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Greenhouse Gas Emissions from Transit Projects: Programmatic Assessment

PREPARED BY

John A. Volpe National Transportation Systems Center

APRIL 2024

U.S. Department of Transportation
Federal Transit Administration

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Courtesy of Carson Poe, Volpe National Transportation Systems Center.

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U.S. Department of Transportation
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
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)		
^{o}F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^{o}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 that assessing the effects of greenhouse gas (GHG) emissions and climate change for transit projects at a programmatic level is practicable. This update to FTA's January 2017 Programmatic Assessment on Greenhouse Gas Emissions from Transit Projects serves to revise and supersede the original report on whether certain types of proposed transit projects merit detailed analysis of their GHG emissions at the project level. This report can be a source of data and analysis for FTA and its project sponsors to reference in future environmental documents for projects in which detailed, project-level GHG analysis is not necessary.

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The U.S. Department of Transportation's Volpe National Transportation Systems Center (Volpe Center) in Cambridge, Massachusetts, prepared this report for the Federal Transit Administration (FTA) Office of Environmental Programs. The Volpe Center project team included Gina Filosa and Carson Poe. Megan Blum, Alexandra Brun, and Saadat Khan of FTA's Office of Environmental Programs provided guidance.

The original programmatic assessment was made possible with the input of several transit agencies and subject matter experts from the public and private sectors and from academia. FTA and the Volpe Center wish to thank those stakeholders who initially contributed data, insight, and feedback, and to extend that appreciation to FTA's Capital Project Development Team.

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) 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, which updates and supersedes FTA's January 2017 programmatic assessment, is intended to aid future transit project-level NEPA reviews more efficient by providing a programmatic analysis of GHG emissions from a sample of transit projects.

Specifically, the Programmatic Assessment serves to:

- Report on whether certain types of proposed transit projects merit detailed analysis of their GHG emissions at the project-level, and
- Provide a source of data and analysis for FTA and its project sponsors to incorporate by 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 here.

The Programmatic Assessment is not intended to be used as a resource to compare projects from one transit mode to another or to compare a transit project to highway project.

Methodology

This programmatic assessment presents estimates of GHG emissions generated from a sample of 68 transit project scenarios in the United States. The sample represents transit projects that applied for funding through the Section 5309 Capital Improvement Grants (CIG) Program in fiscal years 2015 through 2023. In total, the updated sample included 38 bus rapid transit (BRT) projects, 12 light rail (LR) projects, 8 streetcar rail (SR) projects, 6 commuter rail (CR) projects, and 4 heavy rail (HR) projects.

The project team used FTA's Transit Greenhouse Gas Estimator version 3.0 (Estimator) to quantify both direct and indirect transit GHG emissions for each sample project. Direct transit GHG emissions, also referred to as downstream emissions in this assessment, are those caused by the transit project and occur at the same time and place, such as emissions generated during the construction of the project and tailpipe emissions produced transit vehicle operation. Indirect transit GHG emissions, referred to as upstream emissions in this assessment, are those that occur later in time or are farther removed in distance from the proposed transit project, such as extracting, processing, refining, and transporting of the fossil fuel used to power the transit vehicle.

Table ES-1: GHG Emissions Sources Included in Assessment

Phase	GHG Emissions Sources Included
Construction	Transitway track construction Paving of separated rights-of-way Station construction Parking construction Catenary system (construction/copper)
Maintenance	Routine maintenance of transitway Routine maintenance of pavement Routine maintenance of vehicles
Vehicle Operations	Transit vehicle miles traveled (VMT)
Displaced emissions	Automobile VMT Transit VMT

Scenario Results

Transit projects can generate GHG emissions during their construction, operations, and maintenance phases and displace emissions by reducing automobile emissions due to transit's "ridership effect," e.g., trips made by public transportation that would have otherwise involved personal vehicle travel. The analysis presented in this programmatic assessment provides insight into the estimated net GHG emissions associated with transit modes.

The following results are based on a representative sample of projects within each transit mode. The results for each transit mode should not be compared against one another, as available CIG data for individual projects in the sample are for that project only and not for other viable transit mode alternatives.

- LR projects, regardless of length, alignment, and number of stations, generally result in net reductions in annual GHG emissions over the minimum useful LR lifespan of 50 years. Annual displaced GHG emissions due to LR's "ridership effect" are greater than the GHG emissions from construction, maintenance, and vehicle operation phases for the LR project.
- SR and BRT projects generally result in relatively low but net increases in annual GHG emissions over the minimum useful SR and BRT lifespans of 50 and 40 years, respectively. The annual GHG emissions from construction, maintenance, and vehicle operation phases are greater than the GHG emissions displaced as a result of SR and BRT projects' "ridership effect."
- CR projects result in annual net increases in GHG emissions over the minimum useful CR lifespan of 50 years. The annual GHG emissions from construction, maintenance, and vehicle operation phases are greater than the GHG emissions displaced as a result of CR's "ridership effect."
- The sample of HR projects was small, and the projects within the sample had a wide variation in the estimated GHG emissions, from a small net reduction in annual GHG emissions to a larger net increase in annual GHG emissions. The disparity in estimated GHG emissions across the HR sample was primarily due to a

large spread in the proportion of HR VMT to displaced automobile VMT reported for the HR projects in the sample.

Recommendations for Incorporating Results into NEPA Documents

These observations provide a reference for FTA and its project sponsors to use in future project-level NEPA documents to describe the effects of proposed transit investments on partial lifecycle GHG emissions, as follows:

- Calculating project-specific GHG emissions for LR, SR, BRT, and CR projects is expected to provide only limited information beyond the information collected and considered in this Programmatic Assessment. Therefore, in cases in which the project characteristics and assumptions are similar to the sample projects analyzed, it is recommended that NEPA reviews for individual LR, SR, BRT, and CR projects incorporate by reference this assessment's analysis construction-related, operations-related, and maintenance-related upstream and downstream GHG emissions.
- Due to the small sample size of HR projects and the wide variation in the estimated GHG emissions across that sample, it is recommended that transit agencies developing HR projects use the Estimator or another locally recommended approach to make project-specific GHG emissions estimates for their NEPA analyses.

Project sponsors completing environmental reviews for a multi-modal project should reach out to the appropriate U.S. Department of Transportation modal staff to coordinate the GHG analysis of the non-transit project elements.

The programmatic assessment does not provide information relevant to assessing present and future impacts from climate change on the environment and on proposed actions, although environmental reviews should do so. Consistent with NEPA, environmental reviews should continue to provide relevant information that agencies can use to consider siting issues, the initial project design and consistency with existing state, tribal, and local adaptation plans, as well as reasonable alternatives with preferable overall environmental outcomes and improved resilience to climate effects.

Section 1

Introduction

Human activities have elevated atmospheric concentrations of greenhouse gases (GHGs)[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, 2021). In the United States, transportation accounted for the largest portion of total GHG emissions in 2020 (Environmental Protection Agency, 2022). Within the transportation sector in 2020, light-duty vehicles[2] accounted for the majority (57 percent) of GHG emissions, whereas bus and rail accounted for one percent and two percent, respectively (EPA, 2022a).

The National Environmental Policy Act (NEPA) of 1969, as amended (42 U.S.C. §§ 4321-4327) and the Council on Environmental Quality (CEQ) implementing regulations at 40 C.F.R. Parts 1500-1508, 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 are funded or permitted by Federal agencies, can cause emissions of GHGs; however, it is unlikely that any individual activity or 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 January 2023, the CEQ issued guidance to assist agencies in analyzing GHGs and climate change effects of their proposed actions under NEPA (CEQ guidance). The CEQ guidance, which builds upon CEQ's 2016 Final Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in NEPA Reviews (CEQ 2016), provides a framework for agencies to consider the effects of a proposed action on climate change, as indicated by its estimated GHG emissions. It also advises agencies to assess the effects of climate change on proposed actions.

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. It 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, noting that "an agency may decide that it would be useful and efficient

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

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

to provide an aggregate analysis of GHG emissions or climate change effects in a programmatic analysis and then incorporate by reference that analysis into future NEPA reviews" (CEQ, 2023). FTA considers it practicable to assess the effects of GHG emissions and climate change for transit projects at a programmatic level, where possible.

This programmatic assessment presents results from an analysis to estimate direct and indirect GHG emissions generated from the construction, operations, and maintenance phases of example transit projects across select transit modes. It does not provide information relevant to assessing present and future impacts from climate change on the environment and on proposed actions, although environmental reviews should do so. The findings here provide a reference for FTA and its project sponsors to use in future NEPA documents to describe the effects of proposed transit investments on partial lifecycle GHG emissions.[3] The assessment's results can inform transit project proponents who are considering the GHG emissions of future transit investments or who might independently want to evaluate the GHG emissions benefits and costs of such investments. Consistent with NEPA, environmental reviews should continue to provide relevant information that agencies can use to consider siting issues, the initial project design and consistency with existing state, tribal, and local adaptation plans, as well as reasonable alternatives with preferable overall environmental outcomes and improved resilience to climate effects.

[3] A full lifecycle assessment accounts for GHG emissions from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling.

Section 2 Methodology

To develop the original 2017 programmatic assessment, 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. The team also investigated the requirements for completing project-level analyses where state and local governments require the project-level analysis of GHG emissions during the environmental review process. The team reviewed more than 120 environmental documents for transit to better understand where project-specific GHG analyses have occurred, the methods and tools used, and the associated data needs.

The project team used the literature review to identify the sources of transit GHG emissions and the available tools and data resources for estimating the direct and indirect GHG emissions generated from each GHG emission source. The project team used available GHG emissions factors and estimation tools to develop a "GHG Emissions Typology Matrix" and subsequently, the Transit Greenhouse Gas Estimator (Estimator), an Excel-based tool that allows users to calculate partial lifecycle GHG emissions estimates by transit mode for the construction, maintenance, and operations phases of transit project development, as well as for automobile emissions displaced due to transit's "ridership effect." The Estimator provides scalable estimates per unit of each GHG emissions source in terms of metric tons of CO_2 equivalent ($MTCO_2eq$).[4] Although the Estimator 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. In April 2022, FTA updated the Estimator to provide enhanced functionality and to update the GHG emission factors.

For this programmatic assessment update, the project team relied upon the Estimator version 3.0 (April 2022) and applied it to a sample of transit project scenarios in the United States to estimate the GHG emissions generated. The following section provides more details about the transit GHG emission sources considered as part of the scenario testing and the emission factors included in Estimator v3.0, including the sources from which the emissions factors derive. The factors are available in Appendix A.

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

Transit GHG Emissions Sources

This programmatic assessment provides information on the GHG emissions generated from the following type of transit modes:

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

Light rail (LR): Light rail is a mode of transit service operating passenger rail cars singly (or in short, usually two- 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. LR vehicles are typically driven electrically with power being drawn from overhead catenaries.

Streetcar (SR): 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.

Commuter rail (CR): 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.

Heavy rail (HR): 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 programmatic assessment considers both direct and indirect transit GHG emissions produced during the construction, maintenance, and operational phases of a transit project. Direct transit GHG emissions, also referred to as downstream emissions in this assessment, are those caused by the transit project and occur at the same time and place, such as emissions generated during the construction of the project and tailpipe emissions produced by the operation of transit vehicles. Indirect transit GHG emissions, referred to as upstream emissions in this assessment, are those that occur later in time or farther removed in distance from the proposed transit project, such as extracting, processing, refining, and transporting of the fossil fuel used to power the transit vehicle. Table 2-1 outlines the emissions sources included in the scenario testing. The following section describes the upstream and downstream emissions associated with each phase and source.

Table 2-1 *GHG Emissions Sources Included in Scenario Testing*

Phase	GHG Emissions Sources Included
Construction	• Transitway track construction • Paving of separated rights-of-way • Station construction • Parking construction • Catenary system construction/ copper
Maintenance	• Routine maintenance of transitway • Routine maintenance of pavement • Routine maintenance of vehicles
Vehicle Operations	• Transit vehicle miles traveled (VMT)
Displaced emissions	• Automobile VMT • Transit VMT

Estimator Data Sources

The project team relied upon the Estimator to produce GHG emission estimates for each of the scenario projects included in this programmatic assessment. Table 2-2 lists the data sources for the Estimator's GHG emissions factors, by phase and transit mode, used in the analysis.

Table 2-2 *Estimator GHG Emissions Data Sources by Project Phase*

Project Phase	GHG Source	GHG Source Categories Included	Data Source
Construction	Rail	New, at-grade track mile	FHWA ICE v2.1.3
		New, elevated track mile	
		New, underground track mile	
		Converted or upgraded existing track mile (LR only)	
		New, at-grade rail station	
		New, elevated rail station	
		New, underground rail station	
		Rail catenary system	Hanson et al (2015)
	Bus/BRT	New lane or right-of-way mile	FHWA ICE v2.1.3
		Converted or upgraded lane mile	
		New, at-grade station	
		Bus/BRT catenary system	Hanson et al (2015)
	Parking	Surface parking	FHWA ICE v2.1.3
		Structured (garage) parking	

Table 2-2 (cont.) *Estimator GHG Emissions Data Sources by Project Phase*

Project Phase	GHG Source	GHG Source Categories Included	Data Source
Maintenance	Rail	Rail transit vehicle	Chester (2008)
		Track	ICE v2.1.3
	Bus/BRT	Vehicle	Chester (2008)
		Pavement	ICE v2.1.3
Vehicle Operations	Rail[5]	Electric vehicle	NTD electricity use and VMT data; EPA eGRID 2020
		Diesel vehicle (CR only)	NTD diesel use and VMT data
	Bus/BRT	Electric vehicle	GREET 2021
		Diesel vehicle	
		Hybrid diesel vehicle	
		Compressed Natural Gas (CNG) vehicle	
	School bus	Diesel vehicle	GREET 2021
		CNG vehicle	
	Vanpool	Diesel vehicle	GREET 2021
		Gas vehicle	
	Sedan/ automobile	Gas vehicle	GREET 2021
		Diesel vehicle	
		All electric vehicle	
		Plug-in hybrid electric vehicle	
		Hybrid electric vehicle	

Construction-Related Emissions Factors

Upstream emissions in the construction phase of a transit project 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

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

Estimator are the Federal Highway Administration's (FHWA) Infrastructure Carbon Estimator v2.1.3 (ICE)[6] and research by Hanson et al (2015).

- Lifecycle emission factors for the construction of BRT facilities, and underground, at-grade, and elevated HR and LR lines and stations, and structure (garage) parking and surface parking on a per-space basis use data from ICE. ICE's lifecycle emissions include those resulting from the embodied energy and emissions associated with the extraction, transport, and production of the materials (e.g., asphalt, concrete, base stone, and steel) used in the construction of the transportation facilities, the fuel used to transport materials to site, and the energy and fuel used in construction equipment. CR track and CR station construction emissions factors are based on ICE's HR construction estimates, as ICE does not currently include data specific to CR.
- Due to the wide variability in the size, design, and amenities offered among transit stations, it is difficult to create generic assumptions regarding station construction within or across transit modes. ICE includes emissions factors for rail stations that are based on the materials required for station structures and platforms, but it does not provide details on the transit station design upon which its station construction emissions are based.
- The Estimator's GHG emission factors for the construction of structure (garage) and surface parking on a per-space basis uses data from ICE. The ICE tool accounts for GHG emissions related to 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 build the parking infrastructure.
- GHG emission factors for catenary system construction are based on data for CR electrified track from Hanson et al (2015) and include the emissions associated with the steel and aluminum in the scaffolding and copper in the copper wire.

Maintenance-Related Emissions Factors

Maintenance-related GHG emissions are considered downstream emissions. The Estimator includes GHG emission factors for maintenance of track/lane-miles and transit vehicles. The GHG emission factors for track/lane-mile maintenance used data from ICE, which accounts for direct emissions associated with routine maintenance activities, such as snow removal and vegetation management.

[6] The 2017 Programmatic Assessment relied on FHWA's ICE v1. Like its predecessor, ICE v2.1 is a planning and pre-engineering analysis tool that provides the lifecycle estimates of energy and GHG emissions based on national emission and energy use factors for materials and construction activities. ICE2.0 employs an updated database of lifecycle emission factors; many of the construction material emission factors are higher in the updated version of the tool due to the use of higher quality data and modeling. The tool is available at www.dot.state.mn.us/sustainability/ghg-analysis.html.

The Estimator'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.

Vehicle Operations-Related Emissions Factors

The Estimator 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.

Road-Based Vehicles

The Estimator's GHG 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, 2021 release.

The Estimator's downstream emissions factors for road vehicle operations represent GREET's default "pump-to-wheels"[7] emissions factors for the 2020 simulation year. The Estimator's upstream emissions (well-to-pump)[8] 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 Estimator use the following GREET vehicle types:

- *Diesel bus*: Compression-ignition direct-injection (CIDI) Transit Bus, conventional and low-sulfur diesel
- *CNG bus*: Spark-ignition (SI) Transit Bus, CNG, NA NG
- *Hybrid diesel bus*: Grid-independent CIDI hybrid transit bus, conventional and low-sulfur (LS) diesel
- *Electric bus*: Transit bus, electricity
- *Vanpool and DR bus diesel*: CIDI: Light Heavy-Duty Vocational, Conventional and LS diesel
- *Vanpool gas*: SI – Medium heavy-duty vocational vehicle, low-level EtOH blend with gasoline
- *School bus diesel:* CIDI school bus, CNG, NA NG
- *DR bus CNG:* SI light heavy-duty vocational, CNG, NA NG

[7] 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).

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

- *Sedan/auto gas:* SI gasoline vehicle, gasoline
- *Sedan/auto diesel:* CIDI vehicle, conventional and LS diesel
- *Sedan/auto HEV-gas:* Grid-independent SI HEV, gasoline
- *Sedan/auto all electric:* Battery electric vehicle
- *Sedan/auto plug-in hybrid electric (PHEV)-gas:* grid-connected SI PHEV, gasoline and electricity

Rail-Based Transit Vehicles

The Estimator's GHG emissions factors for transit vehicles are based 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.

Emissions factors for each rail mode's electric vehicle operations are based on energy consumption rates derived from energy use and transit VMT data reported in the NTD[9] and electricity emission rates from the Environmental Protection Agency's (EPA) Emissions & Generation Resource Integrated Database (eGRID) 2020 (released January 27, 2022).[10] For LR/SR and HR, the project team retrieved kWh data for each mode from the NTD for a five-year period (2017–2021). Records with incomplete kWh or VMT data total kWh for propulsion were removed. Total kWh used for propulsion for each mode was multiplied by the eGRID2020 U.S. Mix emissions rate. The product for each mode was then divided by total VMT for each mode for the same five-year period to return $MTCO_2eq$/vehicle-mile.

Unlike HR and LR, commuter rail consumes both diesel and electricity. Therefore, the project team calculated GHG emissions rates for both diesel-powered and electricity-powered CR. For both fuel types, the project team retrieved CR fuel use and VMT data from the NTD for a five-year period (2017–2021). Records with incomplete fuel or VMT data, as well as records for CR systems fueled solely by biodiesel, were removed. For diesel-powered CR, total gallons of diesel used was multiplied by 0.01018 ($MTCO_2eq$/gallon of diesel).[11] The product was then divided by diesel-powered CR VMT for the same five-year period to return $MTCO_2eq$/vehicle-mile. For electricity-powered CR, kWh used for propulsion was multiplied by the eGRID2020 U.S. Mix emissions rate. The product was then divided by electricity-powered CR VMT for the five-year period to return $MTCO_2eq$/vehicle-mile.

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[9] 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.

[10] eGRID annual total output emission rates are available at www.epa.gov/egrid/download-data. 2020 data last accessed 1/11/2023 at www.epa.gov/system/files/documents/2022-01/egrid2020_summary_tables.pdf

[11] The amount of GHGs emitted per gallon of diesel burned is 0.01018 $MTCO_2eq$. Federal Register (2010). Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule. www.govinfo.gov/content/pkg/FR-2010-05-07/pdf/2010-8159.pdf

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 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 and constructing tunnels through hard stone also generally requires more electricity than doing so through soft stone, resulting in relatively elevated emissions. The Estimator's underground track construction emissions factors are based on construction through hard stone, corresponding to ICE's most conservative emissions estimate (i.e., generates the most GHG emissions).[12]
- **Rail and BRT station construction:** Due to wide variability in the size, design, and amenities offered among transit stations, it is difficult to create generic assumptions regarding station construction within or across transit modes. ICE includes emissions factors for CR 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 (2015) includes emissions factors for CR stations that are based on the materials required for station platforms. It does not include any additional structures due 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 Estimator's station construction emissions figures use ICE's emissions estimates to include emissions associated with the structure as well as the station platforms.
- **Commuter rail emissions:** The Estimator's CR track and CR station construction emissions factors are based on ICE's HR construction figures. ICE provides data for HR and LR only and does not currently include data specific to CR.
- **Catenary:** The Estimator's catenary system construction emissions factors are based on data for CR electrified track from Hanson et al (2015). The material components for catenary systems in the Estimator's emissions factors for LR and SR include the emissions associated with the steel and aluminum in the scaffolding and copper in the copper wire. No data regarding the amount of copper in HR's third rail or the GHG emissions associated with that component were readily available and thus are not included. Due to the lack of data, it is unknown whether HR's third rail materials, which include copper, and construction are considerable sources of GHG emissions.

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

Vehicle Operations-Related Emissions

- **Transit vehicle operations**: GHG emission factors for transit vehicles are based 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. The bus operations GHG emissions data is based on a 40-foot bus.

Displaced Emissions

- **Land use effect:** In addition to displacing VMT, transit can help reduce congestion and spur more compact, transit-oriented development, thus avoiding GHG emissions that may have otherwise occurred. Even residents who do not ride transit themselves reduce GHG emissions generated because transit enables denser, more energy-efficient land use patterns that keep GHG emissions low through fewer and/or shorter driving trips, more trips on foot or by bicycle, and a reduction in car ownership and use (TCRP, 2021 and APTA, 2018). 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 pace of many development projects.[13] Therefore, when the land use effect is considered, 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 these anticipated additional GHG emissions reductions at a programmatic level.[14]
- **Other displaced emissions:** The programmatic analysis does not consider GHG emissions displaced due to a reduced need for highway maintenance or emissions reductions associated with displaced automobile ownership as a result of a new transit project.

Scenario Testing

The scenario testing results in the 2017 programmatic assessment were based on a sample of 36 transit projects that applied for funding through the Section 5309 Capital Investment Grants (CIG) Program in fiscal years 2015 through 2018. For this update to the programmatic assessment, the project team supplemented the original sample with 32 additional transit projects that had

[13] 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.

[14] Regarding the land use effect, *TCRP 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.

applied for CIG Program funding through fiscal year 2023, for a total of 68 projects. In total, the updated sample includes 38 BRT projects, 12 LR projects, eight SR projects, six CR projects, and four HR projects. The project team used information provided on the CIG templates for the following project characteristics to quantify the GHG 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[15] between the build and the no-build scenario) for the forecast year
- Annual 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

Although the Estimator includes emission factors for additional sources of transit GHG emissions, due to a lack of available information provided in the CIG templates, the following emissions sources were not included in the scenario testing:

- Operation of stations and maintenance/storage facilities
- VMT associated with transit access trips
- Operation of non-revenue vehicles
- Tree removal

To calculate a project's expected net annual GHG emissions, the project team calculated each transit project's estimated amortized construction emissions,[16] annual maintenance-related emissions, and annual operations-related emissions and subtracted annual displaced emissions. (See Appendix C for the detailed results.)

Scenario Testing Data Quality Assumptions and Limitations

The following section outlines the project team's assumptions about the scenario data used and the limitations of that data in generating GHG emissions estimates for the sample of transit projects:

- **Amortized construction emissions:** The Estimator's construction GHG emissions factors represent the total amount of emissions per unit to complete construction. To develop annual GHG emissions, the project team amortized construction emissions over a 40-year period for BRT

[15] For rail modes, VMT was reported in terms of total rail passenger car mileage.
[16] The short-term construction emissions are divided over the life of a project to develop annual construction-related emissions estimates.

projects and over a 50-year period for rail projects (SR, LR, CR, and HR). These time periods correspond to the minimum useful lifespan of facilities per FTA guidance.[17] Truncating the amortization period for the transit scenarios would increase the net annual GHG emissions reported for the project since construction-related GHG emissions would be spread over fewer years.

- **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 the projects' environmental document to confirm whether catenary overhead systems would be used to supply the electricity to power the respective transit vehicles. All SR and LR projects in the sample 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 Estimator includes GHG 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 involve new construction of fixed-guideway BRT lanes.
- **Annual VMT forecasts:** Using travel forecasts and transit operating plans, project sponsors provide FTA with estimated annual transit and automobile VMT for no-build[18] and build[19] scenarios for the current year and a horizon year. For this analysis, when a CIG project template included both a current and horizon-year forecast, the horizon-year data were used. BRT was the only transit mode that did not uniformly provide horizon-year data; 14 of the 40 BRT projects did not provide horizon-year data. For these 14 projects, the project team used the annual VMT estimate for the current year.
- **Electric vehicles:** The Estimator includes both a "U.S. Mix" and region-specific emissions factors based on the EPA's eGRID2020 for electrically-powered vehicles. The U.S. Mix, which represents an average value for the country, was used in this programmatic assessment. For regions with cleaner electricity generation mixes than the U.S. Mix, this approach will overestimate emissions for electrically-powered vehicles. Likewise, this approach will underestimate emissions for the same in regions where electricity production is less clean than the U.S. Mix.

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[17] Awards Management Requirements (February 13, 2017). FTA Circular 5010.1E Chapter IV. 3.f.(2) (f). Available at www.transit.dot.gov/sites/fta.dot.gov/files/docs/Grant%20Management%20 Requirements%20Circular_5010-1E.pdf. Note: The 2017 Programmatic Assessment used a 50-year amortization period for BRT projects. That amortization period has been revised here to 40 years to align with FTA minimum useful lifespan guidance.

[18] 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 or the metropolitan planning organization's fiscally-constrained long range transportation plan excluding the proposed transit project.

[19] The build scenario for the current year is the proposed course of action.

- **Displaced emissions:** The scenario testing analysis assumes that all the displaced automobile VMT is from gasoline-fueled sedans. The automobile fleet is expected to shift toward cleaner vehicles over time concurrently with an increasing shift towards cleaner electricity production. As automobiles produce fewer emissions, the VMT displacement benefit of transit may also be reduced.[20]

Contextualizing Climate Impacts

CEQ's 2023 guidance indicates that project proponents should place potential GHG emissions and their impacts in "appropriate context" given that "metric tons of GHGs can be difficult to understand and assess the significance of in the abstract." The guidance presents as a best practice using the social cost of GHG (SC-GHG) estimates to translate climate impacts into the more accessible metric of dollars. Specifically, the guidance notes that in most circumstances, once agencies have quantified GHG emissions, they should apply the best available estimates of the SC-GHG to the incremental metric tons of each individual type of GHG emissions expected from a proposed action and its alternatives. Such a contextualization through monetization can allow decision-makers and the public to make comparisons, help evaluate the significance of an action's climate change effects, and better understand the tradeoffs associated with an action and its alternatives.

[20] One of the samples of 40 BRT projects reported in its 2021 CIG template an unexpected increase in automobile VMT. The project team assumed this to be a data entry error and treated the figure as an automobile VMT displacement. In addition to its being the only BRT to report an increase in automobile VMT, the figure reported was on the same order of the other projects' reported automobile VMT decreases, suggesting a mistake in the template. Furthermore, the 2019 template for the same project also reported a similar figure to the 2021 template for automobile VMT but as a decrease.

In order to provide additional context for the GHG estimates included in this programmatic assessment, the project team estimated the net social benefits of reduced operational emissions resulting from each transit project in the sample. The project team multiplied the quantity of net operational GHG emissions for CO_2 in various future years by the dollar value of avoiding each ton of emissions in that year.[1] The project team used a 20-year horizon spanning 2023 to 2042, which aligns with the CIG templates' 20-year period for the travel forecast horizon year. The economic value of reduced emissions during each year of those 20 years for the individual transit projects in the sample was then discounted to its present value using a discount rate of 2.0% as per the December 2023 U.S. DOT Benefit-Cost Analysis Guidance for Discretionary Grant Programs.

The 2023 CEQ guidance suggests that it is best to apply GHG-specific costs rather than transforming the gases into CO_2eq and then multiplying CO_2eq by the social cost. The guidance also discusses using the best available data and advises on disclosing assumptions, alternative inputs, and uncertainty related to these analyses, including choosing to monetize some but not all effects of an action.

[20]See Table A-6 in the December 2023 Benefit-Cost Analysis Guidance for Discretionary Grant Programs, available at www.transportation.gov/sites/dot.gov/files/2023-12/Benefit%20Cost%20Analysis%20Guidance%202024%20Update.pdf

The project team opted to monetize only the estimated net CO_2eq emissions from vehicle operations given recommended monetized values available in the U.S. DOT guidance (i.e., CO_2 is the only GHG for which monetized values are given).

Results

This section presents mode-specific GHG estimates for the transit project sample. It is organized in low to high order of total estimated annual emissions by mode.

Light Rail Sample Results

Annual GHG emissions from the sample of light rail projects (n=12) averaged approximately –9,900 $MTCO_2eq$ (median ~ –8,300 $MTCO_2eq$); estimated emissions ranged from a reduction of 41,000 $MTCO_2eq$ per year to an increase of 2,600 $MTCO_2eq$ per year (Figure 3-1).

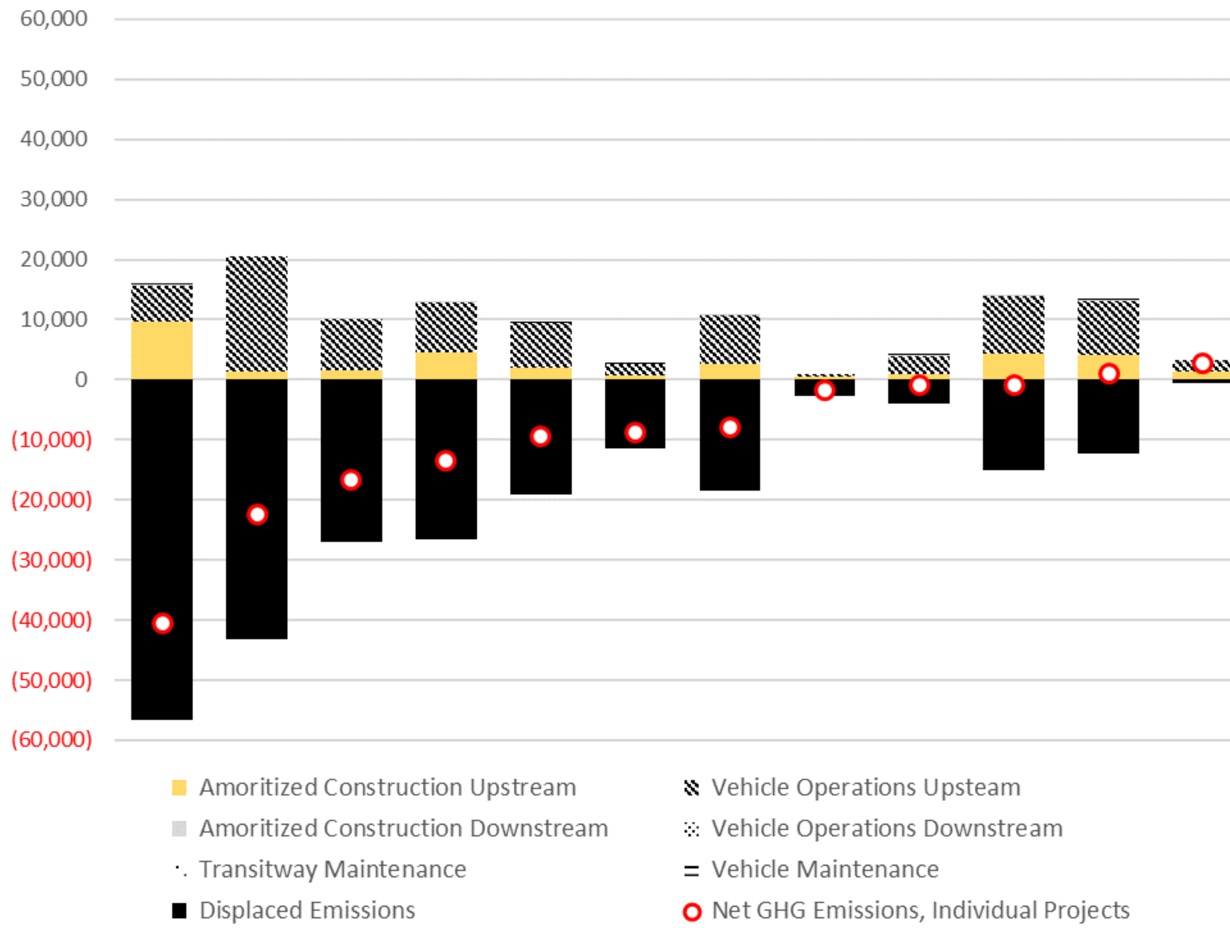

Figure 3-1 ***GHG emissions from Light Rail Projects by Project Lifecycle Component****. Each project in the LR sample is represented by an individual bar. The portion of a bar above 0 shows the aspects of the transit project (e.g., construction) that result in an increase in GHG emissions, and the portion of the bar below 0 shows the aspects of the project (e.g., displaced emissions) that result in a decrease in GHG emissions. The red circle represents the net GHG emissions for the individual project.*

The LR projects in the sample varied in length, track alignment, and number of stations; though all had relatively high rates of displaced automobile VMT as compared to transit VMT. The majority of GHG emissions that LR projects are expected to generate are operations-related upstream emissions. For this reason, the net volume of annual GHG emissions from LR projects largely depend on the fuel source used for electricity generation.

Each of the LR projects analyzed was expected to displace emissions through a reduction in automobile VMT. In 10 of the 12 sample LR projects (83 percent), the annual volume of displaced emissions was greater than the annual volume of GHG emissions generated by the LR project.

On average, a LR project in the sample is estimated to avoid $59,100,000 (2023 dollars) in economic damages over 20 years because o of the operational GHG emissions it displaces. This estimate assumes a social cost of carbon ranging from $228/ton in 2023 to $308/ton in 2042.

Streetcar Sample Results

Annual GHG emissions from the sample of SR projects analyzed (n=8) averaged approximately 270 $MTCO_2eq$ (median ~ 680 $MTCO_2eq$). Each of the SR projects analyzed was expected to have net GHG emissions of less than 1,700 $MTCO_2eq$ annually (Figure 3-2).

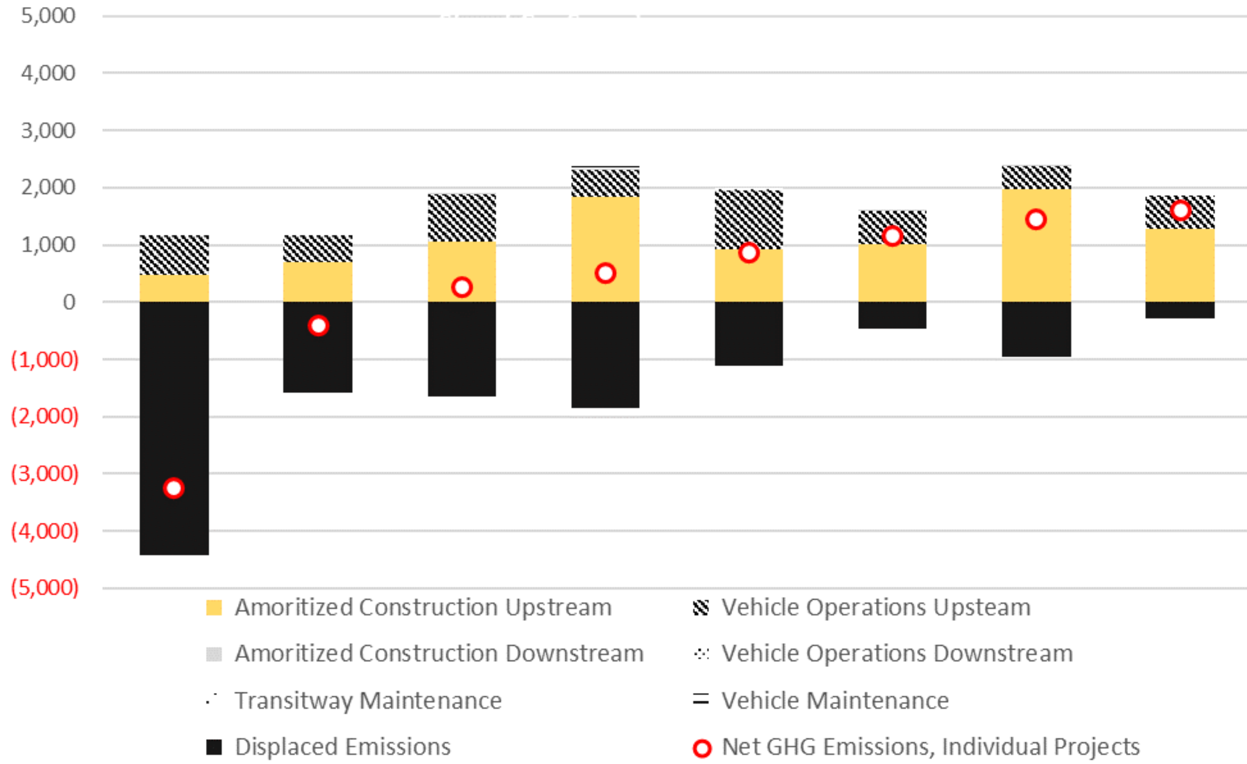

Figure 3-2 ***GHG emissions from Sample Streetcar Projects by Project Lifecycle Component****. Each project in the SR sample is represented by an individual bar. The portion of a bar above 0 shows the aspects of the transit project (e.g., construction) that result in an increase in GHG emissions, and portion of the bar below 0 shows the aspects of the project (e.g., displaced emissions) that result in a decrease in GHG emissions. The red circle represents the net GHG emissions for the individual project.*

The SR projects in the sample were predominately at-grade with annual transit VMT ranging between 134,000 and 338,000. The majority of the GHG emissions generated from the sample SR projects are expected to be from construction-related upstream emissions. Although the SR projects analyzed were expected to displace emissions through a reduction in automobile VMT, the annual volume of their displaced emissions were typically less than the annual volume of GHG emissions SR projects were estimated to generate.

On average, a SR project in the sample is estimated to avoid $4,300,000 (2023 dollars) in economic damages over 20 years because of the operational GHG emissions it displaces. This estimate assumes a social cost of carbon ranging from $228/ton in 2023 to $308/ton in 2042.

Bus Rapid Transit Sample Results

Annual GHG emissions from the BRT projects sample (n=38) averaged approximately 1,450 $MTCO_2eq$ (median ~ 1,220 $MTCO_2eq$). All of the BRT projects analyzed resulted in total annual GHG emissions of less than 4,500 $MTCO_2eq$ per year; two projects resulted in overall reductions in annual GHG emissions (Figure 3-3).

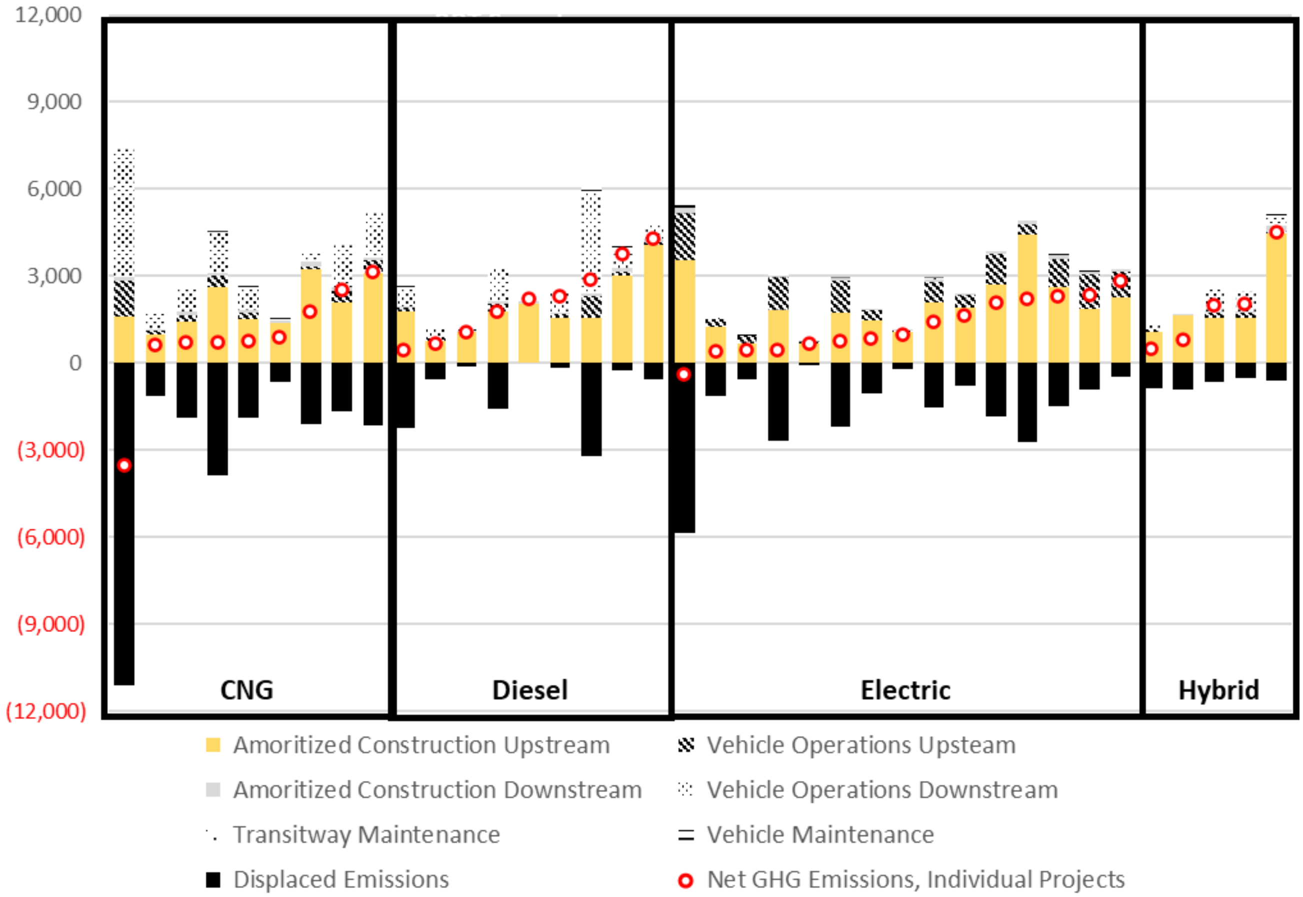

Figure 3-3 ***GHG Emissions from Sample BRT Projects by Lifecycle Component.*** *Each project in the BRT sample is represented by an individual bar. The portion of a bar above 0 shows the aspects of the transit project (e.g., construction) that result in an increase in GHG emissions, and the portion of the bar below 0 shows the aspects of the project (e.g., displaced emissions) that result in a decrease in GHG emissions. The red circle depicts represents the net GHG emissions for the individual project.*

The BRT projects in the sample included a variety of fuel types, including nine diesel-, six hybrid-, nine CNG-, and 14 electricity-powered vehicles.[23] The projects also varied in length, number of stations, transit VMT, and displaced VMT. All of the BRT projects were at-grade.

The majority of the GHG emissions generated from the BRT projects in the sample are estimated to be construction-related upstream emissions. Although most of the BRT projects analyzed were expected to displace emissions through a reduction in automobile VMT, the annual volume of their displaced emissions was typically less than the annual volume of GHG emissions BRT projects were expected to generate when construction was also considered.

On average, a BRT project in the sample is estimated to avoid $3,100,000 (2023 dollars) in economic damages over 20 years because of the operational GHG emissions it displaces. This estimate assumes a social cost of carbon ranging from $228/ton in 2023 to $308/ton in 2042.

[23] Thirty-six (36) of the BRT projects involved buses fueled by a single fuel type. Three (3) involved buses fueled by multiple fuel types.

Commuter Rail Sample Results

Annual GHG emissions from the sample of CR projects (n=6) averaged approximately 9,900 $MTCO_2eq$ (median ~ 8,600 $MTCO_2eq$); estimated emissions ranged from approximately 450 $MTCO_2eq$ per year to 23,000 $MTCO_2eq$ per year (Figure 3-4).

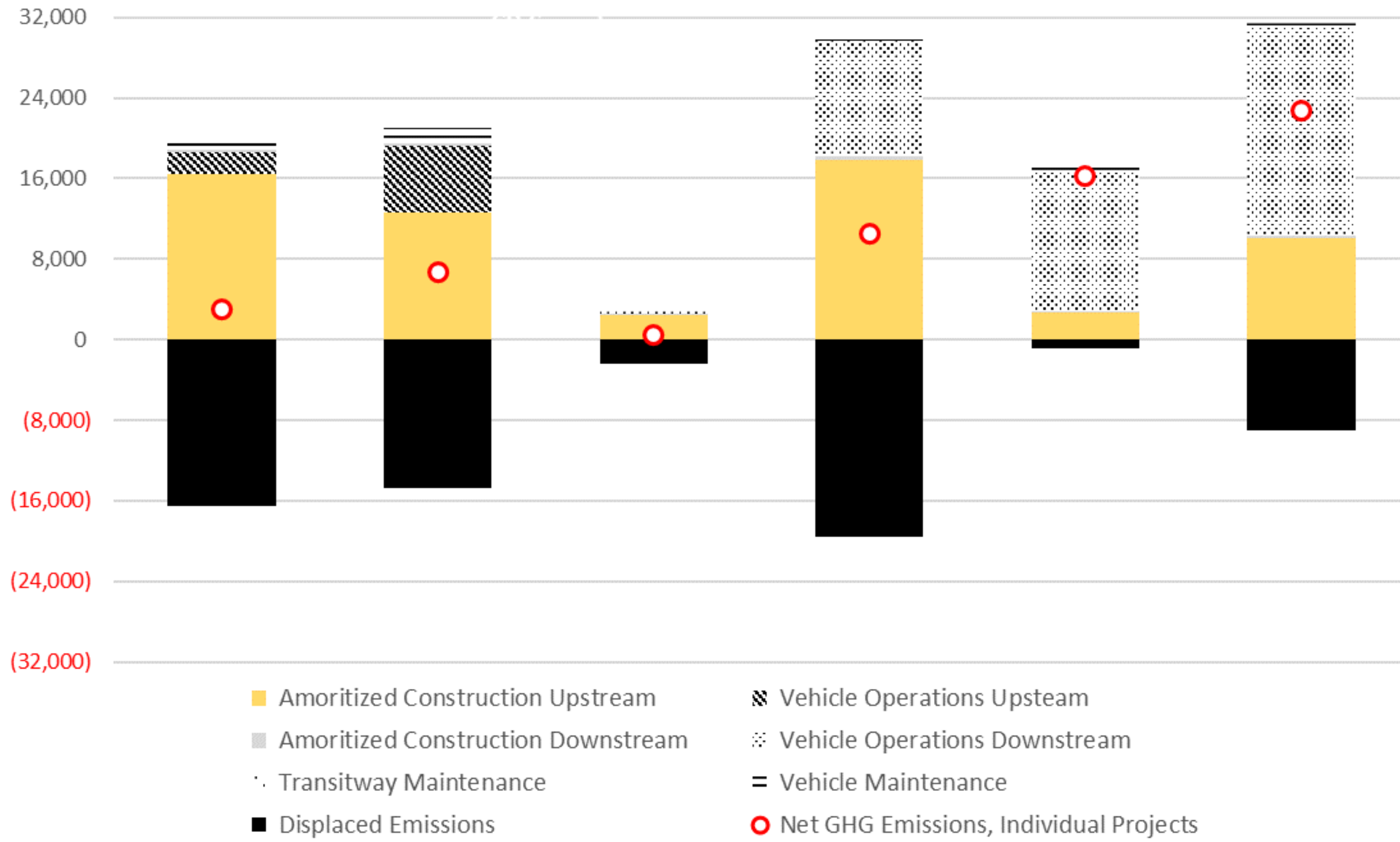

Figure 3-4 *GHG emissions from Commuter Rail Projects by Lifecycle Component. Each project in the CR sample is represented by an individual bar. The portion of a bar above 0 shows the aspects of the transit project (e.g., construction) that result in an increase in GHG emissions, and the portion of the bar below 0 shows the aspects of the project (e.g., displaced emissions) that result in a decrease in GHG emissions. The red circle represents the net GHG emissions for the individual project.*

The CR projects in the sample varied in length, track alignment, number of stations, and rates of displaced automobile VMT as compared to transit VMT. The majority of the GHG emissions that commuter rail projects generate are expected to be from construction-related upstream emissions.

Although the CR projects analyzed were expected to displace emissions through a reduction in automobile VMT, the annual volume of their displaced emissions were typically less than the annual volume of GHG emissions CR projects were estimated to generate.

On average, a CR project in the sample is estimated to avoid $6,500,000 (2023 dollars) in economic damages over 20 years because of the operational GHG emissions it displaces. This estimate assumes a social cost of carbon ranging from $228/ton in 2023 to $308/ton in 2042.

Heavy Rail Sample Results

Annual GHG emissions from the sample of HR projects (n=4) averaged approximately 10,200 MTCO_2eq (median ~ 3,800 MTCO2eq); estimated emissions ranged from a reduction of approximately 1,800 MTCO2eq per year to an increase of approximately 35,000 MTCO_2eq per year (Figure 3-5).

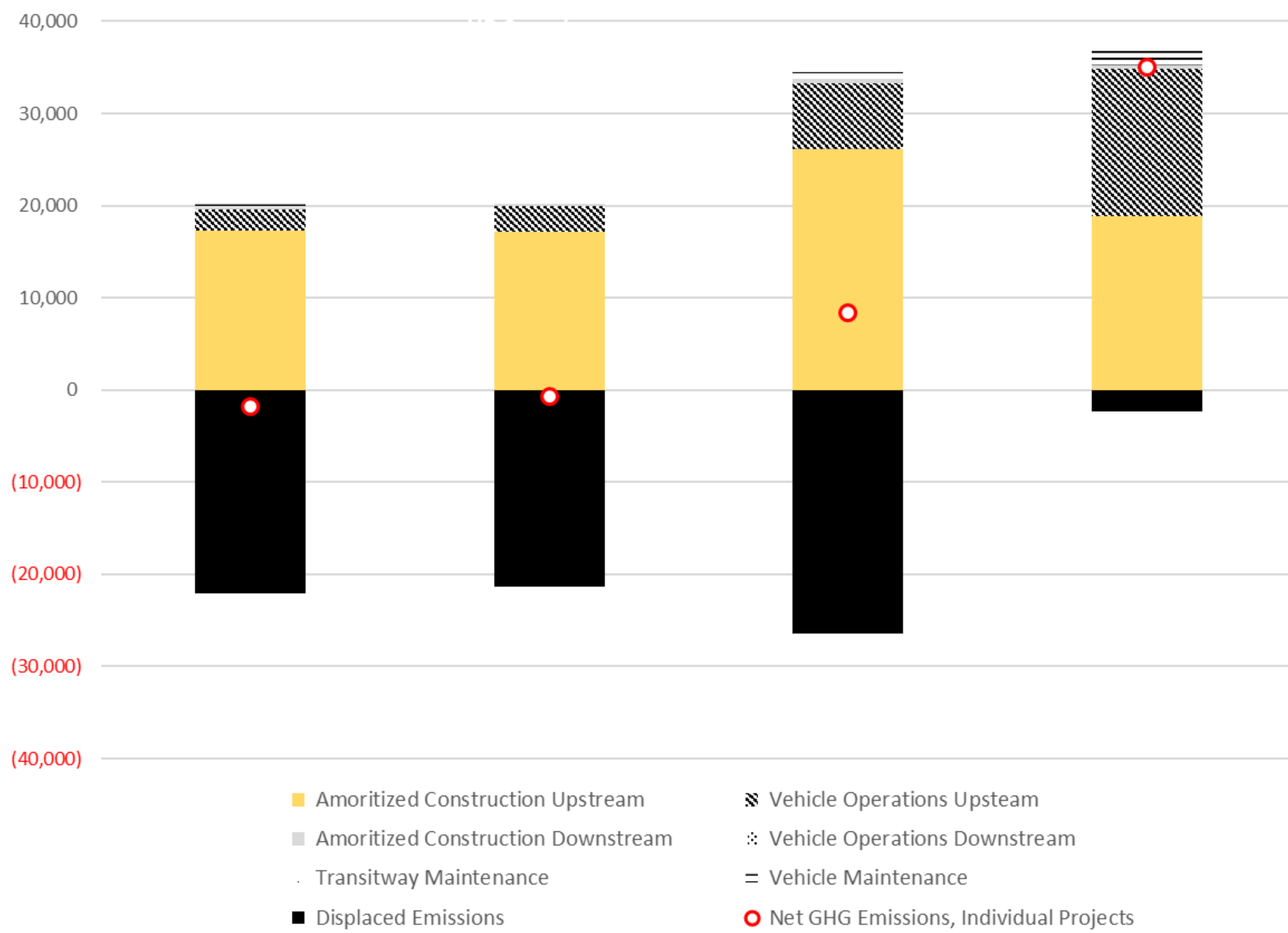

Figure 3-5 ***GHG emissions from Heavy Rail Projects by Lifecycle Component****. Each project in the HR sample is represented by an individual bar. The portion of a bar above 0 shows the aspects of the transit project (e.g., construction) that result in an increase in GHG emissions, and the portion of the bar below 0 shows the aspects of the project (e.g., displaced emissions) that result in a decrease in GHG emissions. The red circle represents the net GHG emissions for the individual project.*

The lengths of the HR projects in the sample ranged from 1.76 miles to 3.92 miles and were all below-grade projects. The projects involved construction of either two or three below-grade stations; none of the projects had a parking component. The majority of the GHG emissions that HR projects generate are expected to be from construction-related upstream emissions. There was wide variation in the proportion of transit VMT to displaced automobile VMT across the HR projects in the sample. The ratios of displaced automobile VMT to transit VMT ranged from approximately 1:1 to 48:1.

An estimate of avoided economic damages due to displaced operational GHG emissions was not calculated for HR due to the small size of available HR sample.

Section 4

Conclusions

Transit projects can generate GHG emissions during their construction, operations, and maintenance phases and displace emissions by reducing automobile emissions due to transit's "ridership effect." This Programmatic Assessment provides and analysis of the estimated net GHG emissions from proposed transit projects. LR projects are expected to result in a net reduction of GHG over their minimum useful lifespans. SR and BRT projects are expected to generate a relatively low net increases in GHG emissions over their minimum useful lifespans.

The findings also indicate that CR and HR projects are expected to generate a net increases in GHG emissions. However, transit infrastructure associated with these two modes may have useful life spans that extend beyond the time period over which construction GHG emissions – the largest contributor to transit GHGs – have been amortized in this analysis. For example, nearly a third of the more than 1,000 HR stations in the U.S. were built in 1969 or before (i.e., more than 50 years in the past), and the percentage is higher when only underground stations are considered (Figure 4-1). Using a longer amortization period would result in lower annual GHG emissions, since the construction-related GHG emission would be spread across a longer period.

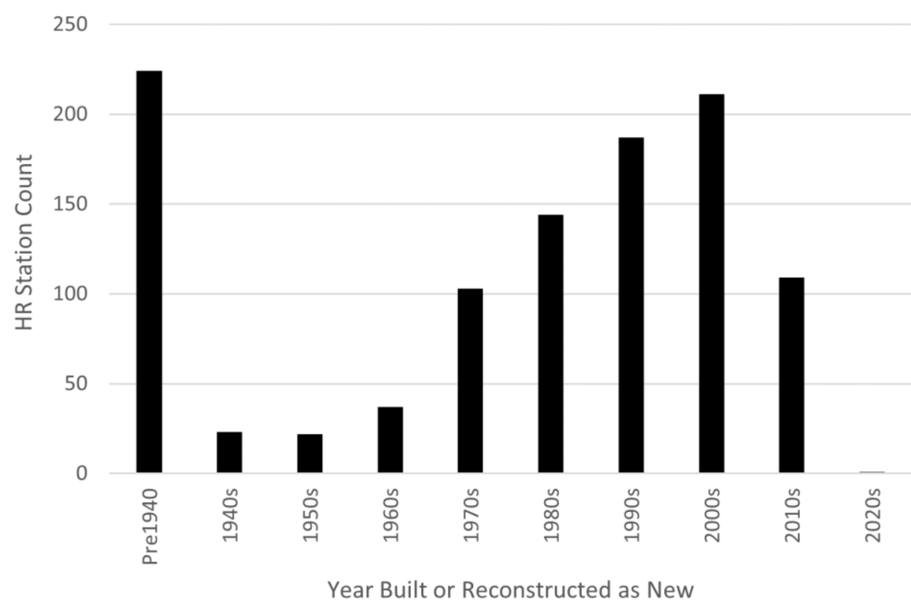

Figure 4-1 *Age Distribution of Heavy Rail Stations in the United States*

These results are not intended to be used as a resource to compare transit modes to one another or compare potential transit projects to potential highway projects.

Other Considerations in Assessing Transit GHG Emissions Results

CEQ's 2023 CEQ guidance discusses the potential utility of using multiple methods for contextualizing a proposed action's GHG emissions and climate change effects, noting that NEPA requires more than a statement that emissions from a proposed Federal action or its alternatives represent only a small fraction of global or domestic emissions. In addition to explaining how a proposed action and alternatives might help meet or detract from achieving relevant climate action goals and commitments, transit agencies might also consider describing the unique contexts of their projects. This can be especially helpful in light of the fact that the act of shifting from personal automobile use to other modes, including transit, itself embodies an important climate mitigation strategy.[24] Some additional contexts to consider when assessing transit projects' GHG emissions include the impact of electricity generation on operations, the impact of ridership on emissions, and the social cost of carbon— each of which are discussed below.

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. This "electricity mix" influences the degree to which electricity use emits GHGs. The estimated net difference in GHGs between an electrically-powered transit project that relies on electricity from cleaner energy sources, such as hydro, solar, and wind, and the same project powered by electricity with a more dominant fossil fuel energy profile, such as coal, can be substantial.

Figure 4-2 illustrates the differences in the GHG emissions associated with an example LR project across different eGRID subregions. In a region that uses a cleaner electricity mix, the LR project results in a net GHG reduction. In contrast, in a region that uses a less clean electricity mix, the same project results in a net increase in GHG emissions. This effect that the electricity generation mix has on the example LR project's annual lifecycle GHG emissions is relevant to any project that involves the operation of any electrically-powered vehicle.

[24]Transit agencies have also adopted or are considering various strategies supplementary to the transit systems themselves to mitigate or offset their GHG emissions. 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.

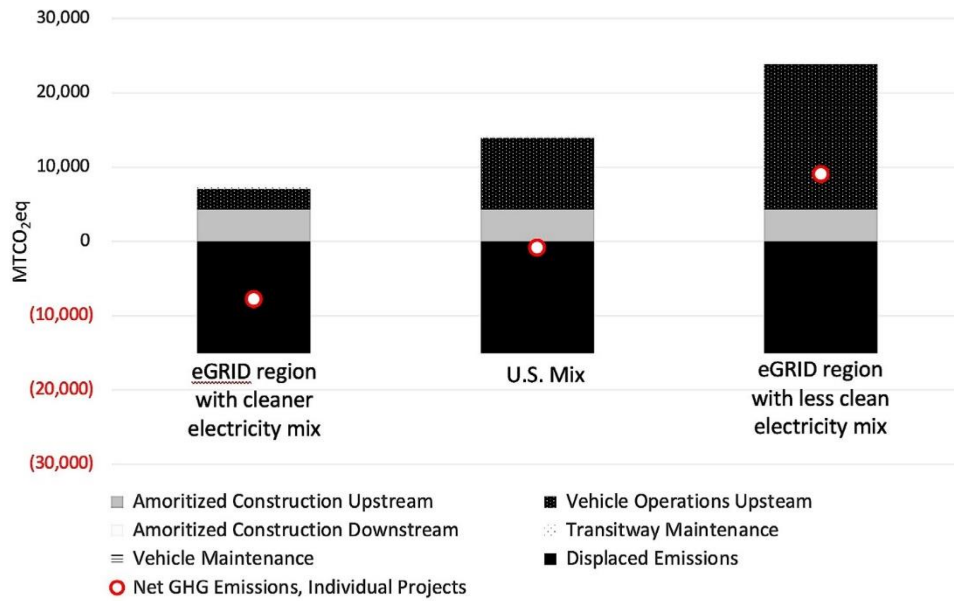

Figure 4-2 ***Total GHG Emissions for Sample LR Project Using Different Electricity Generation Mixes***. *Each bar represents one of the sample LR projects powered by electricity generated in different eGRID regions. an individual bar. The portion of a bar above 0 shows the aspects of the transit project (e.g., construction) that result in an increase in GHG emissions, and portion of the bar below 0 shows the aspects of the project (e.g., displaced emissions) that result in a decrease in GHG emissions. The red circle represents the net GHG emissions for the individual project.*

Impact of Ridership on Results

The results presented in this programmatic assessment rely on an analysis that uses GHG emissions per VMT as the metric to evaluate vehicle operations. Other metrics, such as emissions per revenue vehicle hour, which measures operational efficiency, and emissions per passenger- or seat-mile, which take service productivity into account, offer useful benchmarks.[25] The latter metric provides insight into how the GHG emissions on a per-passenger basis changes based on changes in ridership and load factors.

For illustrative purposes, the project team recast the results to account for passenger loads for each mode. To do so, the project team divided estimated annual lifecycle GHG emissions for each project in the sample by average occupancy loads for each mode. For example, according to NTD data, from 2019 to 2021, all CR service nationally operated at 12.3 percent capacity, or 23 passengers, assuming a vehicle capacity of 183. In this case, the estimated GHGs generated by each CR project were divided by 23. The estimated displaced GHG emissions from automobiles were divided by 1.7 to correct for typical automobile occupancies. Displaced GHG emissions were then subtracted from generated GHG emissions to obtain a total annual GHG emissions estimate that considers ridership. This approach was repeated for each mode (Table 4-1).

[25]See APTA's *Recommended Practice for Quantifying GHG emissions from Transit, Rev. 1* at www.apta.com/wp-content/uploads/Standards_Documents/APTA-SUDS-CC-RP-001-09_Rev-1.pdf for more information.

When considering GHG emissions on a per-passenger basis, the results suggest that even during times of lower than usual transit ridership, such as those experienced during the COVID-19 pandemic, all transit modes – including CR and HR - can be expected to result in net annual GHG emissions reductions.

Table 4-1 *Estimated Annual GHG Emissions Considering Ridership and Auto Occupancy*

	Typical Vehicle Capacity (Standing and Sitting Passengers	**Average Vehicle Load 2019-2021** (Passengers, (Rate)	**Average Net Annual GHG Emissions Considering Ridership and Auto Occupancy** ($MTCO_2eq$)	**Average Net Annual GHG Emissions, Original Estimate** ($MTCO_2eq$)
CR	183	23 (12.3%)	(-5,200)	9,900
HR	140	17 (12.1%)	(-8,900)	10,200
LR	155	15 (9.7%)	(-11,000)	(-9,900)
BRT	74	6 (8.2%)	(-450)	1,450

Sources: NTD 2021 Revenue Vehicle Inventory for estimated transit capacities; FHWA "Average Vehicle Occupancy Factors for Computing Travel Time Reliability Measures and Total Peak Hour Excessive Delay Metrics (April 2018)" for automobile occupancy.

Considering annual transit project GHG emissions through these or similar lenses can offer another way to demonstrate the relative GHG benefits of a transit project, including reducing the project's "payback period" for GHG emissions, or length of time necessary for displaced or avoided GHG emissions to offset all the GHG emissions generated during construction.

Social Cost of Carbon

The 2023 CEQ guidance presents as a best practice using SC-GHG estimates to translate climate impacts into the more accessible metric of dollars to allow decision-makers and the public to make comparisons, help evaluate the significance of an action's climate change effects, and better understand the tradeoffs associated with an action and its alternatives. Because all the sample transit projects, regardless of mode, are expected to reduce emissions related to vehicle operations, they are all expected to generate benefits, in dollars terms, when those displaced or avoided emissions are monetized. These estimated benefits are expected to begin accruing immediately in the first year of the project and may reach $15,000,000 (2023 dollars) or more after 20 years for LR projects at current social cost of carbon values.

Recommendations for Incorporating Results into NEPA Documents

From a programmatic perspective, in cases where project characteristics and assumptions are similar to those analyzed here, transit agencies that are considering BRT, SR, LR, and CR projects may incorporate this programmatic assessment by reference into their NEPA documents. Mode-specific recommendations for doing so are:

- **Light rail projects:** LR projects are expected to generate net reductions in GHG emissions. The LR projects in the sample are predominately at-grade (74 percent of track miles), with just more than a quarter of track miles being above- (22 percent) or below-grade (4 percent) and entailed as many as 21 stations. LR projects that share these or similar characteristics (see Appendix B) are expected to have similar GHG emissions levels as those estimated for the LR sample. Calculating project-specific GHG emissions for LR 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 LR projects incorporate the analysis of construction-related, operations-related, and maintenance-related upstream and downstream GHG emissions presented in this programmatic assessment by reference.
- **Streetcar projects:** SR projects are expected to generate relatively low levels of GHG emissions or net reductions. The SR projects in the sample had relatively low infrastructure needs compared to other rail modes, being almost entirely (99.5 percent of track miles) at-grade and without a parking component (88 percent). They were also expected to displace automobile VMT at nearly the same rate per transit VMT as LR projects. SR projects that share these or similar characteristics (see Appendix B) are expected to have similar GHG emissions levels as those estimated for the SR sample. Calculating project-specific GHG emissions for SR 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 SR projects incorporate the analysis of construction-related, operations-related, and maintenance- related upstream and downstream GHG emissions presented in this programmatic assessment by reference.
- **Bus rapid transit projects:** BRT projects generate relatively low levels of GHG emissions, primarily due to their lower infrastructure needs and low operational GHGs. The BRT projects in the sample were almost entirely (99.9 percent of transitway miles) at-grade and mostly (74 percent) involved buses that operate using non-diesel fuels. Fewer than half of the BRT projects involved construction of parking facilities. BRT projects that share these or similar characteristics (see Appendix B) are expected to have

similar GHG emissions levels as those estimated for the BRT sample. Note that, for the purpose of this assessment, all BRT projects were assumed to involve new construction of fixed-guideway BRT lanes, therefore BRT projects that are converting or upgrading an existing lane are expected to have lower annual GHG emissions. 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.

- **Commuter rail projects:** The CR projects in the sample ranged in length from 2.1 miles to more than 27 miles, and in number of stations from 1 to 7 (all at-grade). Most of the transitway mileage (93 percent) was at-grade, with a smaller percentage above-grade (5 percent), and below-grade(2 percent). Although the sample CR projects are expected to have the highest ratio of displaced automobile VMT to transit operations VMT of the transit modes assessed in this programmatic assessment, CR projects are expected to generate a net increase in GHG emissions due to their infrastructure needs and/or the fuel used for propulsion. Due to the limited number of projects in the CR sample, it is recommended that CR projects that have characteristics that differ from the sample analyzed here (see Appendix B) use the Estimator or another locally recommended approach to make project-specific GHG emissions estimates in their NEPA analyses.
- **Heavy rail projects:** HR projects are expected to generate net increases in GHG emissions, though the scale of emissions is largely impacted by the amount of automobile VMT the project is expected to displace. Due to the limited number of projects in the HR sample, and the wide variation in the estimated GHG emissions across the sample projects, it is recommended that HR projects use the Estimator or another locally recommended approach to make project-specific GHG emissions estimates in their NEPA analyses.

In no case is the use of the Estimator 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 GHG analysis may exist that influence the type of analysis that is conducted as part of the NEPA review of a project.

Appendix A GHG Emissions Factors Used in the Matrix and Estimator

Table A-1 *Heavy Rail GHG Emission Factors*

	PHASE	SOURCE		GHG EMISSIONS UPSTREAM	GHG EMISSIONS DOWNSTREAM	GHG EMISSIONS $MTCO_2eq$
HR FACTORS	CONSTRUCTION	TRACK MILE	UNDERGROUND	168,234	See state -specific table	/mi
			ELEVATED	5,510	912	/mi
			AT-GRADE	805	460	/mi
		CATENARY		3,161	-	/mi
		STATION	UNDERGROUND	215,450	2,085	/facility
			ELEVATED	200,542	1,442	/facility
			AT-GRADE	122,621	581	/facility
	MAINTENANCE	TRACK MILE	UNDERGROUND	-	4.42	/mi/yr
			ELEVATED	-	4.42	/mi/yr
			AT-GRADE	-	4.42	/mi/yr
		VEHICLE		-	0.00029	/veh-mile/yr
	OPERATIONS	VEHICLE	ELECTRIC	See region -specific table	-	
		STATION	ELECTRICITY	-	0.00647	/sqft/yr
		MAINTENANCE/ STORAGE FACILITY	ELECTRICITY	-	0.00490	/sqft/yr
			HEAT	-	0.00170	/sqft/yr

Table A-2 *Commuter Rail GHG Emission Factors*

	PHASE	SOURCE		GHG EMISSIONS UPSTREAM	GHG EMISSIONS DOWNSTREAM	MTCO$_2$eq
CR FACTORS	CONSTRUCTION	TRACK MILE	UNDERGROUND	168,234	See state -specific table	/mi
			ELEVATED	5,510	912	/mi
			AT-GRADE	805	460	/mi
		CATENARY		3,161	-	/mi
		STATION	UNDERGROUND	215,450	2,085	/facility
			ELEVATED	200,542	1,442	/facility
			AT-GRADE	122,621	581	/facility
	MAINTENANCE	TRACK MILE	UNDERGROUND	-	4.42	/mi/yr
			ELEVATED	-	4.42	/mi/yr
			AT-GRADE	-	4.42	/mi/yr
		VEHICLE		-	0.00098	/veh-mile/yr
	OPERATIONS	VEHICLE	ELECTRIC	See region -specific table	-	
			DIESEL	-	0.02717	/veh-mile/yr
		STATION	ELECTRICITY	-	0.00647	/sqft/yr
		MAINTENANCE/ STORAGE FACILITY	ELECTRICITY	-	0.00490	/sqft/yr
			HEAT	-	0.00170	/sqft/yr

Table A-3 *Light Rail and Streetcar GHG Emission Factors*

	PHASE	SOURCE		GHG EMISSIONS UPSTREAM	DOWNSTREAM	$MTCO_2eq$
LR and SR FACTORS	CONSTRUCTION	TRACK MILE	UNDERGROUND	168,234	See state -specific table	/mi
			ELEVATED	5,047	793	/mi
			AT-GRADE	425	138	/mi
			CONVERTED OR UPGRADED	269	95	/mi
		CATENARY		3,161	-	/mi
		STATION	UNDERGROUND	53,740	782	/facility
			ELEVATED	10,736	383	/facility
			AT-GRADE	3,786	11	/facility
	MAINTENANCE	TRACK MILE	UNDERGROUND	-	4.42	/mi/yr
			ELEVATED	-	4.42	/mi/yr
			AT-GRADE	-	4.42	/mi/yr
			CONVERTED OR UPGRADED	-	4.42	/mi/yr
		VEHICLE		-	0.00001	/veh-mile/yr
	OPERATIONS	VEHICLE	ELECTRIC	See region -specific table	-	
		STATION	ELECTRICITY	-	0.00647	/sqft/yr
		MAINTENANCE/ STORAGE FACILITY	ELECTRICITY	-	0.00490	/sqft/yr
			HEAT	-	0.00170	/sqft/yr

Table A-4 *Bus/Bus Rapid Transit Rail GHG Emission Factors*

	PHASE	SOURCE		GHG EMISSIONS UPSTREAM	GHG EMISSIONS DOWNSTREAM	GHG EMISSIONS $MTCO_2eq$
BUS/BRT FACTORS	CONSTRUCTION	TRACK MILE	AT-GRADE	220	250	/mi
			CONVERTED OR UPGRADED	111	89	/mi
		CATENARY		902	-	/mi
		STATION	UNDERGROUND	3,786	11	/facility
			ELEVATED	3,786	11	/facility
			AT-GRADE	3,786	11	/facility
	MAINTENANCE	TRACK MILE	AT-GRADE	-	0.50632	/mi/yr
		VEHICLE		-	0.00005	/veh-mile/yr
	OPERATIONS	VEHICLE	DIESEL AT-GRADE	0.00034	0.00162	/veh-mile/yr
			CNG	0.00042	0.00151	/veh-mile/yr
			HYBRID DIESEL	0.00028	0.00134	/veh-mile/yr
			ELECTRIC	See region -specific table	-	/veh-mile/yr
		STATION	ELECTRICITY	-	0.00739	/sqft/yr
			HEAT	-	0.00165	/sqft/yr
		MAINTENANCE/ STORAGE FACILITY	ELECTRICITY	-	0.00856	/sqft/yr
			HEAT	-	0.00056	/sqft/yr

Table A-5 *Vanpool GHG Emission Factors*

VANPOOL FACTORS	PHASE	SOURCE		GHG EMISSIONS		
				UPSTREAM	DOWNSTREAM	$MTCO_2eq$
	OPERATIONS	VEHICLE	DIESEL	0.00024	0.00116	/veh-mile/yr

Table A-6 *School Bus GHG Emission Factors*

SCHOOL BUS FACTORS	PHASE	SOURCE		GHG EMISSIONS		
				UPSTREAM	DOWNSTREAM	$MTCO_2eq$
	OPERATIONS	VEHICLE	DIESEL	0.00031	0.00148	/veh-mile/yr
			CNG	0.00038	0.00137	/veh-mile/yr

Table A-7 *Demand Response Bus GHG Emission Factors*

DEMAND RESPONSE BUS FACTORS	PHASE	SOURCE		GHG EMISSIONS		
				UPSTREAM	DOWNSTREAM	$MTCO_2eq$
	OPERATIONS	VEHICLE	DIESEL	0.00024	0.00116	/veh-mile/yr
			CNG	0.00030	0.00176	/veh-mile/yr

Table A-8 *Sedan/Automobile GHG Emission Factors*

	PHASE	SOURCE		GHG EMISSIONS UPSTREAM	DOWNSTREAM	$MTCO_2eq$
SEDAN / AUTOMOBILE FACTORS	OPERATIONS	VEHICLE	GAS	0.00008	0.00033	/veh-mile/yr
			DIESEL	0.00006	0.00028	/veh-mile/yr
			HYBRID ELECTRIC	0.00006	0.00024	/veh-mile/yr
			ALL ELECTRIC	See region -specific table		
			PLUG-IN HYBRID ELECTRIC	See region -specific table		

Table A-9 *Parking Infrastructure GHG Emission Factors*

	PHASE	SOURCE	GHG EMISSIONS UPSTREAM	DOWNSTREAM	$MTCO_2eq$
PARKING FACTORS	CONSTRUCTION	LOT < 50	0.24	0.180	/space
		LOT 50-500	0.30	0.210	/space
		LOT > 500	0.34	0.210	/space
		GARAGE < 50	5.44	1.000	/space
		GARAGE 50-500	5.52	0.747	/space
		GARAGE > 500	5.57	0.742	/space

Table A-10 *Carbon Storage GHG Emission Factors*

	PHASE		UPSTREAM	DOWNSTREAM	$MTCO_2eq$
CARBON STORAGE GHG EMISSION FACTORS	CONSTRUCTION	Lost/gained carbon sequestration	-	0.83680	/tree/yr

Table A-11 *State- and Region-Specific Emissions Factors for Downstream, Underground Track Mile Construction for HR, CR, and LR/SR (MTCO$_2$EQ/MI)*

State	DOWNSTREAM	State	DOWNSTREAM	State	DOWNSTREAM
US Mix	5,046	KY	6,004	OH	5,520
AL	4,967	LA	4,928	OK	5,096
AK	4,977	ME	4,404	OR	4,365
AZ	4,987	MD	5,066	PA	4,908
AR	5,165	MA	4,878	RI	4,918
CA	4,503	MI	5,155	SC	4,681
CO	5,520	MN	5,066	SD	4,572
CT	4,552	MS	4,987	TN	5,046
DC	4,352	MO	5,738	TX	5,096
DE	4,937	MT	5,303	UT	5,678
FL	5,076	NE	5,333	VT	4,127
GA	5,056	NV	4,819	VA	4,868
HI	5,570	NH	4,374	WA	4,246
ID	4,246	NJ	4,612	WV	6,024
IL	4,868	NM	5,619	WI	5,441
IN	5,886	NY	4,523	WY	6,073
IA	5,046	NC	4,918		
KS	5,244	ND	5,718		

Table A-12 *Region-Specific Upstream Emission Factors for Operation of Electric HR, CR, and LR/SR*

	GHG EMISSIONS (MTC0$_2$eq per veh-mile/yr)		
eGRID Region	HR OPERATIONS, UPSTREAM	CR OPERATIONS, UPSTREAM	LR/SR OPERATIONS, UPSTREAM
US MIX	0.00205	0.00387	0.00289
AKGD	0.00275	0.00520	0.00389
AKMS	0.00134	0.00252	0.00189
AZNM	0.00212	0.00400	0.00299
CAMX	0.00129	0.00243	0.00181
ERCT	0.00205	0.00387	0.00289
FRCC	0.00209	0.00395	0.00295
HIMS	0.00287	0.00542	0.00405
HIOA	0.00416	0.00784	0.00586
MROE	0.00383	0.00723	0.00540
MROW	0.00246	0.00464	0.00347
NEWE	0.00133	0.00251	0.00188
NWPP	0.00151	0.00284	0.00212
NYCW	0.00159	0.00299	0.00224
NYLI	0.00303	0.00571	0.00427
NYUP	0.00059	0.00110	0.00083
PRMS	0.00401	0.00757	0.00566
RFCE	0.00164	0.00308	0.00231
RFCM	0.00289	0.00546	0.00408
RFCW	0.00247	0.00466	0.00349
RMPA	0.00287	0.00542	0.00405
SPNO	0.00240	0.00452	0.00338
SPSO	0.00233	0.00440	0.00329
SRMV	0.00185	0.00349	0.00261
SRMW	0.00372	0.00702	0.00525
SRSO	0.00216	0.00407	0.00304
SRTV	0.00209	0.00395	0.00295
SRVC	0.00156	0.00295	0.00220
100% renewable energy	0	0	0

Table A-13 *Region-Specific Upstream Emission Factors for Operation of Electric Bus, Sedan/Automobile, and PHEV-Gas Vehicles*

	GHG EMISSIONS ($MTCO_2eq$ per veh-mile/yr)			ENERGY USE (MMBTU per veh-mile/yr)		
NERC REGION	ELECTRIC BUS OPERATIONS UPSTREAM	ALL ELECTIC SEDAN/ AUTO OPERATIONS UPSTREAM	PHEV-GAS OPERATIONS UPSTREAM	ELECTRIC BUS OPERATIONS UPSTREAM	ALL ELECTIC SEDAN/ AUTO OPERATIONS UPSTREAM	PHEV-GAS OPERATIONS UPSTREAM
US MIX	0.00104	0.00017	0.00013	0.00833	0.00132	0.00119
ASCC	0.00143	0.00023	0.00017	0.01275	0.00203	0.00163
FRCC	0.00115	0.00018	0.00014	0.00957	0.00152	0.00131
HICC	0.00218	0.00035	0.00024	0.01861	0.00296	0.00221
MRO	0.00148	0.00024	0.00017	0.01113	0.00177	0.00146
NPCC	0.00060	0.00010	0.00008	0.00607	0.00097	0.00096
RFC	0.00103	0.00016	0.00013	0.00830	0.00132	0.00118
SERC	0.00098	0.00016	0.00012	0.00803	0.00128	0.00116
SPP	0.00120	0.00019	0.00014	0.00894	0.00142	0.00125
TRE	0.00098	0.00016	0.00012	0.00827	0.00131	0.00118
WECC	0.00084	0.00013	0.00011	0.00686	0.00109	0.00104
100% renewable energy	0	0	0.00002	0.00041	0.00007	0.00040

Appendix B Transit Scenario Emissions Analysis Results

	TRANSITWAY MILEAGE			# STATIONS			# PARKING SPACES		ANNUAL TRANSIT VMT								ANNUAL DISPLACED VMT					ANNUAL GHG EMISSIONS (MTCO_2EQ)								
																						CONSTRUCTION		MAINTENANCE		OPERATIONS				
MODE	ABOVE	BELOW	AT-GRADE	ABOVE	BELOW	AT-GRADE	SURFACE	STRUCTURE	CNGBUS	HYBRID BUS	DIESEL BUS	ELECTRIC BUS	LIGHT RAIL	DIESEL CR	ELECTRIC CR	HR	DIESELBUS	HYBRID BUS	CNGBUS	ELECTRIC BUS	AUTO	UPSTREAM	DOWN.	TRANSITWAY (DOWN.)	VEHICLE (DOWN.)	UPSTREAM	DOWN.	DISPLACED EMISSION	TOTAL ANNUAL EMISSIONS	20-Year Impact of TailpipeGHGs (in 2020 US$)
BRT			13			28						1,005,146					(943,255)					2,722	89	7	50	1,045	0	1,843	2,070	(987,367)
BRT			13.33			14			10,728												(1,575,335)	1,398	87	7	1	4	16	643	871	(775,145)
BRT			8.75			19						1,069,478					(820,829)				(2,579,100)	1,846	60	4	53	1,112	0	2,656	420	(1,923,719)
BRT			3.23			7						30,081						(36,821)			(57,320)	680	22	2	2	31	0	83	654	(61,221)
BRT			10.33			16				527,469							(216,729)				(196,193)	1,571	69	5	26	146	706	504	2,020	434,016
BRT			20			16			2,950,300								(2,394,168)				(15,759,863)	1,624	129	10	148	1,227	4,446	11,108	(3,523)	(6,771,763)
BRT			24			36	269					1,585,025					(1,160,732)				(8,798,748)	3,541	161	12	79	1,648	0	5,858	(415)	(5,245,079)
BRT			8.5			16	792			586,400							(187,593)				(695,922)	1,568	62	4	29	162	785	650	1,960	369,493
BRT			5			10	100		355,007								(167,921)				(1,919,528)	975	35	3	18	148	535	1,111	601	(534,044)
BRT			16			31	125				427,186										(566,122)	3,023	109	8	21	143	692	231	3,765	752,265
BRT			8.5			16	50				398,272										(365,661)	1,561	58	4	20	133	645	149	2,272	783,776
BRT			6.1			11					21,691										(293,065)	1,075	41	3	1	7	35	120	1,043	(96,174)
BRT			15			42	1051				308,932										(1,320,130)	4,067	111	8	15	103	500	539	4,266	81,040
BRT			15			46						338,700					(1,122,023)	(96,971)			938,204	4,436	106	8	17	425	310	2,349	2,953	(2,003,064)
BRT			19.75			14	480		516,658												(4,648,464)	1,437	130	10	26	215	779	1,897	700	(1,125,188)
BRT			5.3			13	600					224,009					(207,737)				(1,801,657)	1,265	40	3	11	233	0	1,141	410	(1,131,399)
BRT			5.8			20						396,451					(111,006)	(23,505)			(1,286,473)	1,925	42	3	20	412	0	780	1,622	(455,892)
BRT			10			21					32,473											2,043	68	5	2	11	53	0	2,181	79,061
BRT			19			21						658,920							(253,618)		(2,576,830)	2,092	125	10	33	685	0	1,539	1,405	(1,038,933)
BRT			9.9			18						1,041,598					(674,559)				(2,175,915)	1,758	67	5	52	1,083	0	2,206	759	(1,398,759)
BRT			2.6			7					3,799	242,424									(1,348,100)	677	18	1	12	253	6	550	418	(361,939)
BRT			12			23	350					886,782									(1,147,162)	2,246	83	6	44	922	0	468	2,833	565,947
BRT			14			19	150					1,134,895									(2,209,734)	1,876	94	7	57	1,180	0	902	2,313	347,284
BRT			2.3			11				167,173							(30,987)			(18,296)	(1,911,507)	1,054	17	1	8	46	224	859	491	(733,530)
BRT			14.4			30	162	2337	236,000												(5,198,568)	3,245	142	7	12	98	356	2,121	1,740	(2,077,316)
BRT			15.5			27						933,700					(763,761)				(626)	2,641	104	8	47	971	0	1,493	2,278	(649,909)
BRT			11.7			27			950,367								(1,295,997)				(3,262,114)	2,620	81	6	48	395	1,432	3,863	718	(702,254)
BRT			7			15						349,646					(395,753)				(680,741)	1,458	48	4	17	364	0	1,051	840	(856,621)
BRT			17			41	617	3607		261,369											(1,468,948)	4,482	188	9	13	72	350	599	4,514	(220,816)
BRT			5.2			11						49,637									(528,352)	1,070	36	3	2	52	0	216	946	(204,276)
BRT	0.39		9.87			16	450			593,300	1,714,581										(7,893,600)	1,572	68	5	115	738	3,570	3,221	2,849	111,082
BRT			18.5			21			984,373								(836,717)				(34,313)	2,089	121	9	49	409	1,483	1,649	2,513	304,030
BRT			16.8			15	250		516,658												(4,648,464)	1,514	110	9	26	215	779	1,897	756	(1,125,188)
BRT			15.6			32	186		1,032,961								(723,806)				(1,807,668)	3,116	107	8	52	430	1,557	2,152	3,117	(206,165)

	TRANSITWAY MILEAGE			# STATIONS			# PARKING SPACES		ANNUAL TRANSIT VMT								ANNUAL DISPLACED VMT					ANNUAL GHG EMISSIONS ($MTCO_2EQ$)								
																						CONSTRUCTION		MAINTENANCE		OPERATIONS				
MODE	ABOVE	BELOW	AT-GRADE	ABOVE	BELOW	AT-GRADE	SURFACE	STRUCTURE	CNGBUS	HYBRID BUS	DIESEL BUS	ELECTRIC BUS	LIGHT RAIL	DIESEL CR	ELECTRIC CR	HR	DIESELBUS	HYBRID BUS	CNGBUS	ELECTRIC BUS	AUTO	UPSTREAM	DOWN.	TRANSITWAY (DOWN.)	VEHICLE (DOWN.)	UPSTREAM	DOWN.	DISPLACED EMISSION	TOTAL ANNUAL EMISSIONS	20-Year Impact of TailpipeGHGs (in 2020 US$)
BRT			12.3			18	1,355				725,760										(3,816,784)	1,783	89	6	36	243	1,175	1,557	1,775	(173,335)
BRT			10.52			18			27,582	21,353	353,227										(5,441,385)	1,762	71	5	20	136	642	2,220	415	(1,797,173)
BRT			5.9			17				1,464							(1,095)				(2,249,445)	1,642	42	3			2	920	769	(1,143,266)
BRT			3.1			8					189,014						(31,905)	(31,904)			(1,037,023)	774	22	2	9	63	306	537	639	(206,251)
LRT	3	0.5	11			16	2731						2,956,782								(30,273,965)	4,226	143	64	35	8,830		12,352	941	(15,153,615)
LRT	3.63	0.02	4.16			3	550	2,650					2,900,000								(66,327,360)	1,489	113	35	35	8,660		27,062	(16,730)	(33,114,280)
LRT	4.1		4.4			4	250	1,250					6,400,000								(105,707,840)	1,432	98	38	77	19,113		43,129	(22,372)	(53,032,359)
LRT	1.07		11.58			11	240	1,341					2,485,093								(46,585,483)	1,990	72	56	30	7,421		19,007	(9,438)	(23,237,962)
LRT			8			10	2,553	125					619,704								(1,569,477)	1,362	37	35	7	1,851		518	2,652	(797,872)
LRT	0.48		1.12			3		257					179,744								(6,729,300)	415	15	7	2	537		2,746	(1,770)	(3,383,519)
LRT	3	0.5	11			16	1,847	640					3,235,204								(36,894,915)	4,291	154	64	39	9,661		15,053	(844)	(18,316,583)
LRT	1.02		3.68			7	180						1,021,545								(12,188,214)	963	29	21	12	3,051		4,022	(898)	(6,196,098)
LRT	4.04	0.04	6.85			9	650	520					2,770,880								(45,122,744)	2,035	100	48	33	8,275		18,410	(7,918)	(22,610,748)
LRT	0.3		2			3	75	2025					662,712								(27,966,900)	646	41	10	8	1,979		11,410	(8,726)	(13,682,993)
LRT	0.7	0.6	9.7			21							2,821,918								(65,227,432)	4,457	97	49	34	8,427		26,613	(13,549)	(32,898,630)
LRT		1.9			3								2,003,400								(138,743,400)	9,737	218	8	24	5,983		56,607	(40,598)	(69,548,765)
SC	0.04		2.54			11							193,234								(1,143,600)	1,022	10	11	2	577		467	1,156	(580,642)
SC	0.1		4.05			10	42						273,981								(4,059,483)	1,064	15	18	3	818		1,656	263	(2,063,711)
SC			2.4			7							153,000								(3,898,425)	702	8	11	2	457		1,591	(411)	(1,952,462)
SC			3			14							192,720								(681,264)	1,275	11	13	2	576		278	1,600	(341,089)
SC			3.4			23							134,361								(2,368,438)	1,985	14	15	2	401		966	1,451	(1,195,300)
SC			4.4			20							161,318								(4,532,304)	1,830	17	19	2	482		1,849	500	(2,228,973)
SC			3.5			9							337,774								(2,737,231)	933	12	15	4	1,009		1,117	856	(1,375,411)
SC			2.53			4							227,289								(10,854,078)	484	8	11	3	679		4,428	(3,244)	(5,473,831)
CR			2.1			1								10,074							(5,818,845)	2,486	31	9	10		282	2,374	445	(2,952,358)
CR	1.28	1.9	4.59			4	2,322								656,820						(40,577,320)	16,433	293	34	640	2,166		16,556	3,011	(20,468,718)
CR			12.25			1	383							493,200							(2,271,280)	2,652	126	54	481	0	13,824	927	16,211	(1,123,488)
CR			17.2			4	1,272							738,730							(22,248,800)	10,095	210	76	720	0	20,707	9,078	22,731	(10,950,282)
CR	2.6	0.01	24.58			7	1,779							401,448							(47,929,535)	17,895	363	120	391	0	11,253	19,555	10,467	(24,089,971)
CR	0.29		17.7			5	2,530								2,017,770						(36,234,240)	12,593	235	79	1,967	6,653		14,784	6,743	(18,159,732)
HR		2.56			2											1,105,877					(53,963,010)	17,232	314	11	321	2,309		22,017	(1,802)	(27,312,030)
HR		1.76			3											7,670,522					(5,679,289)	18,849	284	8	2,224	16,018		2,317	35,066	(2,878,526)
HR		3.92			3											3,418,818					(64,672,300)	26,117	478	17	991	7,140	-	26,386	8,357	(32,020,311)
HR		2.55			2											1,298,203					(52,190,705)	17,198	313	11	376	2,711	-	21,294	(684)	(26,071,167)

Appendix C

Comparison of Sample Transit Project Results to No Action Alternatives

The CEQ guidance suggests that NEPA reviews identify the current and projected future state of the affected environment without the proposed action (i.e., the no action alternative), which serves as the baseline for considering the effects of the proposed action and its reasonable alternatives. In the context of this programmatic assessment, the effects of the no action alternative are implicitly reflected as GHG emissions avoided from automobile VMT displaced by the transit project. However, for additional clarity, the following charts compare the estimated net GHG emissions from the sample projects to the estimated GHGs produced from the automobiles were they not displaced. In other words, in the absence of the transit project (i.e., the no action alternative) the displaced automobile VMT would be expected to occur and thus produce GHGs, as illustrated in the figures below.

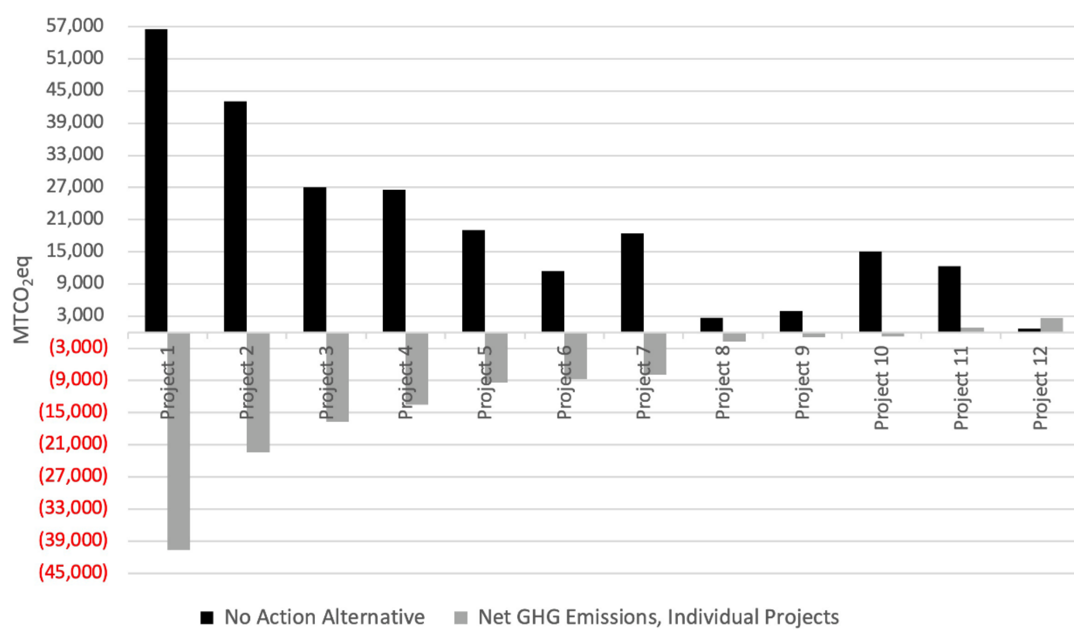

Figure C-1 *Light Rail Sample – Comparison of Action and No Action Alternatives*

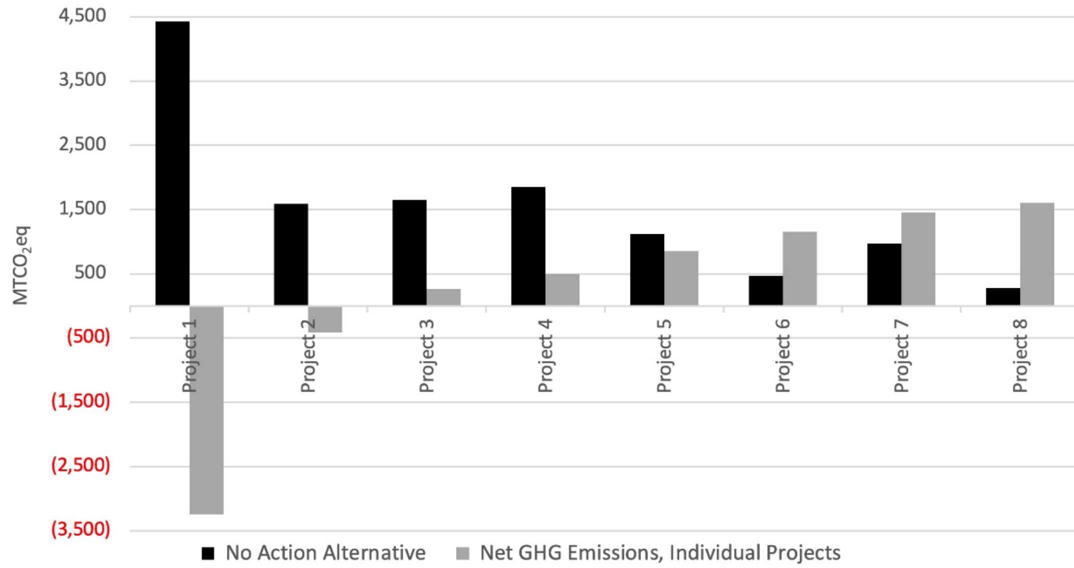

Figure C-2 *Streetcar Sample – Comparison of Action and No Action Alternatives*

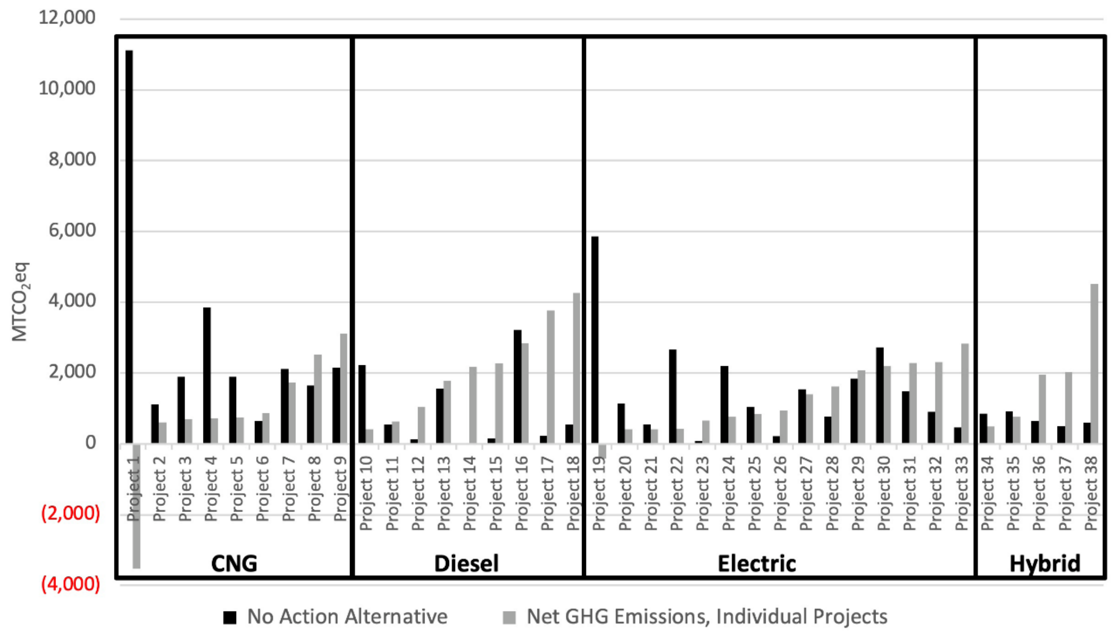

Figure C-3 *Bus Rapid Transit Sample – Comparison of Action and No Action Alternatives*

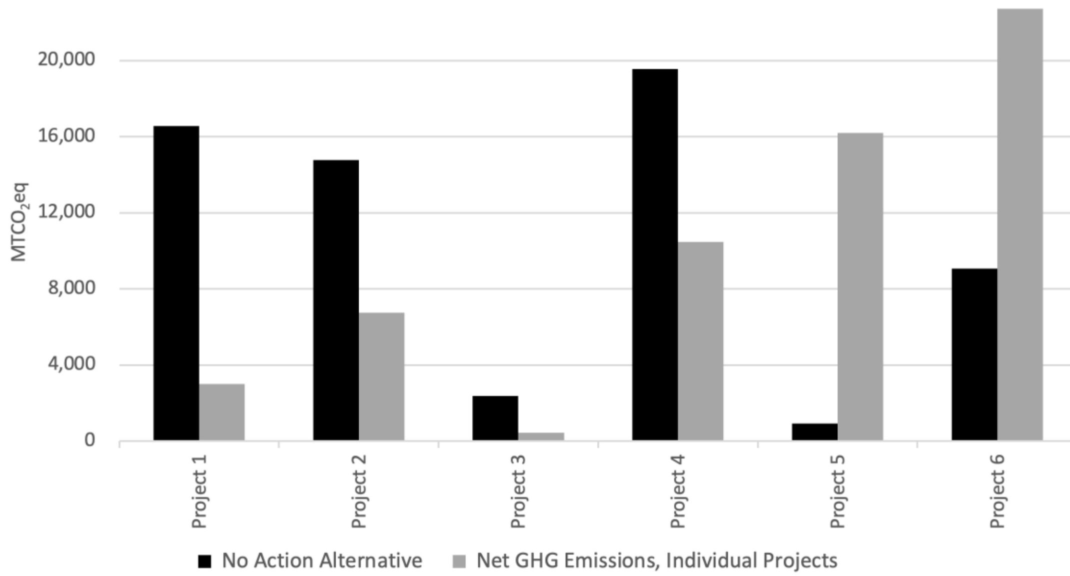

Figure C-4 *Commuter Rail Sample – Comparison of Action and No Action Alternatives*

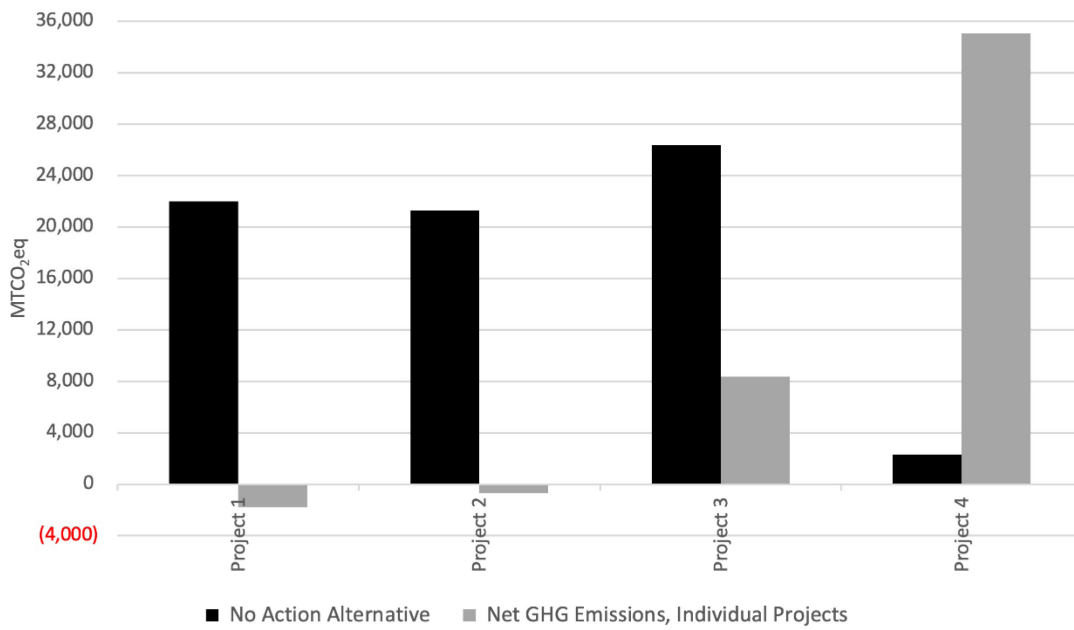

Figure C-5 *Heavy Rail Sample – Comparison of Action and No Action Alternatives*

Acronyms and Abbreviations

APTA	American Public Transportation Association
BRT	Bus rapid transit
CEQ	Council on Environmental Quality
CEQ guidance	NEPA guidance on consideration of greenhouse gas emissions and climate change
CIDI	Compression-ignition direct-injection
CIG	Capital Improvement Grants Program
CNG	Compressed natural gas
CO2	Carbon dioxide
CR	Commuter rail
DR	Demand response
eGRID	Emissions & Generation Resource Integrated Database
EPA	Environmental Protection Agency
Estimator	Transit GHG Emissions Estimator v.3
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
LR	Light rail
LS	Low-sulfur
Matrix	GHG Emissions Typology Matrix
MBTA	Massachusetts Bay Transportation Authority
MT	Metric ton
MTCO2e	Metric ton of carbon dioxide equivalent
NEPA	National Environmental Policy Act
NG	Natural gas
NTD	National Transit Database
PHEV	Plug-in hybrid electric vehicle
SC-GHG	Social cost of greenhouse gas
SI	Spark-ignition
SR	Streetcar rail
TSD	Technical support document
TCRP	Transit Cooperative Research Program
USDA	U.S. Department of Agriculture
VMT	Vehicle miles traveled

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 for public transportation vehicles, and short headway bidirectional services for a substantial part of weekdays and weekend service.

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, one pound of methane will trap as much heat as 21 pounds of carbon dioxide. Thus, one 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 that is equipped with a pantograph.

Commuter rail – A mode of transit 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 automobile travel that are avoided through a mode shift from 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, nitrous oxide, methane, and hydrofluorocarbons.

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- 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 may have either high platform loading or low-level boarding using steps, and are typically driven electrically (with power being drawn from an overhead electric line via a trolley or a pantograph) or by an operator on board the vehicle.

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. NEPA 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 travelers from private vehicles to 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 travels while in service.

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

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