Comparison of Energy Use & CO_2 Emissions From Different Transportation Modes

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Introduction

This analysis is intended to evaluate the environmental performance of Highway Motor Coach operations, by comparing the energy use and carbon dioxide (CO_2) emissions of motor coaches with the energy use and CO_2 emissions of other common transportation vehicles/modes.

Including motor coaches, a total of twelve transportation modes are included in the analysis, as follows:

- **Highway Motor Coach** - According to the American Bus Association vehicles in the motor coach 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 motor coach mode includes motor coach buses used for private charters, tours, scheduled inter-city service, and commuter service between a central city and adjacent suburbs.
- **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 40 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.

For all modes both energy use and CO_2 emissions are expressed in terms of units per passenger mile operated. The metrics used for energy intensity are passenger miles per diesel-equivalent gallon[1] (pass-mi/DEG) and btu[2] per passenger mile (btu/pass-mi).

The metric used for CO_2 emissions is grams of emissions per passenger mile (g/pass-mi). Carbon dioxide is a greenhouse gas that has been linked to global warming. The transportation sector is a significant contributor to total man-made CO_2 emissions from the burning of fossil fuels. For the transportation sector fuel use and CO_2 emissions are linked and are generally proportional for each travel mode.

Most 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[3]; the Department of Transportation, Bureau of Transportation Statistics,

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[1] 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. 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.

[2] A British Thermal Unit (btu) is a measure of energy. One btu is equivalent to 0.000293 kwh.

[3] 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.

National Transportation Statistics; and a Coach Industry Census conducted by Nathan Associates for the American Bus Association (ABA) and supplemented by additional targeted surveys of selected coach operators by ABA staff. For most modes the data is from calendar year 2005, the most recent year available.

1 Results of Analysis

Average energy use and CO_2 emissions by mode are shown in Table 1.1. Selected data from Table 1.1 is also summarized in Figures 1.1 – 1.3.

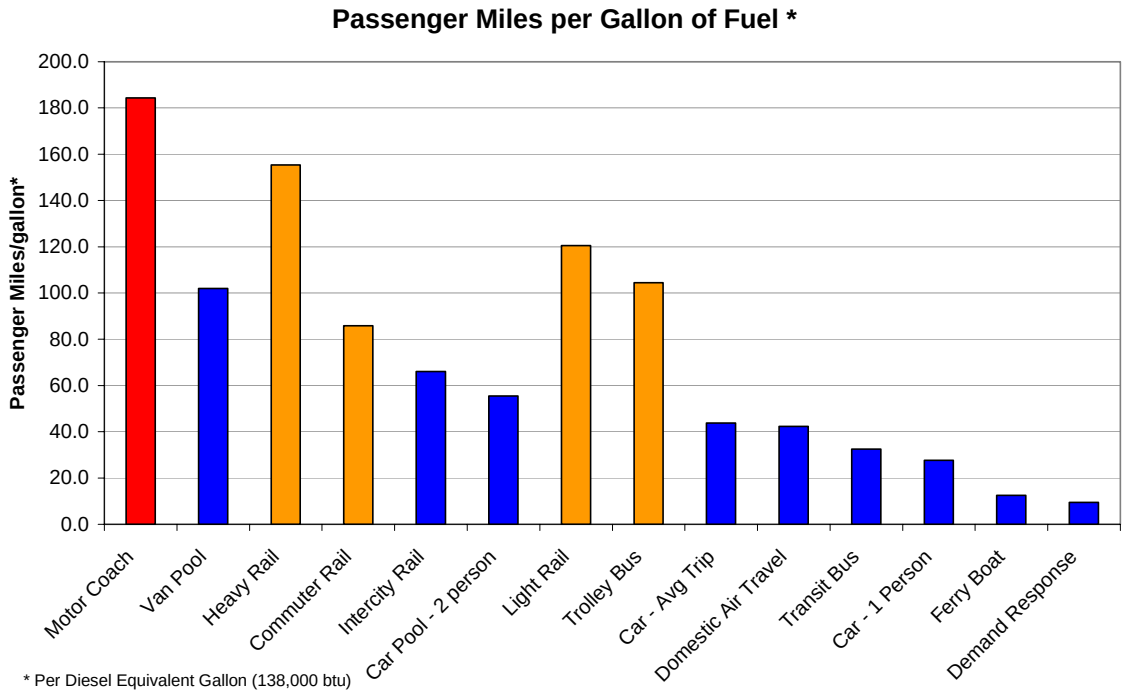
MODE	Pass-mi/Gal**			Btu/pass-mi			CO2 g/pass-mi		
	low	AVG	high	low	AVG	high	low	AVG	high
Motor Coach	160.0	**184.4**	201.5	685	**749**	862	51	**56**	64
Van Pool	28.2	**101.9**	194.6	709	**1,354**	4,891	53	**101**	364
Heavy Rail	47.0	**155.3**	200.6	688	**889**	2,939	121	**156**	517
Commuter Rail	58.2	**85.8**	249.1	1,127	**1,608**	2,372	108	**177**	286
Intercity Rail	52.4	**66.0**	175.7	785	**2,091**	2,635	138	**179**	196
Car Pool - 2 person	41.2	**55.4**	111.4	1,239	**2,492**	3,353	92	**185**	250
Light Rail	14.4	**120.5**	214.9	642	**1,146**	9,596	113	**202**	1,689
Trolley Bus	53.4	**104.4**	122.1	1,130	**1,321**	2,582	199	**233**	454
Car - Avg Trip	32.5	**43.8**	88.0	1,569	**3,154**	4,244	117	**235**	316
Domestic Air Travel		**42.3**			**3,260**			**243**	
Transit Bus	3.9	**32.5**	126.8	1,088	**4,245**	35,123	81	**299**	2,615
Car - 1 Person	20.6	**27.7**	55.7	2,478	**4,983**	6,706	184	**371**	499
Ferry Boat	2.0	**12.6**	31.0	4,447	**10,987**	68,632	331	**818**	5,109
Demand Response	1.4	**9.5**	48.4	2,849	**14,562**	99,468	212	**1,063**	7,401

**Passenger miles per Diesel Equivalent gallon

Table 1.1 Energy Use and CO_2 Emissions, by Mode

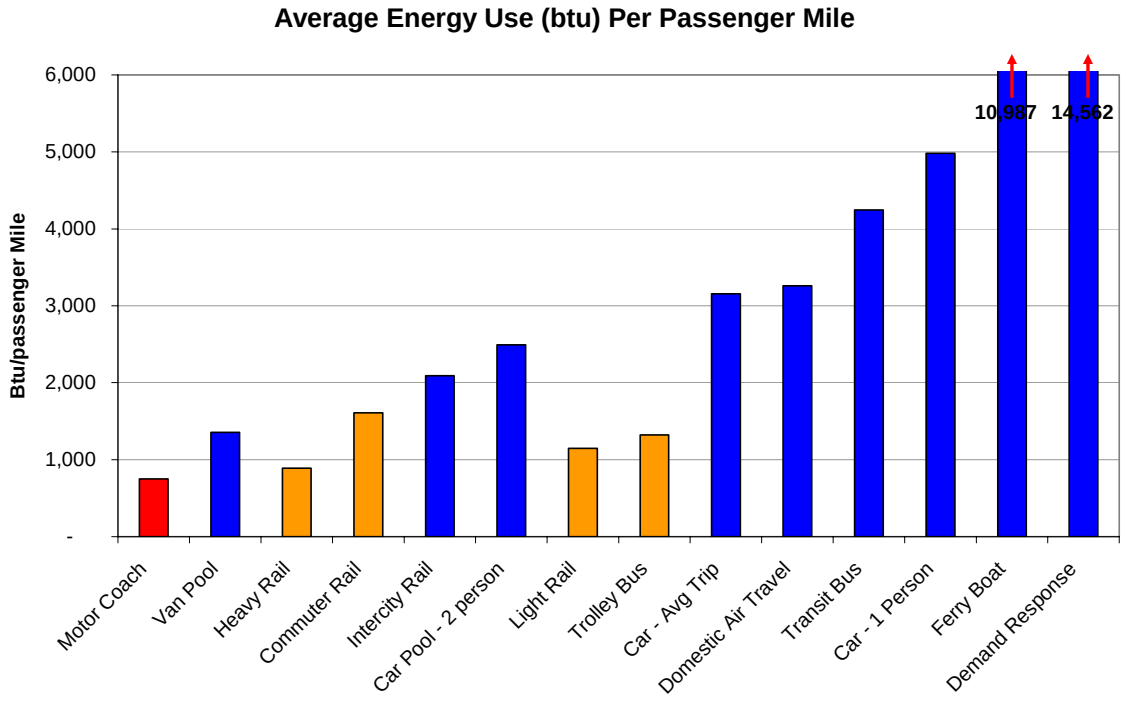
In Table 1.1 the high and low figures for motor coaches are based on averages for different industry segments (charter, tour, scheduled service, commuter service). For the other public modes the high and low figures are based on the range of results from individual transit agencies in the NTD database. For private autos the averages are based on US fleet average fuel economy (22.9 MPG) while the high figures are based on the use of a "typical" sport utility vehicle (17 MPG) and the low figures are based on use of a hybrid car (46 MPG).

As shown, Motor Coaches on average used 749 btu/pass-mi and produced 56 g/pass-mi of carbon dioxide. Motor coaches use the least amount of energy and produce the lowest carbon dioxide emissions per passenger mile of any of the transportation modes analyzed.



*NOTE: Gallon equivalents for **rail and trolley modes** does not account for efficiency of electricity production*

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



*NOTE: Btu/passenger mile for **Rail and Trolley modes** does not account for efficiency of electricity production*

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

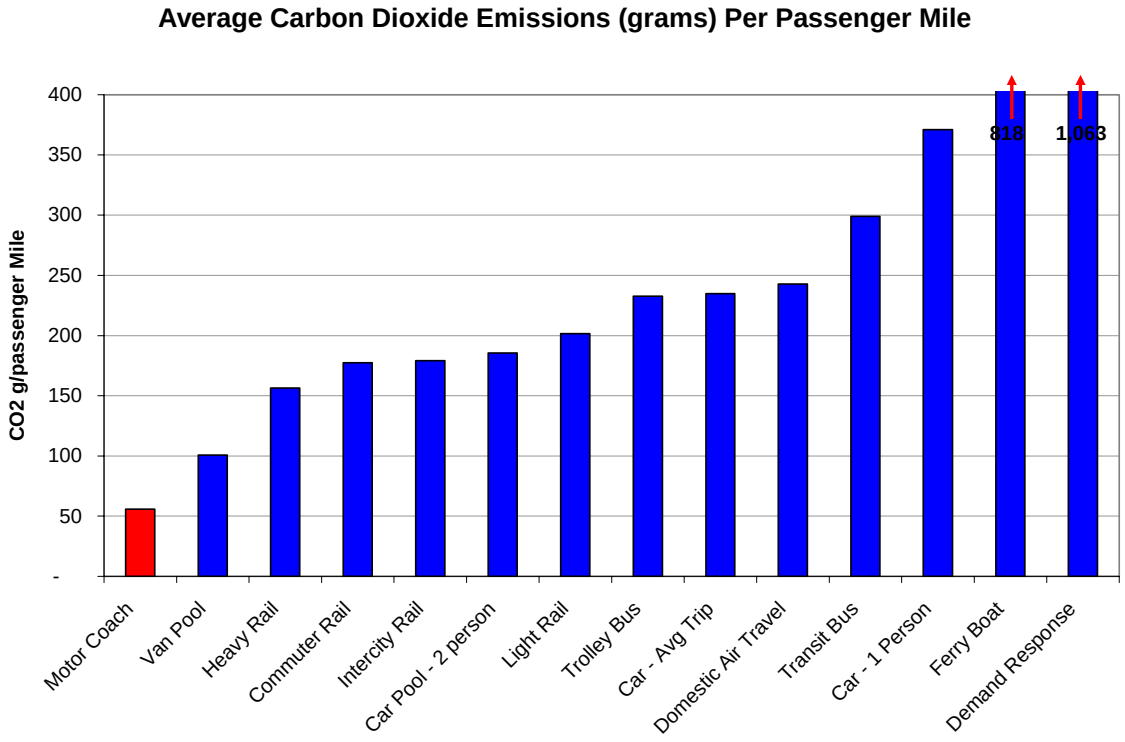


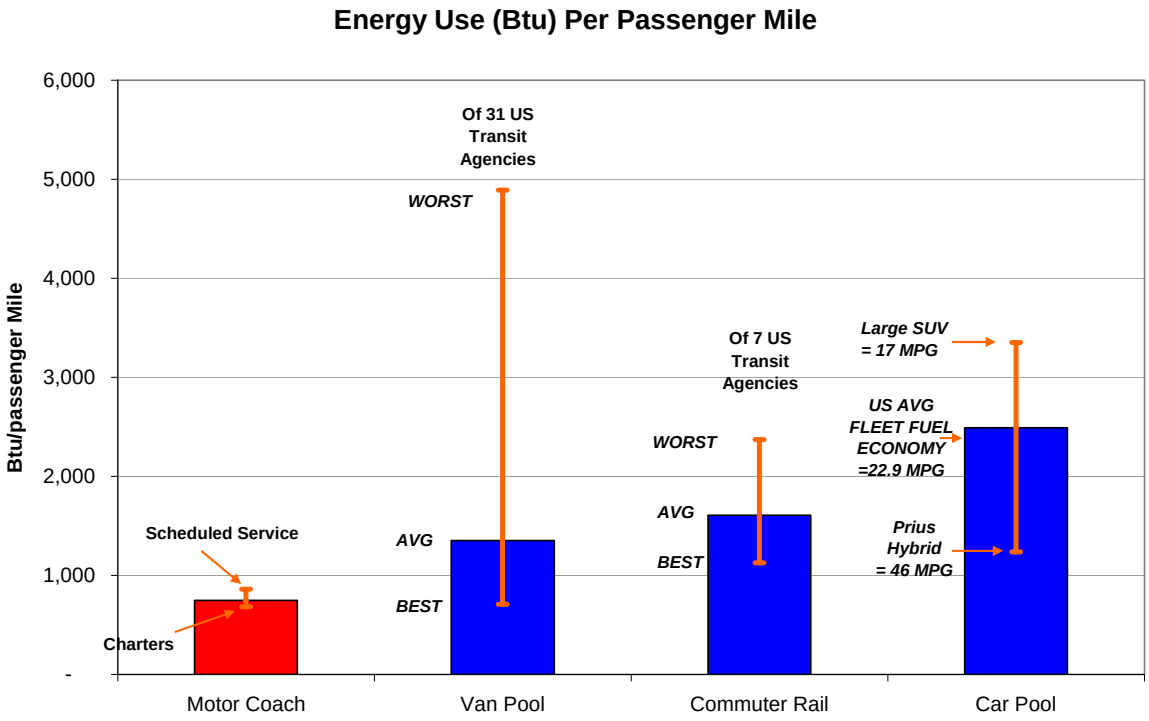
Figure 1.3 CO_2 Emissions (g) per Passenger-Mile, by Mode

The most energy- and carbon dioxide-intensive mode is Demand Response at 14,562 btu/pass-mi and 1,063 g CO_2/pass-mi. Van Pools on average produce twice as much carbon dioxide per passenger mile as motor coaches, commuter rail produces three times as much, two-person car pools produce four times as much, and single commuters produce almost seven times as much.

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_2/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_2 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-one agencies in the NTD database that operate van pools the worst performer produced almost seven times as much CO_2 per passenger mile as the best performer, primarily based on lower average passenger loads.

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.



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

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

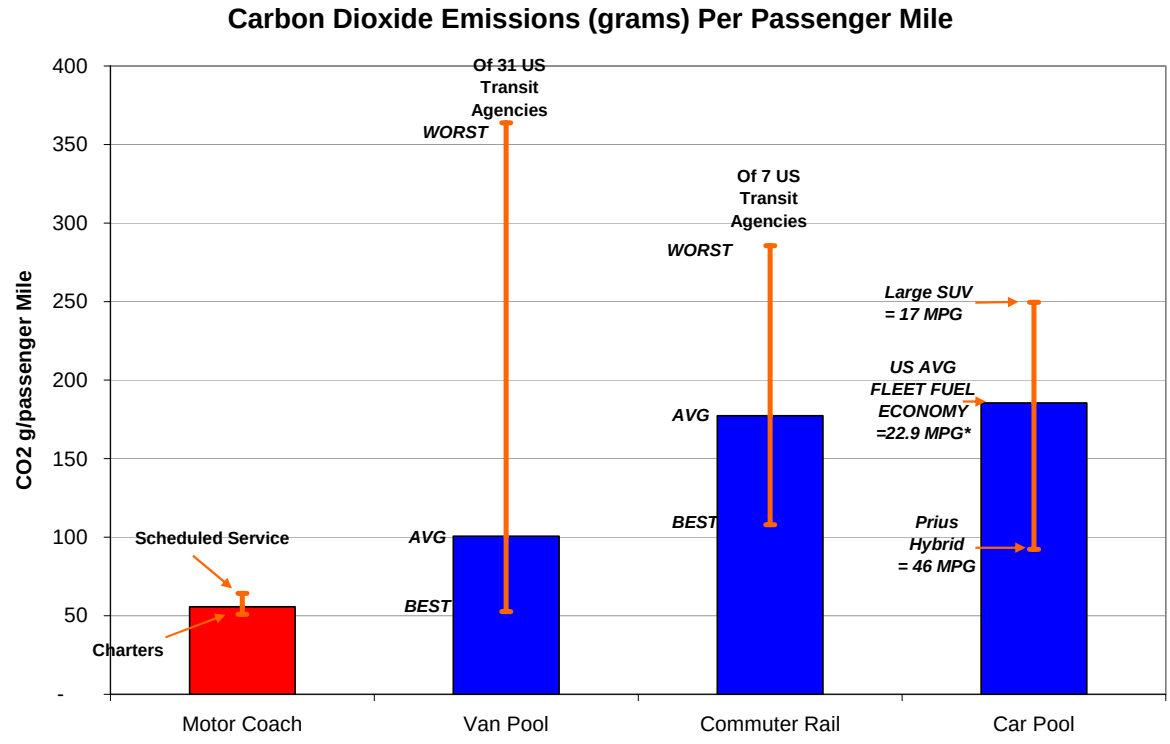


Figure 1.5 Range of CO_2 Emissions (g) per Passenger-Mile, Selected Modes

2 Data Sources

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 2005 National Transit Database, Tables 17 and 19. This 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	31	4,131	3.7	378
Heavy Rail	14	8,931	92.8	14,407
Commuter Rail	7	4,581	96.3	8,261
Light Rail	26	1,166	13.7	1,650
Trolley Bus	4	482	1.7	173
Transit Bus	353	42,184	523.9	17,030
Ferry Boat	7	57	25.1	315
Demand Response	238	5,690	24.0	227

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

The following fields from Table 17 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 Table 19 were used: ID, Mode, VOMS, Annual Vehicle Revenue Miles, Annual Vehicle Revenue Hours, Unlinked Passenger Trips, and Annual 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 one 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 Motor Coach, 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 March 20, 2007. Data was used from the following tables: Domestic Air Travel, Table 4-21 (2005 data); Personal Autos, Table 4-22 (2005 data); Intercity Rail (AMTRAK) Tables 4-26 (passenger miles and fuel, 2001 data) and 4-18 (train miles, 2001 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.

In order to evaluate the difference between AMTRAK North East Corridor operations and operations in all other AMTRAK corridors additional data was taken from the *AMTRAK Monthly Performance Report for November 2006*, February 2, 2007, page A-1.3, including: Revenue and Revenue per Passenger Mile for each type of operation. Passenger miles for each type of operation were calculated by dividing total revenue by revenue per passenger mile. This analysis showed that year-to-date as of November 2006 29% of all passenger miles were on the Northeast corridor. This percentage was applied

to the 2001 BTS passenger mile data to calculate approximate passenger miles on the North East Corridor. The analysis also assumed that all electricity used by AMTRAK in 2001 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 (22.9 miles per gasoline gallon, or 27.9 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 for the Toyota Prius hybrid car and Jeep Grand Cherokee and GMC Yukon sport utility vehicles. This data shows that EPA estimates a Toyota Prius will get 46 mpg in combined city/highway driving (55.7 miles per DEG) and that both the and Jeep Grand Cherokee and GMC Yukon will get 17 mpg in combined city/highway driving (20.6 miles per DEG). These numbers were used to calculate minimum and maximum fuel use and CO_2 emissions per mile and per passenger mile from private autos.

Data on Motor Coach miles operated and fuel consumed was taken from the *Motor Coach Industry Census 2005, Second Benchmarking Study of the Motor Coach Industry in the United States and Canada*, September 2006, which was conducted by Nathan Associates for the American Bus Association. To calculate passenger miles by industry segment (charter, tour, scheduled, commuter, other) individual survey responses were further analyzed and additional data was gathered from selected survey respondents to calculate a weighted-average load factor (average passengers per trip) by industry segment, which was used to calculate total passenger miles (passenger miles = total miles x load factor). For Scheduled coach service the published metric for Greyhound Lines, Inc. average load factor was used. This was taken from Greyhound's *2005 10K Annual Report*, page 16. Greyhound operated approximately 43% of the industry total Scheduled service in that year. The data on coach industry mileage, fuel use, average load factor, and passenger miles used in the analysis is shown Table 2.2.

Service Type	Total Motorcoach Mileage	Total Motorcoach Fuel Consumption	Miles per Gallon	Avg Passenger Load	Passenger Miles
Charter	1,124,000,000	212,000,000	5.30	38.0	42,712,000,000
Scheduled	656,000,000	107,000,000	6.13	26.1	17,121,600,000
Commuter	275,000,000	52,000,000	5.29	37.0	10,175,000,000
Tour	185,000,000	34,000,000	5.44	32.8	6,068,000,000
Other	150,000,000	28,000,000	5.36	25.0	3,750,000,000
Industry Total	**2,390,000,000**	**433,000,000**	**5.52**	**33.4**	**79,826,600,000**

"Commuter" consists of contract and private commuter services.
"Other" consists of airport shuttle, sightseeing, and other services.

Table 2.2 Coach Industry Data Used (2004)

3 Calculation Methodology

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[4]:

Annual DEG = Fuel Energy Content (btu/gal) ÷ Diesel Energy Content (btu/gal) x Annual Fuel (gal)

Equation 1

Annual DEG = Annual Energy (kwh) x 3,412 btu/kwh ÷ 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:

Passenger Miles per DEG (Pass-mi/DEG) = Annual Passenger Miles ÷ Annual DEG

Equation 3

Btu per Passenger Mile (btu/pass-mi) = Annual DEG x 138,000 btu/DEG ÷ 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.

CO_2 (g/gal) = 44 ($CO2_{mw}$) ÷ 12 (C_{mw}) x 453.6 g/lb x Fuel Density (lb/gal) x Fuel Wt % Carbon

Equation 5

Total CO_2 (g) = Sum (CO_2 (g/gal) x Annual Gallons)$_{All\ fuels}$ + Electricity (kwh) x 600.6 g CO_2/kwh[5]

Equation 6

CO_2 per Passenger Mile (g/pass-mi) = Total CO_2 (g) ÷ Annual Passenger Miles

Equation 7

[4] Note that CNG fuel usage in the NTD database was already expressed in units of DEG

[5] This is the US industry average for electricity production in 2007, per Report # DOE/EIA-0383(2007). Depending the mix of fuels for electricity production regional values could be lower or higher.

Table 3.1 Fuel Properties Used in the Analysis

Fuel	Energy (btu/gal)	Density (lb/gal)	Weight % Carbon	CO_2 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

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.

Ferryboat
A transit mode comprised of vessels carrying passengers and / or vehicles over a body of water that are generally steam or diesel powered.
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

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.

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.

APPENDIX A

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 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.