



# Updated Comparison of Energy Use & Emissions from Different Transportation Modes

June 2019

Submitted to:



aba foundation  
AMERICAN BUS ASSOCIATION  
EDUCATION • RESEARCH • INVESTMENT

111 K Street NE  
9<sup>th</sup> Floor  
Washington, D.C. 20002

Prepared by:

MJB & A





## **Table of Contents**

<b>INTRODUCTION</b>	<b>1</b>
<b>1 RESULTS – MODE COMPARISONS</b>	<b>3</b>
<b>1.1 Fuel and CO<sub>2</sub> Emissions</b>	<b>4</b>
<b>1.2 NO<sub>x</sub> and PM Emissions</b>	<b>8</b>
<b>2 DATA SOURCES</b>	<b>12</b>
<b>2.1 Fuel and CO<sub>2</sub> Emissions</b>	<b>12</b>
<b>2.2 NO<sub>x</sub> and PM Emissions</b>	<b>14</b>
<b>3 CALCULATION METHODOLOGY</b>	<b>16</b>
<b>3.1 Energy Use and CO<sub>2</sub> Emissions</b>	<b>16</b>
<b>3.2 NO<sub>x</sub> and PM Emissions</b>	<b>17</b>
<b>APPENDIX A - NTD Mode Definitions</b>	

## Introduction

This analysis is intended to evaluate the environmental performance of Highway Motorcoach operations, by comparing the energy use, and carbon dioxide (CO<sub>2</sub>), nitrogen oxide (NO<sub>x</sub>), and particulate matter (PM) emissions of motorcoaches with the energy use and emissions of other common transportation vehicles/modes. This analysis is an update of a similar March 2014 analysis conducted by M.J Bradley & Associates for the American Bus Association Foundation.

Including motorcoaches, a total of thirteen transportation modes are included in the analysis, as follows:

- **Highway Motorcoach** – According to the American Bus Association vehicles in the motorcoach fleet are designed for long-distance travel and are characterized by “integral construction with an elevated passenger deck located over a baggage compartment”. For this analysis the motorcoach mode includes motorcoach buses used for private charters, tours/sightseeing, scheduled inter-city service, and airport and commuter service between a central city and adjacent suburbs/airports.
- **Private Automobile** – For this analysis the private automobile mode includes all use of a personally-owned car or light truck for commuting and other travel.
- **Heavy Urban Rail** – A transit mode that uses self-propelled electric-powered passenger cars operating on an exclusive rail right-of-way, either below or above-ground, to provide scheduled service within an urban area. Typically, the system is designed to accommodate very high passenger volumes, and trains are operated in multi-car sets. The electricity to power the vehicles is drawn either from overhead wires or from a power rail.
- **Light Rail** – A transit mode that uses self-propelled electric-powered passenger cars operating on an exclusive or shared above-ground rail right-of-way to provide scheduled service within an urban area. Typically, the system is designed to accommodate lower passenger volumes than heavy rail, and passenger cars are operated singly or in two-car sets. The electricity to power the vehicles is drawn from overhead wires.
- **Commuter Rail** – A transit mode that uses electric or diesel-powered locomotives pulling passenger cars, and operating on an exclusive rail right-of-way, for local short-distance travel between a central city and adjacent suburbs.
- **Intercity Rail** – A transit mode that uses electric or diesel-powered locomotives pulling passenger cars, and operating on an exclusive rail right-of-way, for long-distance travel between cities.
- **Domestic Air Travel** – Scheduled plane service operating between U.S. cities. For this analysis international air travel is not included.
- **Urban Transit Bus** – A transit mode that includes the use of primarily diesel-powered, rubber-tired vehicles for fixed route scheduled service within an urban area, and usually operated in mixed traffic on city streets. The buses used for this mode are typically between 20 and 60 feet in length.
- **Electric Trolley Bus** – A transit mode that uses electric-powered rubber-tired vehicles for fixed route scheduled service within an urban area, and usually operated in mixed traffic on city streets. Electricity to power the vehicles is drawn from overhead wires installed along the route.
- **Ferry Boat** – A transit mode that uses marine vessels to carry passengers and/or vehicles over a body of water. Intercity ferryboat 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.

- **Van Pool** – A transit mode that uses vans, small buses and other vehicles, operating as a ride-sharing arrangement, to provide transportation to a group of individuals traveling directly between their homes and a regular destination within the same geographical area. For this analysis only, vanpools operated by a public entity are included.
- **Demand Response** – Shared-use transit service operating in response to calls from passengers to a transit operator, who schedules a vehicle to pick up the passengers to transport them to their destinations. This analysis only includes demand response service operated by public transit agencies, primarily to provide “para-transit” service to individuals with disabilities that preclude them from using fixed-route transit bus service. For this analysis the demand response mode does not encompass private taxis or private shared-ride van services.
- **Transportation Network Companies (TNC)** – Often referred to as ride-hail or rideshare services, these companies provide door-to-door for-hire transportation service in response to customer requests received through a smart phone app. The largest TNCs are Uber and Lyft, but there are other, smaller companies that serve specific markets. While providing a similar service to traditional taxis or limousines, TNCs treat their drivers as independent contractors, not employees, and the driver is responsible to provide their own vehicle.

This report is an update to similar reports released in March 2014 and October 2008. In addition, to updating all modes with the latest available information, this update adds a comparison to Transportation Network Companies (TNC) – also called ride-hail or rideshare - a new mode that was not included in the previous reports. The ride sharing industry started in 2011 in San Francisco, with a now defunct company called SideCar. While ride sharing services were not a common transit mode when the last update was issued, their use has increased dramatically over the past 5 years. In 2018 alone, it is estimated that customers took nearly 2 billion rides in the United States using ride-hailing services.

This report uses updated 2017 data not available for the previous report, but the results are similar to those reported in 2014.

For all modes both energy use and emissions are expressed in terms of units per passenger mile operated. The metrics used for energy intensity are passenger miles per diesel-equivalent gallon<sup>1</sup> (pass-mi/DEG) and Btu<sup>2</sup> per passenger mile (Btu/pass-mi).

The metrics used for all exhaust emissions are grams of emissions per passenger mile (g/pass-mi). This analysis includes emissions of carbon dioxide (CO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), and particulate matter (PM). Carbon dioxide is a greenhouse gas that has been linked to global warming. The most significant source of U.S. CO<sub>2</sub> emissions is the burning of fossil fuels such as coal, gasoline, diesel fuel and natural gas for electricity production, space heating, industrial processes, and transportation. The transportation sector is the largest contributor to total CO<sub>2</sub> emissions in the United States. NO<sub>x</sub> and PM are the two pollutants emitted by internal combustion engines of most

---

<sup>1</sup> This analysis compares modes that use different types of fuel, including diesel fuel, gasoline, and electricity. Energy use for all modes has been expressed in terms of a “diesel equivalent gallon” based on energy content. In this analysis one diesel equivalent gallon is defined as 138,000 Btu, the energy content of a gallon of “typical” highway diesel fuel in accordance with the National Transit Database data collection instructions. One gallon of typical highway gasoline contains 114,000 Btu, or 0.826 diesel equivalent gallons. One kilowatt hour of electricity is equal to 3,412 Btu, so there are 40.45 kwh of electricity in one diesel equivalent gallon.

<sup>2</sup> A British Thermal Unit (Btu) is a measure of energy. One Btu is equivalent to 0.000293 kwh.

significant concern. NO<sub>x</sub> combines in the atmosphere with volatile organic hydrocarbon, in the presence of sunlight, to produce ground level ozone, also known as smog. NO<sub>x</sub> also contributes to the formation of secondary PM particles in the atmosphere. Atmospheric PM – both directly emitted and secondary PM - has been shown to cause or exacerbate respiratory and cardiac disease and has been linked to an increased incidence of lung cancer and premature mortality.

All of the data used for this analysis is publicly available. As discussed below the major sources of data include the Federal Transit Administration's National Transit Database<sup>3</sup>; the Department of Transportation, Bureau of Transportation Statistics National Transportation Statistics; the National Household Travel Survey; and a Coach Industry Census conducted by John Dunham and Associates for the American Bus Association Foundation (ABAF). Data on TNC trips was taken from a 2018 study by Schaller Consulting.

Throughout the report, we highlight electric modes of travel in yellow and gasoline or diesel-powered modes of travel in blue, with motorcoaches highlighted in red.

---

<sup>3</sup> See Appendix A for the mode definitions used for the National Transit Database (NTD). The modes included in this analysis for which data is included in the NTD are: Commuter Rail, Demand Response, Electric Trolley Bus, Ferry Boat, Heavy Urban Rail, Light Rail, Urban Transit Bus, and Van Pool.

# 1 Results – Mode Comparisons

## 1.1 Fuel and CO<sub>2</sub> Emissions

Average energy use and CO<sub>2</sub> emissions by mode are shown in Table 1.1. Selected data from Table 1.1 is also summarized in Figures 1.1 – 1.3.

**Table 1.1 Energy Use and CO<sub>2</sub> Emissions, by Mode**

MODE	Pass-mi/Gal**			Btu/pass-mi			CO <sub>2</sub> g/pass-mi		
	low	AVG	high	low	AVG	high	low	AVG	high
Motorcoach	230.9	280.1	318.3	433.5	492.7	597.7	32.3	36.7	44.5
Car - Avg Trip	33.6	38.2	83.2	1,658.5	3,614.6	4,106.9	123.5	269.1	305.7
Car - 1 Person	25.4	28.9	62.9	2,192.3	4,777.8	5,428.6	163.2	355.7	404.1
Car Pool - 2 Person	50.8	57.8	125.9	1,096.2	2,388.9	2,714.3	81.6	177.8	202.1
TNC - Avg	24.2	27.4	59.8	2,307.7	5,029.3	5,714.3	171.8	374.4	425.4
Van Pool	43.3	107.1	162.5	849.3	1,289.0	3,259.9	63.2	95.9	242.6
Heavy Rail	63.0	190.8	250.7	551.5	723.4	2,366.9	97.1	127.3	416.6
Intercity Rail (AMTRAK)	75.8	89.8	155.9	885.2	1,536.2	1,820.9	155.8	141.7	135.6
Commuter Rail	50.8	97.0	204.4	700.7	1,422.3	2,730.1	113.2	167.2	271.7
Domestic Air Travel		56.6			2,437.9			181.5	
Light Rail	37.9	110.2	183.1	753.6	1,251.9	3,640.2	132.7	220.4	640.7
Trolley Bus	58.1	90.9	104.3	1,319.6	1,517.4	2,411.7	232.3	267.1	424.5
Transit Bus	11.2	33.7	57.5	2,395.7	4,091.8	11,763.4	177.7	283.2	860.2
Ferry Boat	3.8	11.9	24.0	5,810.4	11,616.6	47,269.1	432.6	863.8	3,519.0
Demand Response	2.3	9.0	24.3	5,677.7	15,280.7	59,515.5	422.6	1,100.8	3,867.3

\*\*Passenger miles per Diesel Equivalent gallon

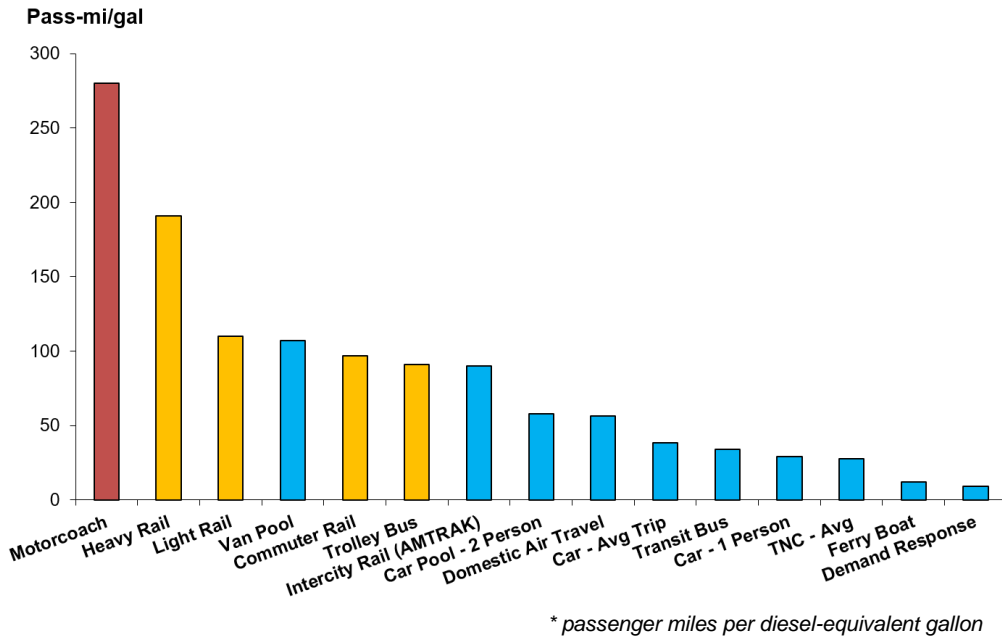
\* Miles per Diesel Equivalent gallon (based on energy content)

In Table 1.1 the high and low figures for motorcoaches are based on average passenger loads for different industry segments (charter/tour/sight-seeing versus commuter/airport/intercity fixed route service). For the other public modes, the high and low figures are based on the range of results from individual transit agencies in the NTD database. For private autos and the TNC mode the averages are based on U.S. fleet average fuel economy (23.9 MPG) while the high figures are based on the use of a “typical” sport utility vehicle (21 MPG) and the low figures are based on use of a hybrid car (52 MPG)<sup>4</sup>.

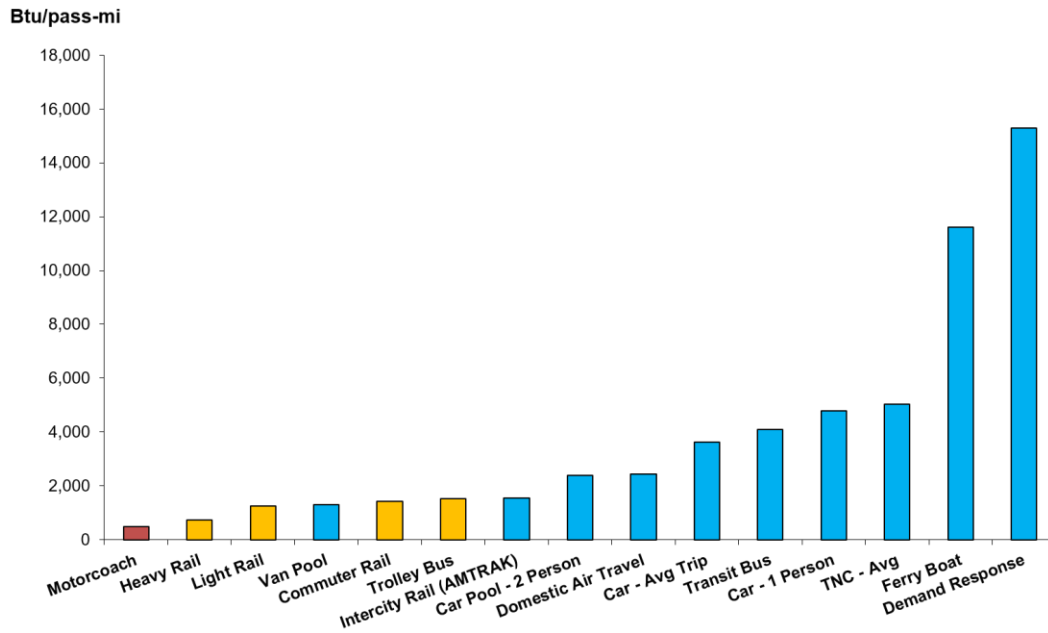
As shown, motorcoaches on average used 493 Btu/pass-mi and produced 37 g/pass-mi of carbon dioxide. On average, motorcoaches use the least amount of energy and produce the lowest carbon dioxide emissions per passenger mile of any of the transportation modes analyzed.

<sup>4</sup> There is no publicly available data on the distribution of vehicles used by TNC drivers. However, in the TNC business model the driver provides the vehicle, which is often the vehicle that they also use for personal travel. As such, it is reasonable to assume that the average fuel economy of the TNC fleet is similar to the average for the entire US light-duty fleet.

**Figure 1.1 Passenger-Miles per Gallon\* of Fuel, by Mode**

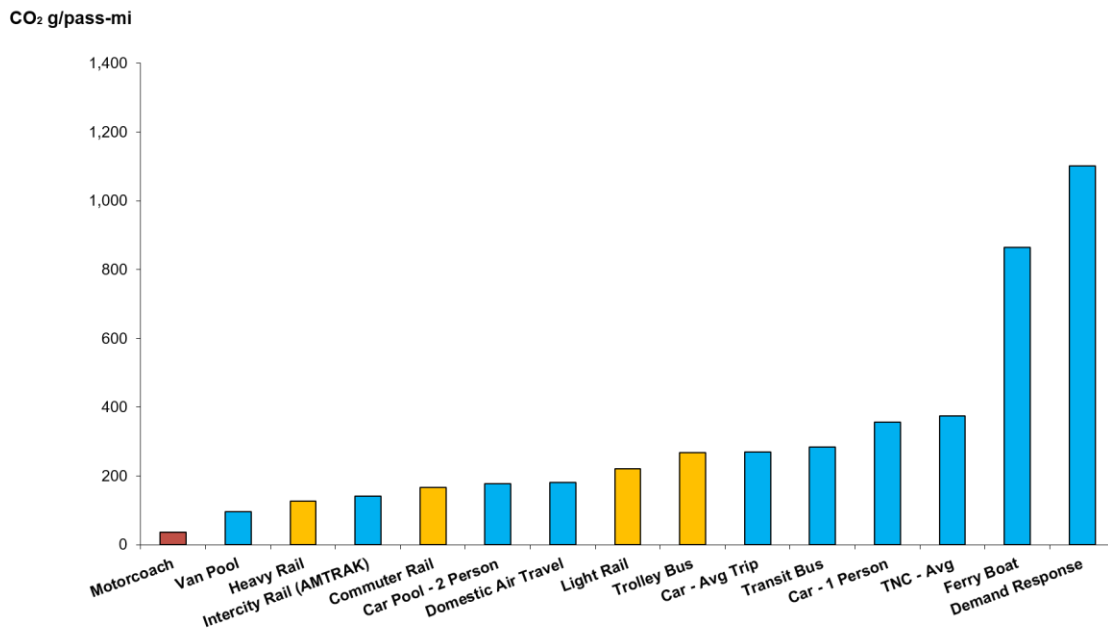


**Figure 1.2 Energy Use (Btu) per Passenger-Mile, by Mode**





**Figure 1.3 CO<sub>2</sub> Emissions (g) per Passenger-Mile, by Mode**



The most energy- and carbon dioxide-intensive mode is Demand Response at an average of 15,281 Btu/pass-mi and 1,101 g CO<sub>2</sub>/pass-mi. Van Pools on average produce two-and-a-half times as much carbon dioxide per passenger mile as motorcoaches, commuter rail produces more than four-and-a-half times as much, two-person car pools produce more than four-and-a-half times as much, and single commuters produce more than seven times as much.

On average TNCs are slightly less energy efficient than single commuting, using 5,029 Btu/pass-mi and emitting 374 g CO<sub>2</sub>/pass-mi. This is because on average TNCs only generate 0.95 passenger miles per vehicle mile driven, compared to one passenger mile per vehicle mile for single commuting<sup>5</sup>.

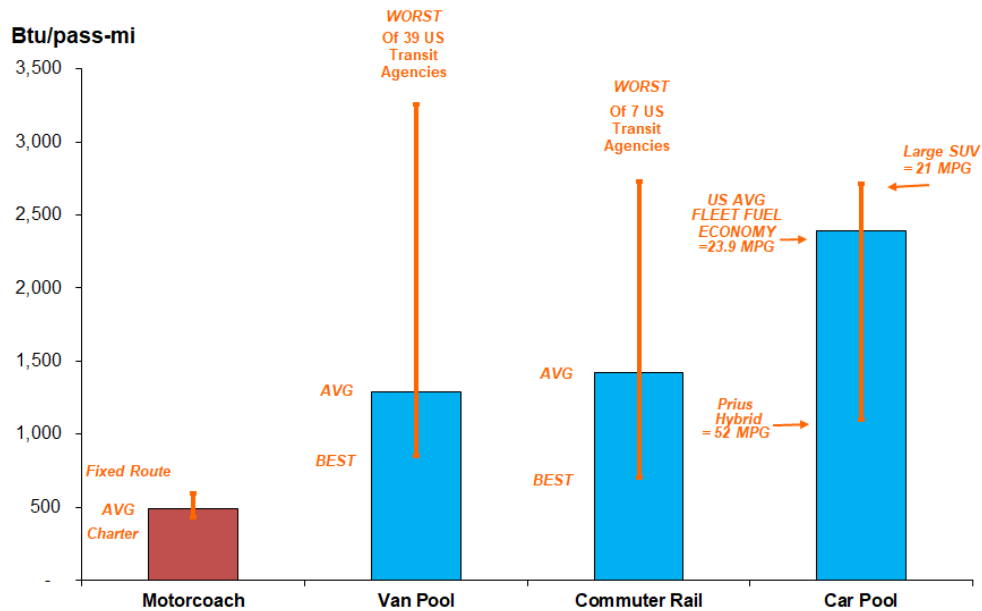
Note that the calculation of passenger miles per gallon of fuel and Btu/pass-mi for electric modes (heavy rail, light rail, trolley bus) is based on kilowatt hours of delivered electricity and therefore does not account for the total fuel energy used to generate the electricity. Comparison of these metrics for electric modes to gasoline and diesel modes is therefore somewhat misleading. The metric CO<sub>2</sub>/pass-mi does account for all carbon dioxide produced by electricity generation and therefore provides a more relevant comparison between electric and diesel/gasoline modes.

Figures 1.4 and 1.5 show the range of energy use and CO<sub>2</sub> emissions from selected modes. As shown, while some modes have favorable energy use and carbon dioxide emissions on average, there can be significant variation from location to location. For example, of thirty-nine agencies in the NTD database that operate van pools, the worst performer produced over twenty times as much CO<sub>2</sub> per passenger mile as the best performer, primarily based on lower average passenger loads.

<sup>5</sup> TNCs carry an average of 1.5 passengers per trip (not including the driver), but for every 5.2 miles driven with passengers the driver travels 3 miles empty, either waiting, or driving from the last drop-off to the next pick-up.

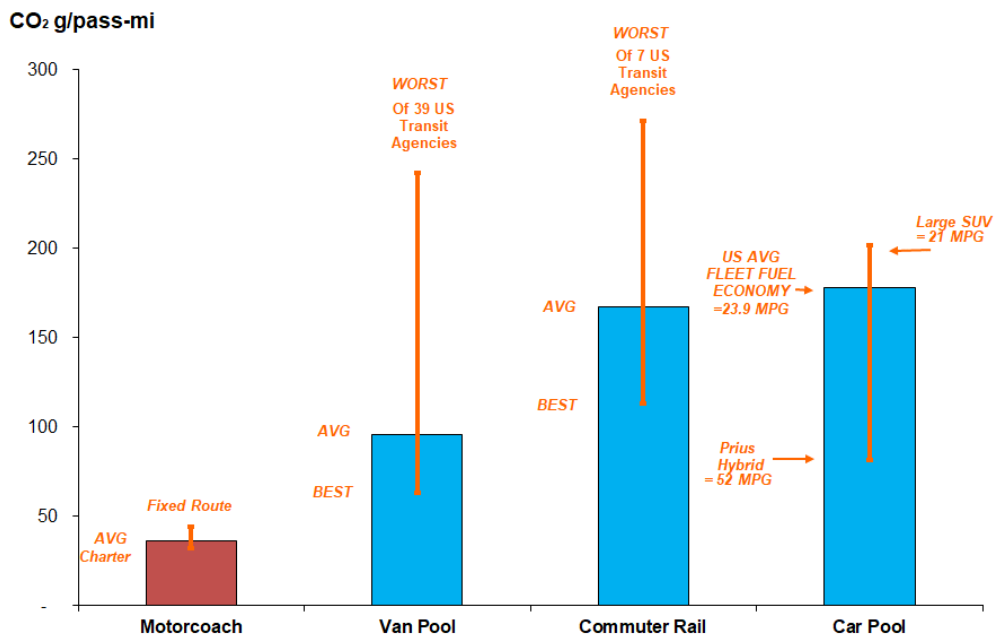
Likewise, actual emissions per passenger mile from shared rides and car pools are highly dependent on the vehicle used, with lower emissions from cars that have better average fuel economy.

Figure 1.4 Range of Energy Use (Btu) per Passenger-Mile, Selected Modes



NOTE: Btu/passenger-mile for Commuter Rail does not account for efficiency of electricity production

Figure 1.5 Range of CO<sub>2</sub> Emissions (g) per Passenger-Mile, Selected Modes



## 1.2 NO<sub>x</sub> and PM Emissions

NO<sub>x</sub> and PM emissions by mode are shown in Table 1.2. The data from Table 1.2 is also summarized in Figures 1.6, 1.7, 1.9, and 1.10.

**Table 1.2 NO<sub>x</sub> and PM Emissions, by Mode**

**EMISSIONS**

Mode	Vehicle	Source	Fleet Age	Fuel Used		Miles per Diesel Equivalent Gallon	Passenger-Miles per Diesel Equivalent Gallon	Emissions	
				(% by Energy Content)				(g/1,000 passenger-mi)	
				Gasoline	Diesel			PM	NO <sub>x</sub>
Car - 1 Person	US Average Car/Light Truck	A	2017 Fleet Avg	100%	0%	25.4	27.8	7.44	311.37
			2017 Model Year	100%	0%	25.4	27.8	2.31	44.61
TNC - .95 Person	US Average Car/Light Truck	B	2017 Fleet Avg	100%	0%	25.4	24.1	10.56	647.24
			2017 Model Year	100%	0%	25.4	24.1	3.58	101.61
Car Pool - 2 Person	US Average Car/Light Truck	A	2017 Fleet Avg	100%	0%	25.4	50.8	4.07	170.39
			2017 Model Year	100%	0%	25.4	50.8	1.27	24.41
Van Pool	8-12 Passenger Van	D	2017 Fleet Avg	100%	0%	13.2	107.1	1.24	75.78
			2017 Model Year	100%	0%	13.2	107.1	0.42	11.90
Transit Bus	40-ft Urban Transit Bus	D	2017 Fleet Avg	0%	100%	3.3	33.7	19.68	799.67
			2017 Model Year	0%	100%	3.3	33.7	1.56	87.79
Motorcoach	45-ft Motor Coach Bus	C	2017 Fleet Avg	0%	100%	6.4	277.0	10.95	253.78
			2017 Model Year	0%	100%	6.4	277.0	0.42	23.64
Demand Response	"Cut Away" Van 10-14,000 lb GVWR	D	2017 Fleet Avg	26%	74%	5.1	9.0	26.20	706.29
			2017 Model Year	26%	74%	5.1	9.0	2.94	201.75

Mode	Vehicle	Fleet Age	Fuel Used		Passenger-Miles per Diesel Equivalent Gallon (DEG)	Emissions	
			(% by Energy Content)			(g/1,000 passenger-mi)	
			Diesel	Electricity		PM	NO <sub>x</sub>
Ferry Boat	Harbor Craft	2017 Fleet Avg	100%	0%	11.9	1,578.07	37,557.32
Air	Jet aircraft	2017 Fleet Avg	100%	0%	58.7	37.48	631.69
Commuter Rail	Locomotive	2017 Fleet Avg	65%	35%	97.0	35.78	1,086.38
Intercity Rail (AMTRAK)	Locomotive	2016 Fleet Avg	85%	15%	89.8	43.29	1,501.97
Heavy Rail	Electric propulsion car	2017 Fleet Avg	0%	100%	190.8	11.09	49.85
Light Rail	Electric propulsion car	2017 Fleet Avg	0%	100%	110.2	19.19	86.31
Trolley Bus	Electric trolley	2017 Fleet Avg	0%	100%	90.9	23.27	104.64

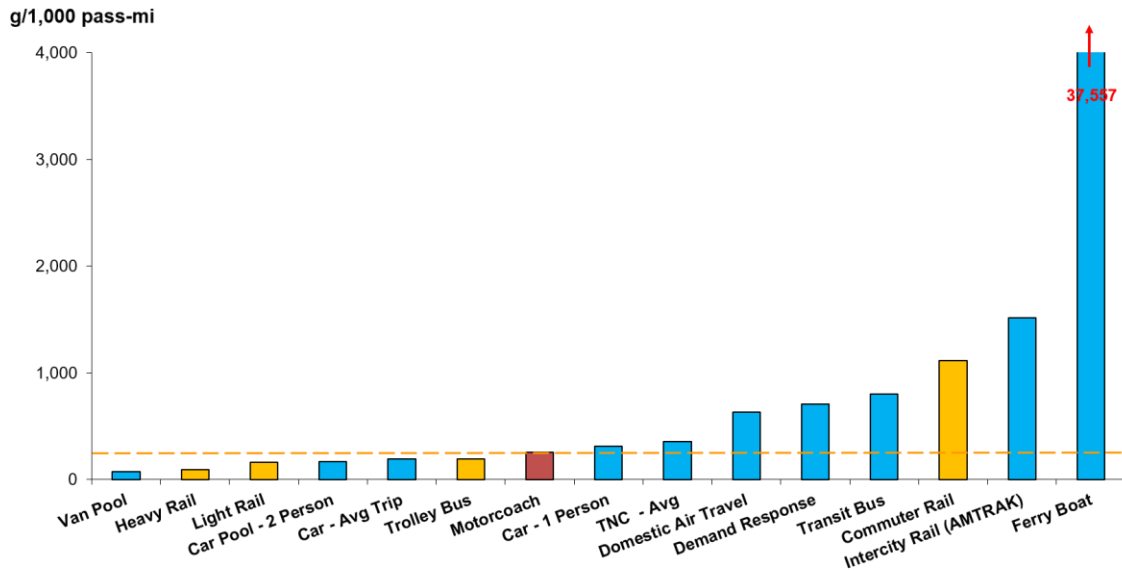
As shown in Figures 1.6 and 1.7, the existing fleet of motorcoaches currently produces, on average, 254 g/1,000 pass-mi NO<sub>x</sub> and 11 g/1,000 pass-mi PM. Only gasoline-powered cars and van pools, and average car trips, as well as the pure electric modes (Light rail, heavy rail, and trolley bus) have lower NO<sub>x</sub> emissions per passenger mile. With respect to PM, the gasoline-powered modes, including single and dual passenger commuters, TNCs, as well as car and van pools, are the only modes that have lower PM emissions per passenger-mile than the existing motorcoach fleet.

As illustrated in Figure 1.8, changes in U.S. EPA new vehicle and engine standards have reduced per-mile NO<sub>x</sub> emissions from new cars and per-mile PM and NO<sub>x</sub> emission from new motorcoaches compared to the current fleet average. As more and more new vehicles enter the

fleet and displace current vehicles in the next ten years NO<sub>x</sub> and PM emission per passenger mile from motorcoach, transit bus, and private vehicle modes will fall. Average NO<sub>x</sub> and PM emissions per passenger mile from brand new (2017 model year) vehicles are shown in in Figure 1.9 and 1.10 for on-road modes.

As shown, with the exception of NO<sub>x</sub> from van pools, brand new motorcoaches produce the lowest NO<sub>x</sub> and PM emissions per 1,000 passenger-miles of any mode, even when the other modes are also operated with brand new vehicles.

**Figure 1.6 Current Fleet Average NO<sub>x</sub> Emissions (g) per 1,000 Passenger Miles, by Mode**



**Figure 1.7 Current Fleet Average PM Emissions (g) per 1,000 Passenger Miles, by Mode**

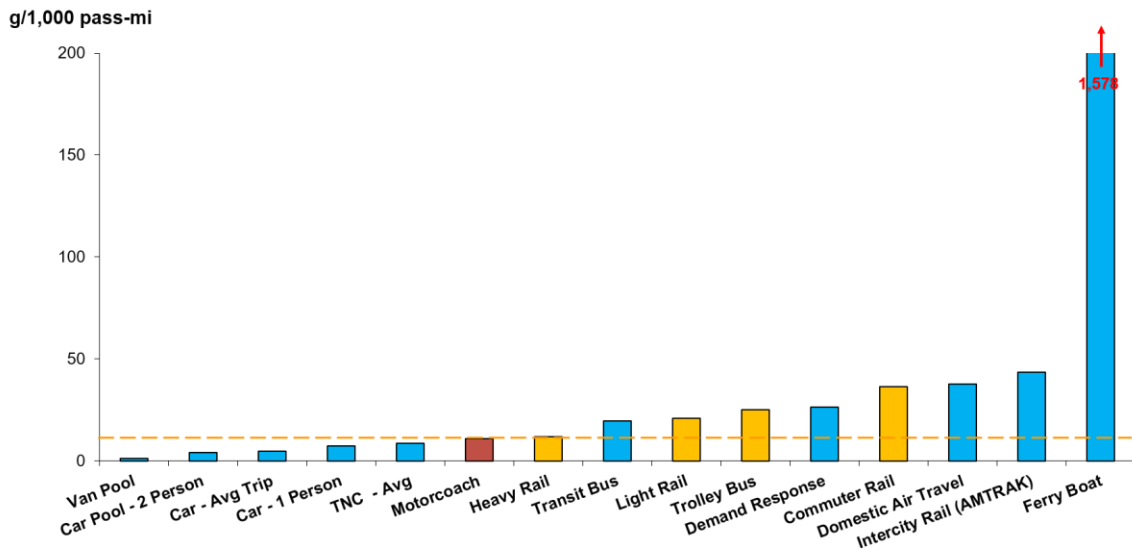


Figure 1.8 Change in NOx and PM Emissions for Cars and Motorcoaches

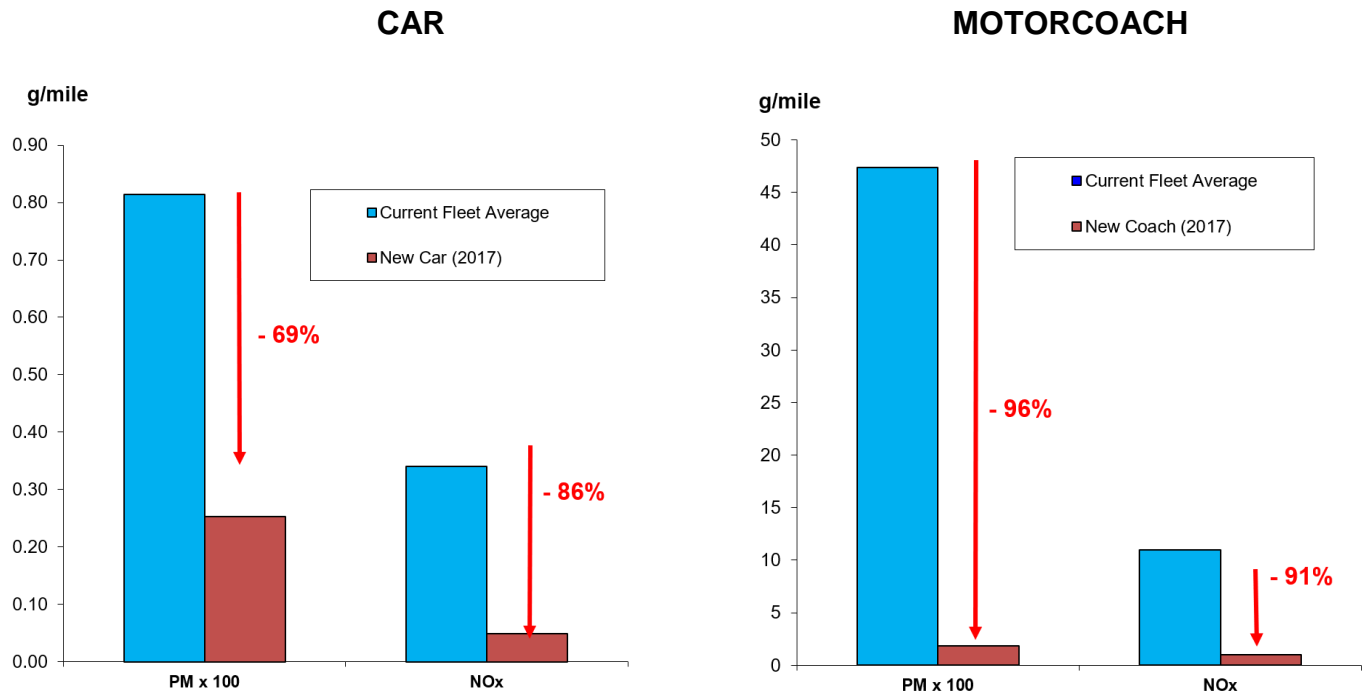


Figure 1.9 NOx Emissions (g) per 1,000 Passenger Miles from New (2017) Vehicles

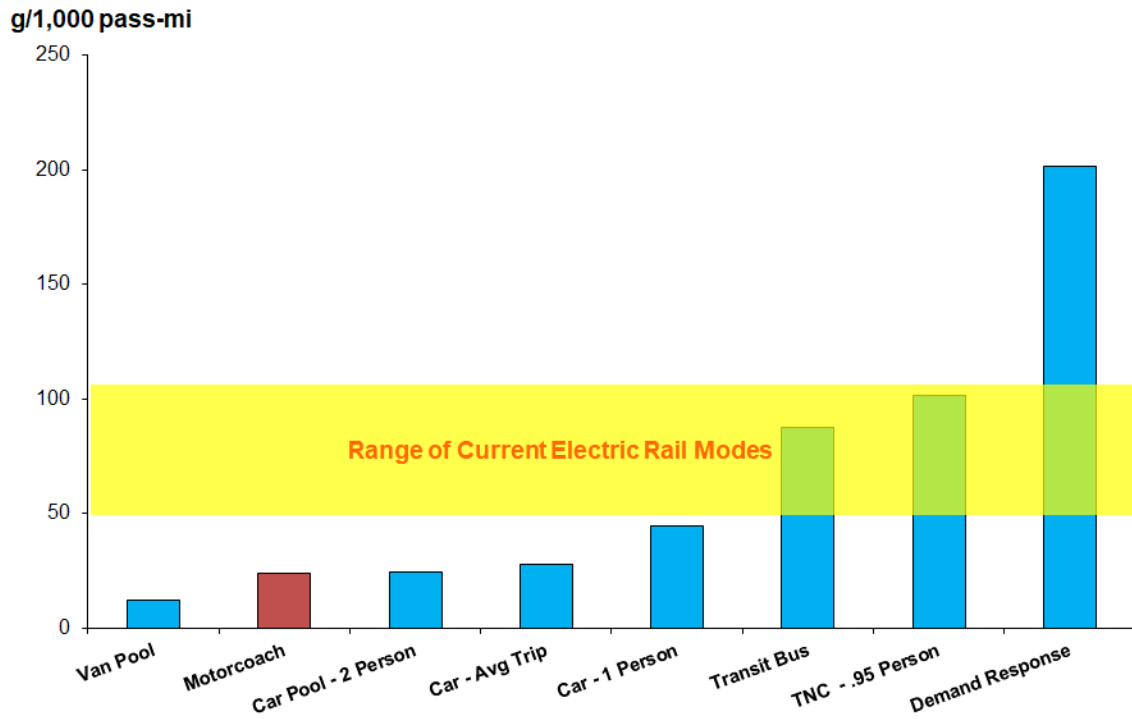
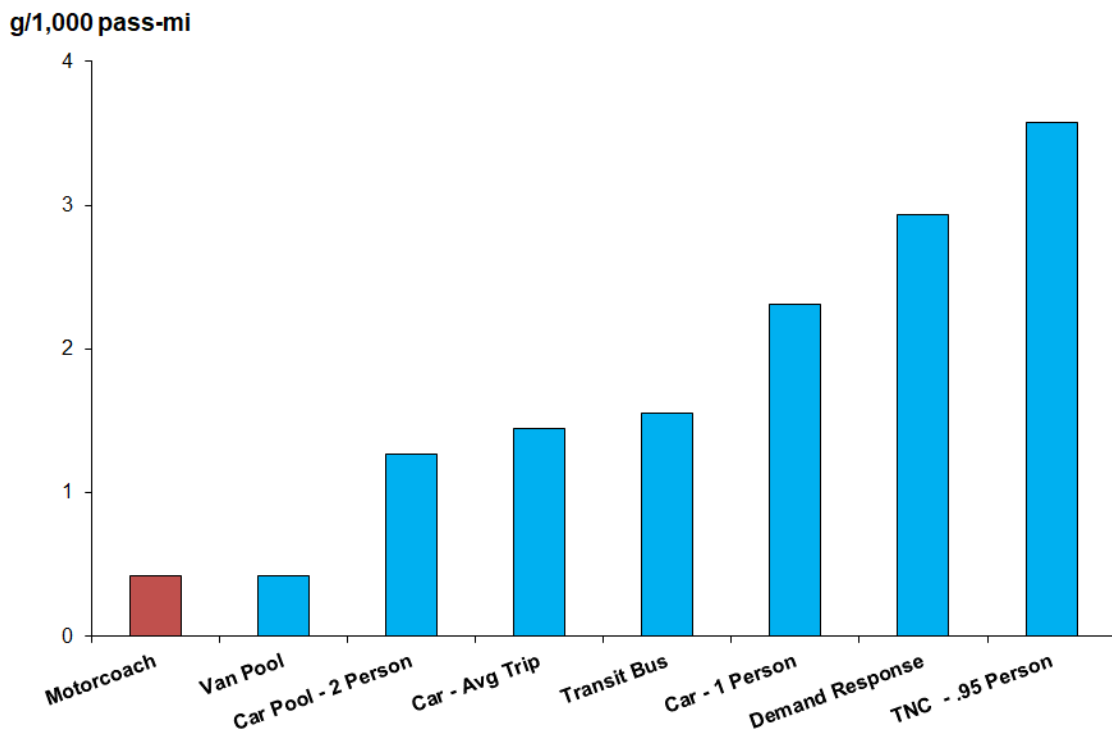


Figure 1.10 PM Emissions (g) per 1,000 Passenger Miles from New (2017) Vehicles



## 2 Data Sources

### 2.1 Fuel and CO2

For the commuter rail, demand response, electric trolley bus, ferry boat, heavy rail, light rail, urban transit bus, and van pool modes all energy use and operating data used in the analysis was taken from the 2017 National Transit Database Annual Service and Energy Consumption datasets (most recent data available). The Service database lists financial and operating data from virtually all transit agencies that receive federal operating and capital assistance. Each table contains rows of data specific to a group of vehicles operated in a single mode by a different U.S. transit agency.

**Table 2.1 Data Used for Transit Modes**

MODE	# of Agencies	# of Vehicles	Total (x000,000)	
			DEG*	Pass-Mi
Van Pool	39	7,196	5.5	587
Heavy Rail	14	9,479	92.0	17,556
Intercity Rail (AMTRAK)	1	259		
Commuter Rail	7	4,916	98.8	9,584
Light Rail	21	1,568	21.8	2,404
Trolley Bus	5	415	1.5	140
Transit Bus	314	40,585	477.1	16,090
Ferry Boat	12	76	32.5	387
Demand Response	219	6,104	23.0	207

\*\*Passenger miles per Diesel Equivalent gallon

\* Miles per Diesel Equivalent gallon (based on energy content)

The following fields from the 2017 Annual Energy Consumption dataset were used: ID, Mode, Vehicles Operated in Maximum Service (VOMS), Type of Service (TOS), and Sources of Energy (diesel, gasoline, LPG, LNG, CNG, kerosene, biodiesel, electricity, battery). For all liquid and gaseous sources of energy the table listing is total annual gallons of fuel used by that group of vehicles (for CNG it is diesel equivalent gallons of fuel) and for electric modes it is total annual kilowatt hours. The following fields from the 2017 Annual Service dataset were used: ID, Mode, VOMS, Actual Vehicle Revenue Miles, Actual Vehicle Revenue Hours, Unlinked Passenger Trips, and Passenger Miles.

ID, Mode, and VOMS were used to match data from each table for the same agency and vehicles. A number of individual rows of data were excluded because required data from one or more fields was missing. The excluded data represented less than five percent of all data in the database. Table 2.1 shows the number of separate agencies and vehicles included in the analyzed data set by mode.

For all other modes other than motorcoach, industry total data was taken from the U.S. Department of Transportation, Bureau of Transportation Statistics, *National Transportation Statistics*, which were downloaded from the web on May 20, 2019. Data was used from the following tables: Domestic Air Travel, Table 4-21 (2017 data); Personal Autos, Table 4-22 (2017 data). For each mode the following data was used from the appropriate table(s): Total Annual Vehicle Miles, Total Fuel Consumed (gallons for diesel and gasoline, and kwh for electricity),

and Total Annual Passenger Miles. For Intercity Rail (Amtrak) data was taken from Amtrak Fiscal Year 2017 Budget and Comprehensive Business Plan (vehicle miles and total diesel fuel use), and Amtrak Annual Report Fiscal Year 2017 (total electricity used for propulsion in kWh).

**Table 2.2 Motorcoach Industry Data Used (2017)**

Service Type	Motorcoach Service Mileage	Motorcoach Service Fuel Consumption	Miles per Gallon	Service Passenger Miles	Avg Passenger Load
Charter, Tour, Sightseeing	828,812,005	129,236,706	6.41	41,139,312,080	37.0
Fixed Route	643,322,995	100,313,394	6.41	23,159,627,820	36.0
<b>Industry Total (2017)</b>	<b>1,472,135,000</b>	<b>229,550,100</b>	<b>6.41</b>	<b>64,298,939,900</b>	<b>43.7</b>

Fixed Route = airport shuttle, commuter, intercity, special operations

In order to evaluate the difference between Amtrak North East Corridor operations and operations in all other Amtrak corridors, passenger miles for each type of operation were calculated by dividing total revenue by revenue per passenger mile. This analysis showed that for 2017 30% of all passenger miles were on the Northeast corridor. This percentage was applied to the 2017 Amtrak Fiscal Year 2017 Budget and Comprehensive Business Plan passenger mile data to calculate approximate passenger miles on the North East Corridor. The analysis also assumed that all electricity used by Amtrak in 2017 was for North East Corridor operations, and all diesel fuel used was for operations in other corridors.

The BTS data for passenger cars was used to calculate current fleet average fuel economy (23.9 miles per gasoline gallon, or 28.9 miles per diesel equivalent gallon). In order to evaluate the range of energy use per passenger mile from different vehicles additional data on new EPA combined city/highway fuel economy ratings was taken from [www.fueleconomy.gov](http://www.fueleconomy.gov) for the 2017 Toyota Prius C hybrid car and 2017 Jeep Grand Cherokee 4WD sport utility vehicle. This data shows that EPA estimates a Toyota Prius C will get 52 MPG in combined city/highway driving (59.8 miles per DEG) and that the and Jeep Grand Cherokee will get 21 MPG in combined city/highway driving (25.4 miles per DEG). These numbers were used to calculate minimum and maximum fuel use and CO<sub>2</sub> emissions per mile and per passenger mile from private autos.

Data on motorcoach miles operated and fuel consumed was taken from the *Motorcoach Industry Census 2017, A Study of the Size and Activity of the Motorcoach Industry in the United States and Canada in 2017*, June 5, 2019, which was conducted by John Dunham and Associates for the ABA Foundation. The data on coach industry mileage, fuel use, average load factor, and passenger miles used in the analysis is shown Table 2.2.

For the TNC mode, data on average passengers per trip and average loaded and unloaded trip length was taken from *The New Automobility: Lyft, Uber and the Future of American Cities*, Schaller Consulting, July 25, 2018. Based on analysis of responses to the 2017 National Household Travel Survey, and other data, the Schaller report estimates that for TNC trips the average number of passengers per trip (not including the driver) is 1.5, the average passenger trip length is 5.2 miles, and the average unloaded mileage between passenger trips is 3 miles. For TNCs this equates to an average of 0.95 passenger-miles per vehicle mile driven.



## 2.2 NO<sub>x</sub> and PM Emissions

NO<sub>x</sub> and PM emissions factors (grams per mile, g/mi) for all on-road vehicles (private autos, van pool vehicles, demand response vehicles, transit buses, and coach buses) were derived using U.S. EPA's MOVES2014b emissions model (available at <https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves>.) Major assumptions used when running the model include: no I/M Program, no anti-tampering program, and diesel sulfur content 15-ppm.

For this analysis we calculated current (2017) fleet average emissions factors, as well as average emissions factors for new (2017 model year) vehicles.

NO<sub>x</sub> and PM emissions factors (grams per gallon, g/gal) for all non-road vehicles (ferry boats, aircraft, diesel commuter rail, and diesel intercity rail) were taken from the U.S. EPA's *Documentation for Aircraft, Commercial Marine Vessel, Locomotive, and Other Nonroad Components of the National Emissions Inventory, Volume 1 – Methodology* (September 30, 2005). And ICAO Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories – Aircraft Emissions.

For aircraft, the factors are given by the ICAO as kilograms of emissions per “landing and take-off” (kg/LTO). To calculate g/gal factors we used an average figure of 850 kg (1,874 lbs) of fuel/LTO and 6.8 lbs/ gallon for the weight of fuel. The average LTO fuel usage is from data compiled by the IAO Committee on Aviation and Environmental Protection. This methodology may overstate the average emission from aircraft since relative emission during take-off and landing may be higher than during cruise. However, there is virtually no-published data on aircraft cruising emission that could be used to calculate a more accurate average figure.

For electric modes (electric commuter rail, electric intercity rail, heavy rail, light rail, and trolley bus), NO<sub>x</sub> and PM emission per kWh of electricity used were calculated based on the U.S. average emission rates for electric utilities in 2017. The NO<sub>x</sub> emission rate (lbs./MWh) was derived from the 2019 EIA Annual Energy Outlook (reference case) data tables for total electricity generation as well as emissions from the electric power sector. The PM emission rate (lbs./MWh) was calculated by dividing total electric utility PM from the 2014 EPA National Emissions Inventory (tons) by total electric utility generation (billion kWh) from EIA's Annual Energy Outlook. It should be noted that the 2014 EPA National Emissions Inventory (NEI) was the best PM information available at the time, since the 2017 NEI is not slated for release until March 2020.

Emission rates from electricity production vary significantly based on the fuel/process used. Hydroelectric plants produce virtually no NO<sub>x</sub> or PM emissions, while coal plants produce significant amount of these pollutants. The U.S. average rates used in this analysis may not be accurate for specific regions of the country due to different electric generation profiles. In particular, actual emissions rates will likely be lower in the Pacific Northwest and higher in the Midwest.

The emission factors used in this analysis are shown in Table 2.3

**Table 2.3 NO<sub>x</sub> and PM Emissions Factors Used**

**Emissions Factors**

Mode	Vehicle (MOVES Description)	Fleet Age	Emissions Rates				
			Source	Gasoline (g/mile)		Diesel (g/mile)	
				PM	NO <sub>x</sub>	PM	NO <sub>x</sub>
Passenger Car	Passenger Car	2017 Fleet Avg	A	0.0081	0.34		
		2017 Model Year	A	0.0025	0.05		
Van Pool	Passenger Truck	2017 Fleet Avg	A	0.0100	0.61		
		2017 Model Year	A	0.0034	0.10		
Transit Bus	Transit Bus	2017 Fleet Avg	A			0.2016	8.19
		2017 Model Year	A			0.0160	0.90
Motorcoach	Intercity Bus	2017 Fleet Avg	A			0.4738	10.98
		2017 Model Year	A			0.0183	1.02
Demand Response	Light Commercial Truck	2017 Fleet Avg	A	0.0094	0.58	0.0592	1.48
		2017 Model Year	A	0.0035	0.11	0.0058	0.44

Mode	Vehicle	Fleet Age	Emissions Rates				
			Source	Diesel (g/gal)		Electric (g/kwh)	
				PM	NO <sub>x</sub>	PM	NO <sub>x</sub>
Ferry Boat	Type 2 Harbor Craft	2012 Fleet Avg	C	18.78	446.93		
Air	Jet aircraft	2012 Fleet Avg	C,D,E,F	2.20	37.08		
Commuter Rail	Locomotive	2012 Fleet Avg	B, F	4.20	157.00	0.05	0.235
Intercity Rail (AMTRAK)	Locomotive	2012 Fleet Avg	B, F	4.20	157.00	0.05	0.235
Heavy Rail	Electric propulsion car	2014 Fleet Avg	F			0.05	0.235
Light Rail	Electric propulsion car	2014 Fleet Avg	F			0.05	0.235
Trolley Bus	Electric trolley	2014 Fleet Avg	F			0.05	0.235

### 3 Calculation Methodology

#### 3.1 Energy Use and CO<sub>2</sub> Emissions

The first step in the analysis was to convert Total Annual Fuel used by each mode to units of Diesel Equivalent Gallons (DEG), using Equation 1 for liquid fuels and Equation 2 for electricity<sup>6</sup>:

$$\text{Annual DEG} = \text{Fuel Energy Content (Btu/gal)} \div \text{Diesel Energy Content (Btu/gal)} \times \text{Annual Fuel (gal)}$$

*Equation 1*

$$\text{Annual DEG} = \text{Annual Energy (kwh)} \times 3,412 \text{ Btu/kwh} \div \text{Diesel Energy Content (Btu/gal)}$$

*Equation 2*

The energy content of the relevant fuels is shown in Table 3.1

The energy intensity metrics presented in the analysis were calculated using Equations 3 and 4:

$$\text{Passenger Miles per DEG (Pass-mi/DEG)} = \text{Annual Passenger Miles} \div \text{Annual DEG}$$

*Equation 3*

$$\text{Btu per Passenger Mile (Btu/pass-mi)} = \text{Annual DEG} \times 138,000 \text{ Btu/DEG} \div \text{Annual Passenger Miles}$$

*Equation 4*

For all liquid and gaseous fuels carbon dioxide emissions per gallon of fuel burned were calculated using Equation 5 and total carbon dioxide emissions for each mode were calculated using Equation 6. The fuel properties used in Equation 5 are shown in Table 3.1. Carbon dioxide emissions per passenger mile were calculated using Equation 7.

$$\text{CO}_2 \text{ (g/gal)} = 44 (\text{CO}_{2\text{mw}}) \div 12 (\text{C}_{\text{mw}}) \times 453.6 \text{ g/lb} \times \text{Fuel Density (lb/gal)} \times \text{Fuel Wt \% Carbon}$$

*Equation 5*

$$\text{Total CO}_2 \text{ (g)} = \text{Sum (CO}_2 \text{ (g/gal)} \times \text{Annual Gallons)}_{\text{All fuels}} + \text{Electricity (kwh)} \times 600.6 \text{ g CO}_2\text{/kwh}^7$$

*Equation 6*

$$\text{CO}_2 \text{ per Passenger Mile (g/pass-mi)} = \text{Total CO}_2 \text{ (g)} \div \text{Annual Passenger Miles}$$

*Equation 7*

---

<sup>6</sup> Note that CNG fuel usage in the NTD database was already expressed in units of DEG

<sup>7</sup> This is the U.S. industry average for electricity production in 2015 per Report # DOE/EIA-0383(2015). Depending the mix of fuels for electricity production regional values could be lower or higher.

Fuel	Energy (Btu/gal)	Density (lb/gal)	Weight % Carbon	CO <sub>2</sub> g/gal
Diesel	138,000	7.1	87%	10,274
Gasoline	114,000	6.0	85%	8,482
LPG	91,330	4.4	82%	6,042
LNG	73,500	3.2	75%	4,017
CNG (DEG)	138,000	6.0	75%	7,517
Kerosene	135,000	6.9	86%	9,935
B20 Biodiesel	135,613	7.0	84%	9,748

**Table 3.1 Fuel Properties Used in the Analysis**

### 3.2 NO<sub>x</sub> and PM Emissions

For on-road vehicle/modes powered by diesel fuel and gasoline, NO<sub>x</sub> and PM emissions per passenger-mile (g/pass-mi) were calculated using equation 8 below. This analysis assumed that all passenger cars and van pool vehicles are powered by gasoline and that all transit buses and coach buses are powered by diesel fuel.

$$\text{Emissions (g/pass-mi)} = \text{Emissions Rate (g/mi)} \times \text{mi/DEG} \div \text{pass-mi/DEG}$$

*Equation 8*

For Demand Response mode approximately 26 percent of fuel used nationally is gasoline or natural gas and 74 percent is diesel. For this mode, average emissions were calculated using equation 9.

$$\text{Emissions (g/pass-mi)} = (0.74 \times \text{Diesel (g/pass-mi)}) + (0.26 \times \text{Gasoline (g/pass-mi)})$$

*Equation 9*

For non-road vehicles/modes powered by diesel fuels, NO<sub>x</sub> and PM emissions per passenger-mile (g/pass-mi) were calculated using equation 10.

$$\text{Emissions (g/pass-mi)} = \text{Emissions Rate (g/DEG)} \div \text{pass/mi/DEG}$$

*Equation 10*

For vehicle/modes powered by electricity, NO<sub>x</sub> and PM emissions per passenger-mile (g/pass-mi) were calculated using equation 11.

$$\text{Emissions (g/pass-mi)} = \text{Emissions Rate (g/kWh)} \times 40.45 \text{ kWh/DEG} \div \text{pass-mi/DEG}$$

*Equation 11*

Commuter Rail and Intercity Rail vehicles can be powered by either electricity or diesel. For these modes, average emission was calculated using equation 12.

$$\text{Emissions (g/pass-mi)} = (\% \text{ Diesel} \times \text{Diesel g/pass-mi}) + (\% \text{ Electricity} \times \text{Electricity g/pass-mi})$$

*Equation 12*

## APPENDIX A

### National Transit Database Mode Definitions

#### **Buses (Urban Transit Bus)**

Vehicle Type: Rubber-tired passenger vehicles powered by diesel, gasoline, battery or alternative fuel engines contained within the vehicle. Vehicles in this category do not include articulated, double-decked, or school buses.

#### **Commuter Rail**

A transit mode that is 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 (UZAs), 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.

It does not include:

- Heavy rail (HR) rapid transit, or
- Light rail (LR) / streetcar transit service.

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. Predominantly commuter a service means that for any given trip segment (i.e., distance between any two stations), more than 50 percent of the average daily ridership travels on the train at least three times a week. Only the predominantly commuter service portion of an intercity route is eligible for inclusion when determining commuter rail (CR) route miles.

#### **Demand Response**

Shared use transit service operating in response to calls from passengers or their agents to the transit operator, who schedules a vehicle to pick up the passengers to transport them to their destinations.

#### **Ferryboats**

Vehicle Type: Vessels for carrying passengers and / or vehicles over a body of water. The vessels are generally steam or diesel-powered conventional ferry vessels. They may also be hovercraft, hydrofoil and other high-speed vessels.

Intercity ferryboat (FB) 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. Predominantly commuter a service means that for any given trip segment (i.e., distance between any two piers), more than 50 percent of the average daily ridership travels on the ferryboat on the same day. Only the predominantly commuter service portion of an intercity route is eligible for inclusion when determining ferryboat (FB) route miles.

## APPENDIX A

### **Heavy Rail (Heavy Urban Rail)**

A transit mode that is 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 (ROW) from which all other vehicular and foot traffic are excluded
- Sophisticated signaling, and
- High platform loading.

### **Heavy Rail Passenger Cars**

Vehicle Type: Rail cars with:

- Motive capability
- Driven by electric power taken from overhead lines or third rails
- Configured for passenger traffic

Usually operated on exclusive right-of-way (ROW).

### **Light Rail**

A transit mode that typically is an electric railway with a light volume traffic capacity compared to heavy rail (HR). It is characterized by:

- Passenger rail cars operating singly (or in short, usually two car, trains) on fixed rails in shared or exclusive right-of-way
- Low or high platform loading, and
- Vehicle power drawn from an overhead electric line via a trolley or a pantograph.

### **Light Rail Vehicles**

Vehicle Type: Rail cars with:

- Motive capability
- Usually driven by electric power taken from overhead lines
- Configured for passenger traffic

Usually operating on exclusive rights-of-way (ROW).

### **Trolleybus (Electric Trolley Bus)**

A transit mode comprised of electric rubber-tired passenger vehicles, manually steered and operating singly on city streets. Vehicles are propelled by a motor drawing current through overhead wires via trolleys, from a central power source not onboard the vehicle.

### **Trolleybuses**

Vehicle Type: Rubber-tired, electrically powered passenger vehicles operated on city streets drawing power from overhead lines with trolleys.

### **Vanpool**

A transit mode comprised of vans, small buses and other vehicles operating as a ride sharing arrangement, providing transportation to a group of individuals traveling directly between their homes and a regular destination within the same geographical area. The vehicles shall have a

## **APPENDIX A**

minimum seating capacity of seven persons, including the driver. For inclusion in the NTD, it is considered mass transit service if it:

- Is operated by a public entity, or
- Is one in which a public entity owns, purchases, or leases the vehicle(s).

Vanpool(s) (VP) must also be in compliance with mass transit rules including Americans with Disabilities Act (ADA) provisions and be open to the public and that availability must be made known. Other forms of public participation to encourage ridesharing arrangements, such as:

- The provision of parking spaces
- Use of high occupancy vehicle (HOV) lanes
- Coordination or clearing house service, do not qualify as public vanpools.

### **Vanpool Service**

Transit service operating as a ride sharing arrangement, providing transportation to a group of individuals traveling directly between their homes and a regular destination within the same geographical area. The vehicles shall have a minimum seating capacity of seven persons, including the driver. Vanpool(s) must also be open to the public and that availability must be made known. Does not include ridesharing coordination.