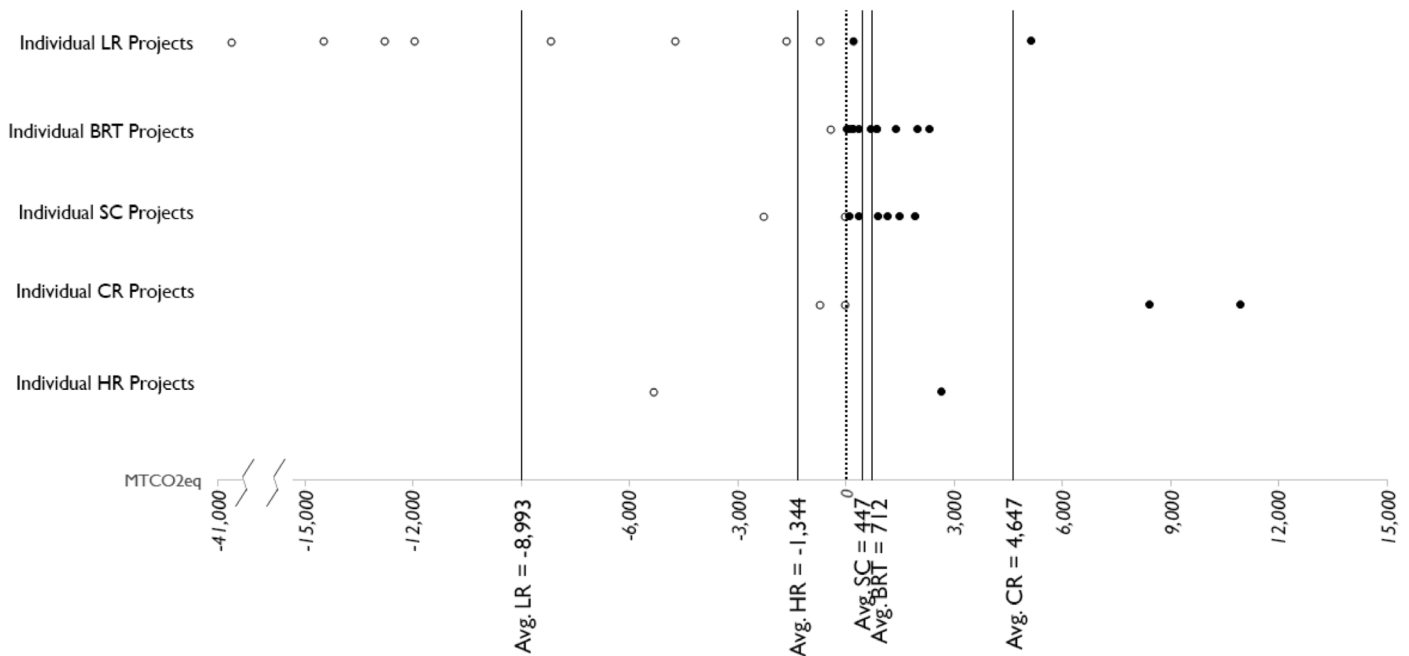


Figure 3-1 Total GHG emissions by transit project analyzed

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 MTCO₂eq. All of the BRT projects analyzed resulted in total annual GHG emissions of less than 2,400 MTCO₂eq 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.

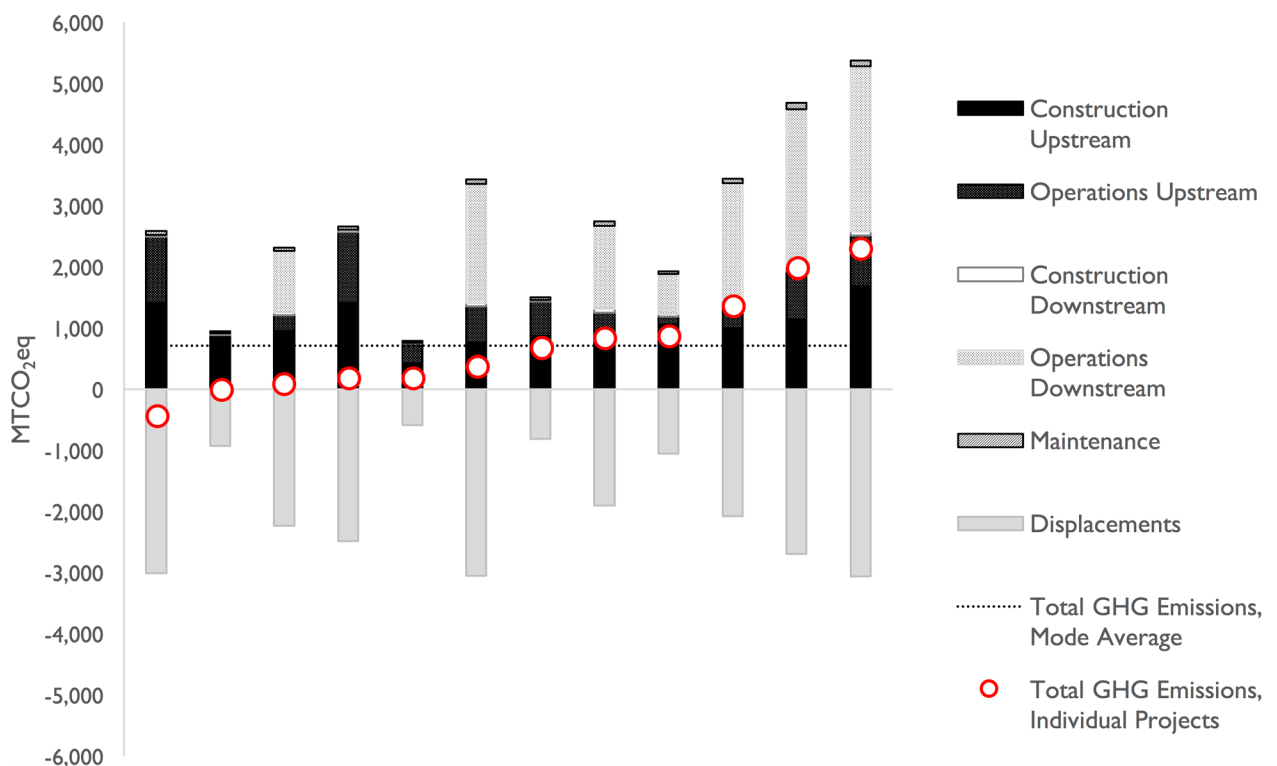


Figure 3-2 GHG Emissions from sample BRT projects by project phase

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 $450 \pm 1,300$ MTCO₂eq. Each of the streetcar projects analyzed was expected to have net GHG emissions of less than 2,000 MTCO₂eq annually (Figure 3-3).

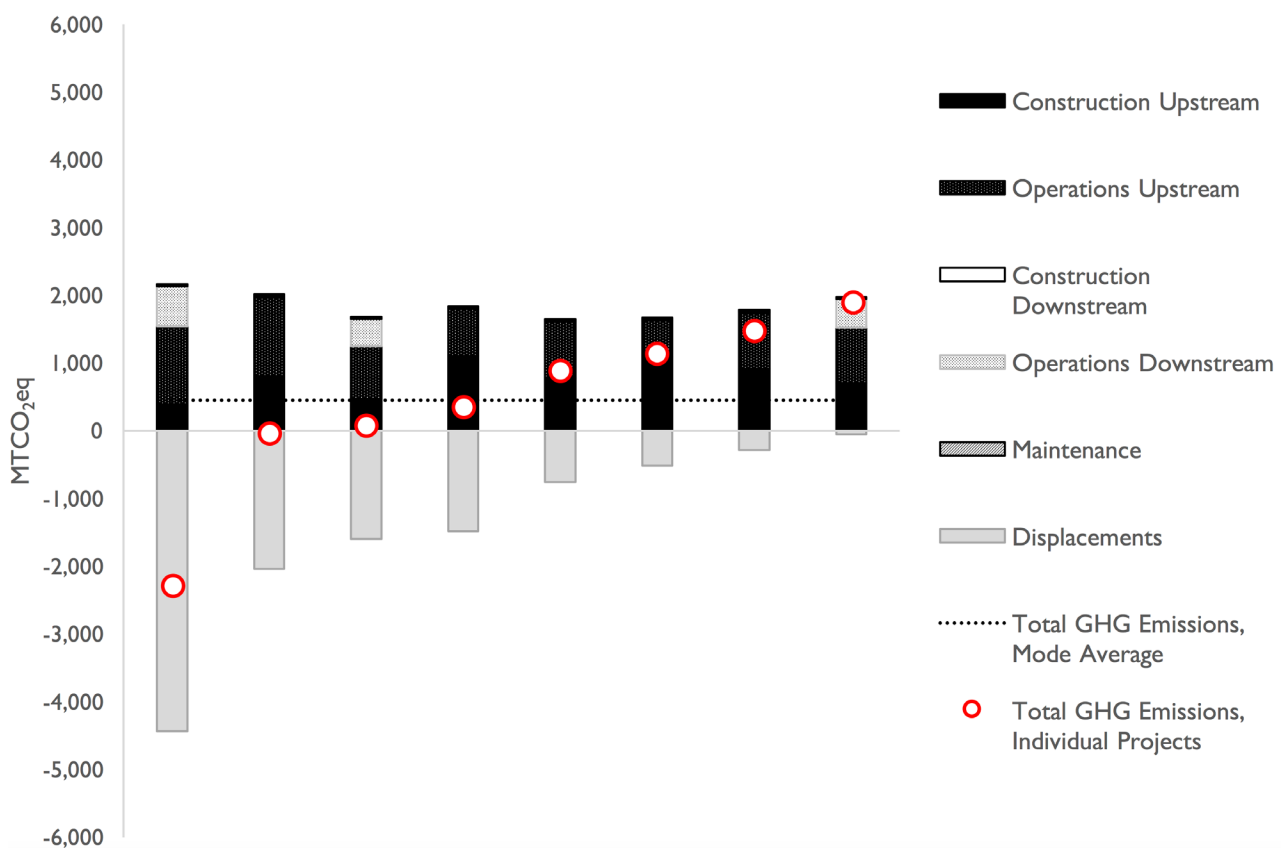


Figure 3-3 GHG emissions from sample streetcar projects by project phase

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 $-9,000 \pm 12,800$ MTCO₂eq; estimated emissions ranged from a reduction of 41,000 MTCO₂eq per year to an increase of 5,000 MTCO₂eq per year (Figure 3-4).

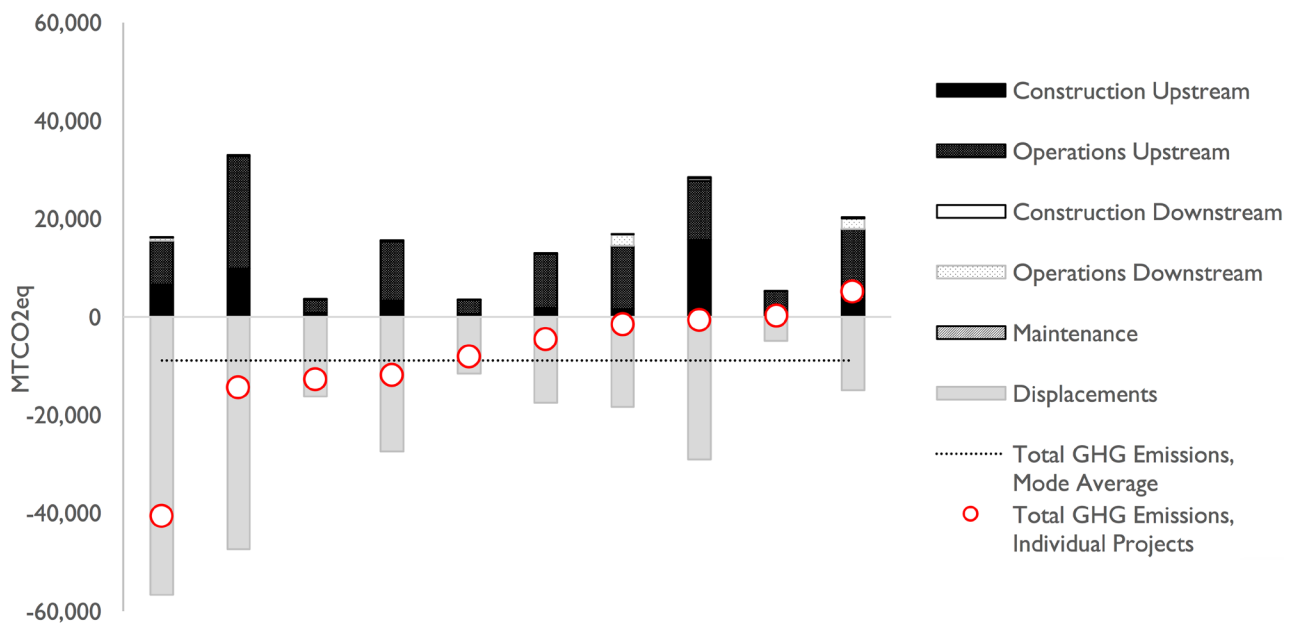


Figure 3-4 GHG emissions from light rail projects by project phase

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 $4,600 \pm 5,900$ MTCO₂eq; estimated emissions ranged from a reduction of 470 MTCO₂eq per year to an increase of 10,700 MTCO₂eq 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.

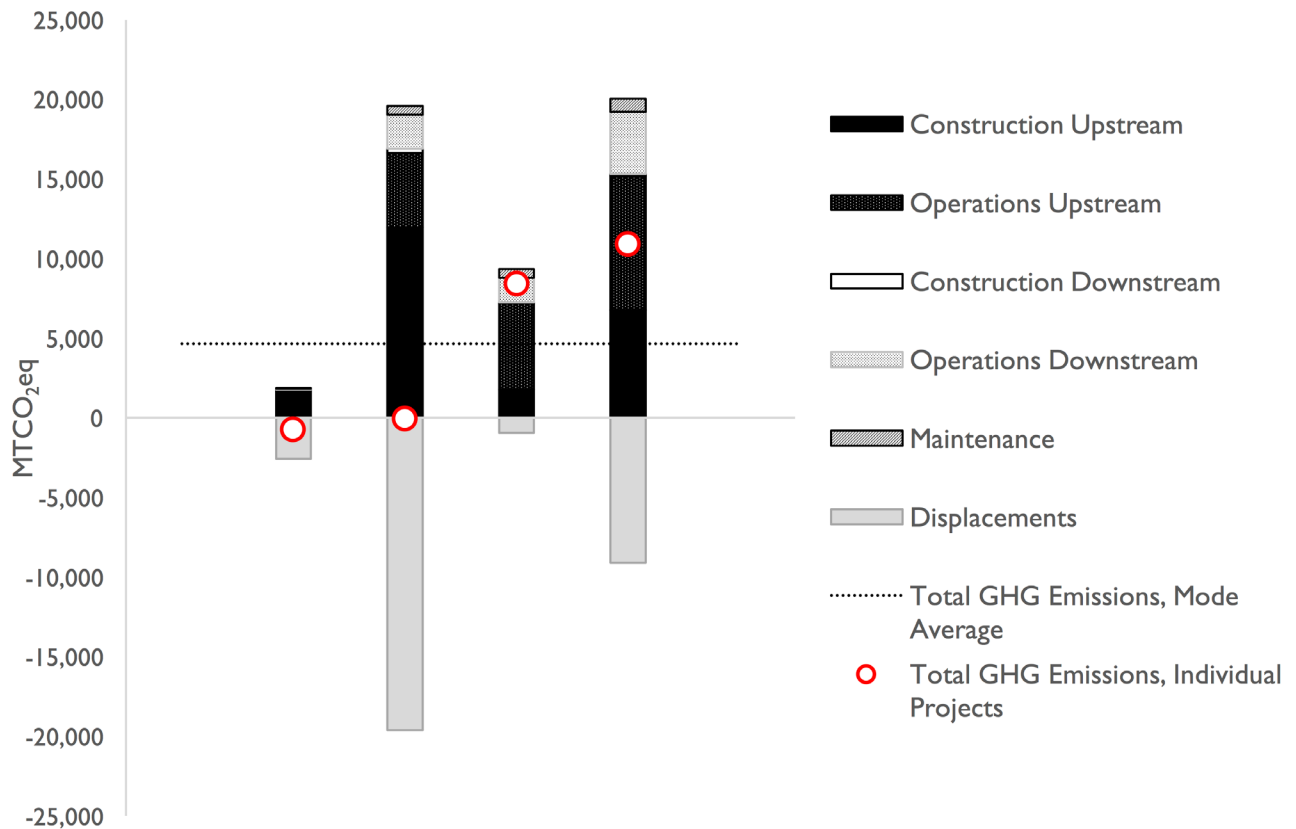


Figure 3-5 GHG emissions from commuter rail projects by project phase

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).

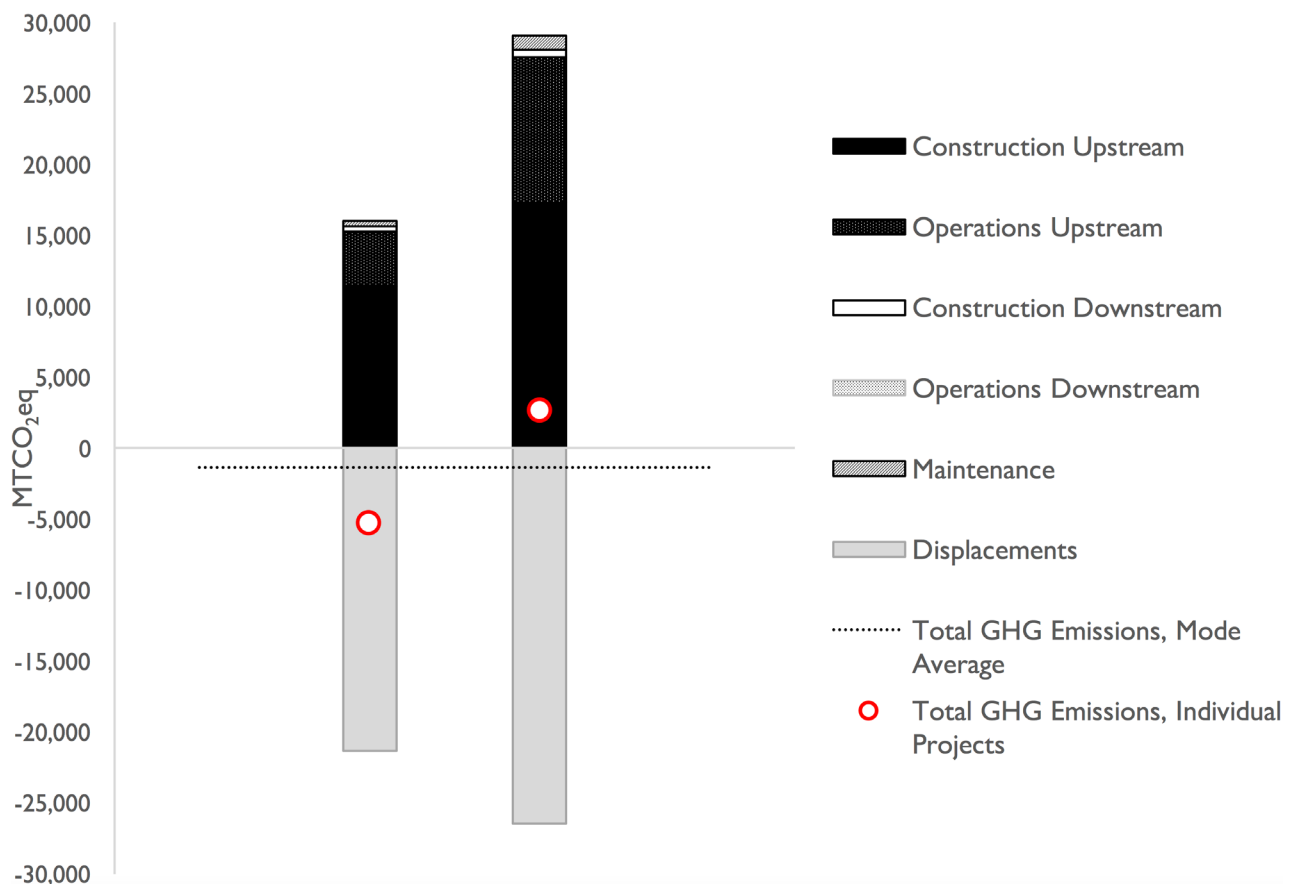


Figure 3-6 GHG emissions from heavy rail projects by project phase

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.

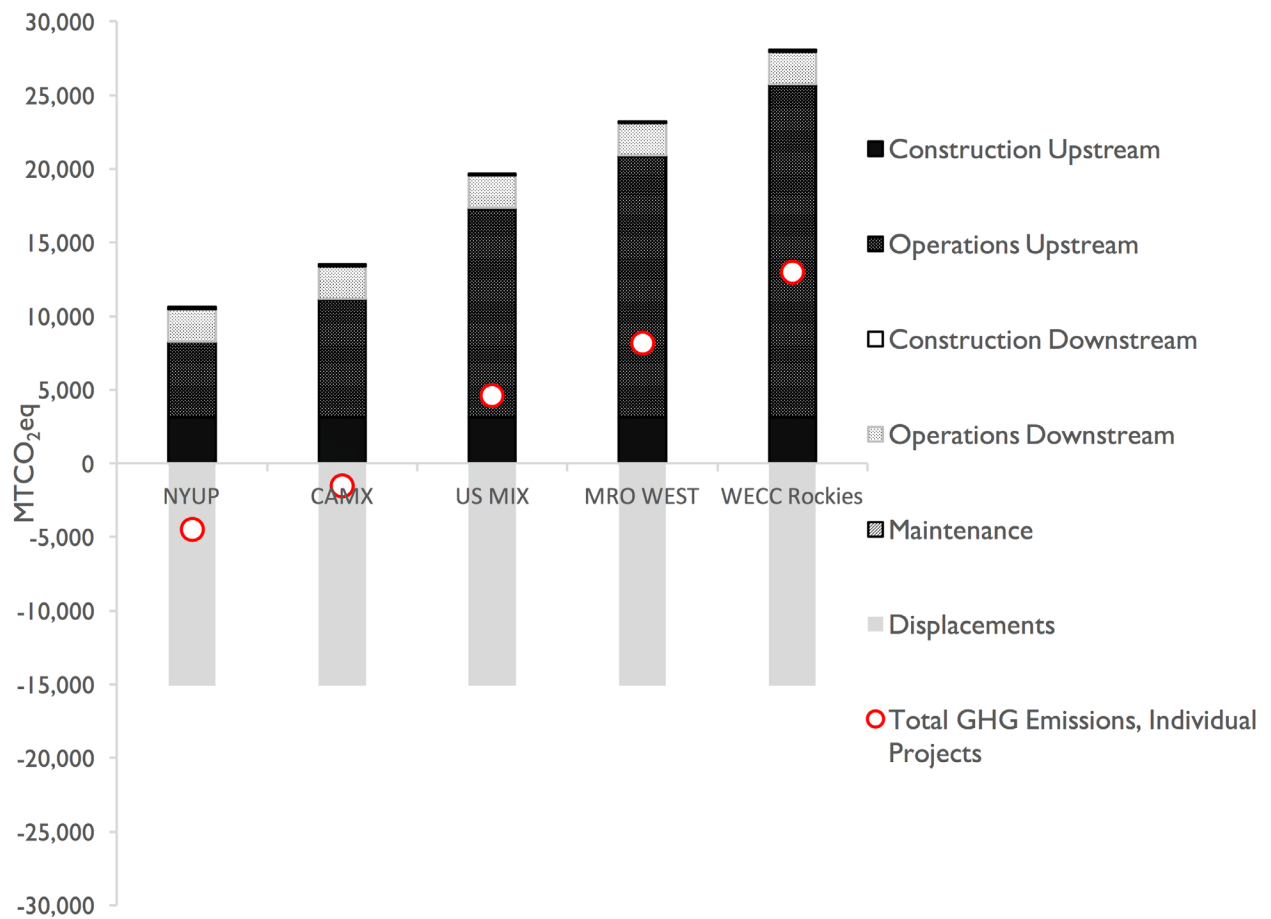


Figure 3-7 Total GHG emissions for light rail project from sample with highest emissions using different electricity generation mixes

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 ₂ e)	Annual GHG Emissions, Original Estimate (MTCO ₂ e)
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.

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 where 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 NO _x 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 ₂ e/yr)	• Ridesharing/transit programs for employers • Transit-oriented development • Vanpool subsidy • On-board railcar energy storage		• Expand rail and BRT systems • Wayside energy storage substation
Moderate (1,000–10,000 MTCO ₂ e/yr)	• 45-foot composite buses • Facility lighting efficiency	• Metro transit subsidy	• Bicycle paths along transit corridors • Gasoline-electric hybrid buses
Small (< 1,000 MTCO ₂ e/yr)	• Tunnel lighting retrofit • Hybrid non-revenue cars • Recycled water for bus washing • Low-water sanitary fixtures	• Solar panels • 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 (CO₂), nitrous oxide (N₂O), methane (CH₄), 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.

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) $\text{GREET GHGs (g/pass-mile) by rail mode} \times \text{NTD's 2014 passenger miles by rail mode} = \text{total 2014 operations GHGs by mode}$
- (2) $\text{Total 2014 operations GHGs by mode} \div \text{NTD's 2014 transit VMT} = \text{GHGs/vehicle-mile}$

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

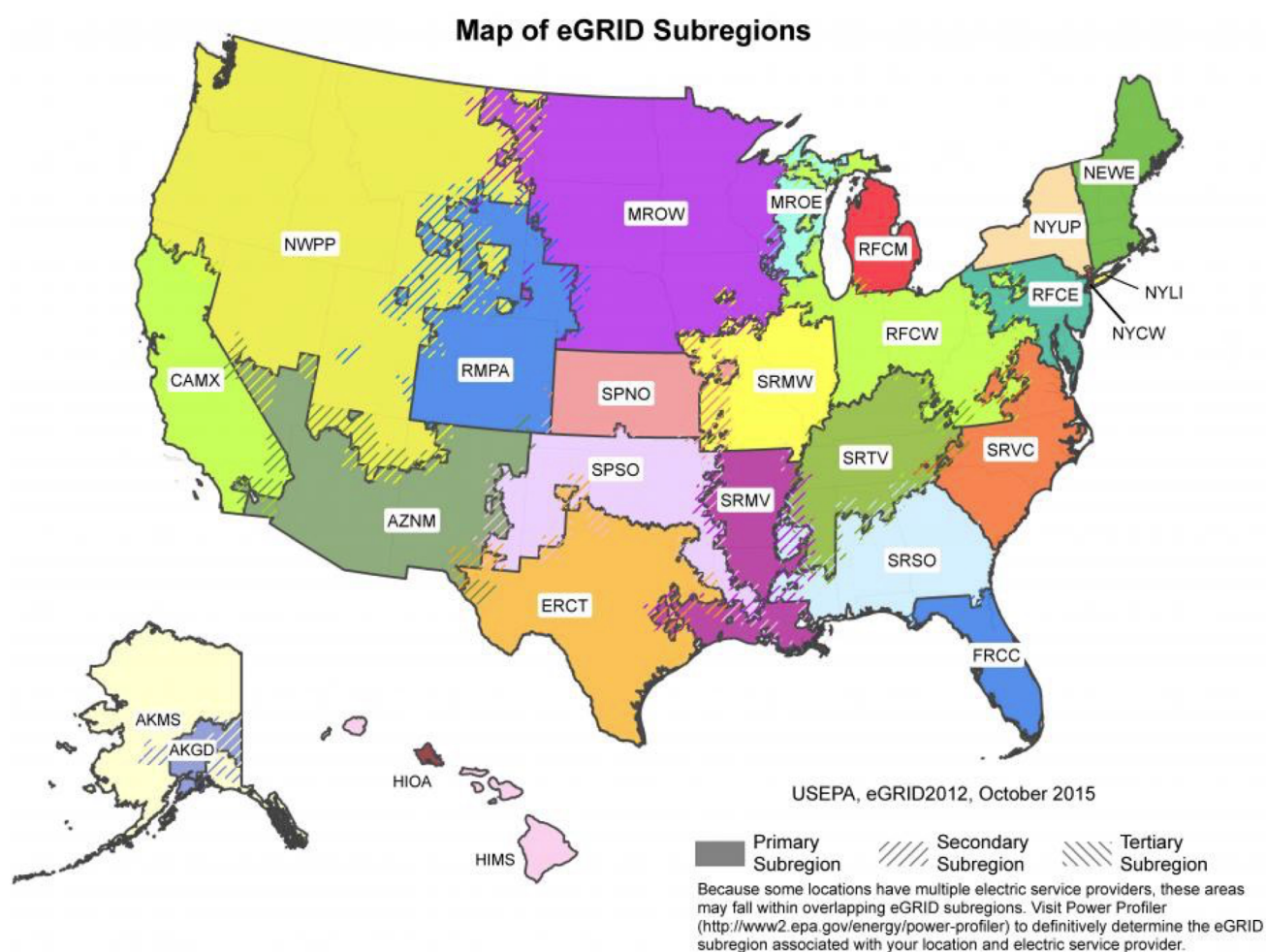
GHGs/vehicle-mile were then multiplied against the operation (VMT) of electrically-powered rail vehicles from the sample of projects. See Table A-2.

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*

Rail Mode	MTCO ₂ eq as Estimated via		Rail Mode	MTCO ₂ eq as Estimated via		Rail Mode	MTCO ₂ eq as Estimated via	
	GREET Rail Module	NTD/ eGRID		GREET Rail Module	NTD/ eGRID		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			

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 $\text{MTCO}_2\text{eq/mile}$

APPENDIX

C

Transit Scenario Emissions Analysis Results

																			GHG Emissions (MTCO ₂ e)						
	TRANSITWAY MILEAGE			# STATIONS			# PARKING SPACES		ANNUAL TRANSIT VMT						ANNUAL DISPLACED VMT				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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