TRANSPORTATION AND CLIMATE CHANGE: PUBLIC TRANSIT AND CLIMATE CHANGE

PART 2 OF 3

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PART 1

INTRODUCTION

This report is the second of three from a research initiative addressing the role of urban travel currently and going forward, in meeting urban mobility needs and in efforts to reduce the impacts of transportation on climate change. The first report, “Transportation’s Role in Climate Change,” established the context by focusing on the contributions of different types of transportation on greenhouse gas (GHG) emissions. This report, “Public Transit and Climate Change,” focuses more specifically on the influence of public transportation. The final report in the series, “The Path Forward: Urban Mobility in a Climate Change Sensitive Post-COVID World,” explores the challenges and opportunities for urban travel going forward as demographic, economic, technological, and cultural/political conditions evolve.

> *The U.S. is lagging behind many other nations when it comes to choosing more efficient travel modes. Before the pandemic, only 5% of U.S. commuters used public transportation, according to a survey by the U.S. Census Bureau, a figure that collapsed to 2.5% in 2021. In the U.K., by contrast, nearly 16% of commuters in 2020 relied on rail or bus.*[1]

[1] Source: Skylar Woodhouse and Saleha Mohsin, "EV Hype Overshadows Public Transit as a Climate Fix," bloomberg.com, *Bloomberg*, January 25, 2023. https://www.bloomberg.com/news/articles/2023-01-25/public-transit-gets-left-behind-in-us-climate-change-conversation.

There are two dominant goals for public transportation. First, it serves to provide mobility for individuals who are unable to secure or do not choose alternative means of travel. The provision of public transportation is intended to enable economic and social opportunities for individuals who otherwise might be severely impeded. The motivation is that this is both humane treatment and provides economic participation in society by facilitating self-sufficiency and potential for constructive contributions to society. The second fundamental goal is to capture the economies of scale of "mass" transportation. The use of large vehicles accommodating group travel can provide resource efficiencies, including savings in energy use, space use, and physical infrastructure, resulting in reduced resource use and reduced transportation impacts, including GHG reduction goals. This report explores that issue, and by documenting current conditions, provides guidance for the path forward addressed in the subsequent report.

Many media and literary references to public transportation are prefaced with words like "sustainable," "green," "environmentally friendly," "energy efficient," or other adjectives indicating to the reader that public transportation is a more environmentally benign means of travel. In prior decades, this translated into reduced energy use and reduced emissions contributing to ozone and smog. More recently, sensitivity centers on the production of GHG emissions that contribute to climate change. Support for public transportation among the public and policymakers is influenced by this perception of transit being a more environmentally sustainable travel mode, and it is among the virtues cited as public subsidies are solicited.[2] This report looks more closely at that perception, exploring historic, current, and anticipated future conditions that influence GHG emissions as they are in turn influenced by public transportation.

Figure 1 characterizes ways to evaluate the energy intensiveness of various means of travel. For this graphic, energy intensiveness is a surrogate measure of GHG emissions. There are a multitude of ways to measure and define the energy consequences of various means of travel. Understanding the interrelationships between the mode and energy use, as well as data availability, are prerequisites to using each possible measure. This report focuses primarily on operating energy intensiveness and transportation energy impacts as affected by public transportation's influence on land use.

2 Ben Welle, Anna Kustar, Thet Hein Tun, Cristina Albuquerque, "Post Pandemic, Public Transport needs to get back on track to meet global climate goals" World Resources Institute, 2023. https://www.wri.org/insights/current-state-of-public-transport-climate-goals (accessed 12 Oct. 2024).

FIGURE 1: TRANSPORTATION ENERGY USE MEASUREMENT CONCEPTS[3]

Complexity and Uncertainty	Basic Energy Use Component	Possible Measures of Energy Use
	Propulsion energy per vehicle mile	Operating energy intensiveness
	Average number of occupants	
	Fuel production and delivery	Energy intensiveness
	Facility and maintenance energy	Life cycle energy intensiveness
	Construction/recycling energy	
	Vehicle manufacturing/recycling energy	
	Mode of access	Modal energy intensiveness
	Network circuity	
	Travel and location behavior changes	Transportation energy impact
	Non-travel energy consequences of transportation	Total energy impact

3 Framework based on significant modifications to framework in "Urban Transportation and Energy: The Potential Savings of Different Modes," Congress of the United States, Congressional Budget Office, cbo.gov, December 1977. https://www.cbo.gov/sites/default/files/95th-congress-1977-1978/reports/1977_12_urban.pdf (accessed August 2023).

PART 2

OPERATING ENERGY INTENSIVENESS

Operating energy intensiveness is the most used and simplest measure of energy use because the required data are relatively available. It is also typically the largest component of total energy impact and the most narrowly defined measure because it includes only the energy required to move the vehicle and power the vehicle amenities (lighting, heating, air conditioning, etc.). This measure is typically represented as propulsion energy per vehicle mile, per passenger mile, or per passenger trip. The miles per gallon (or per kilowatt-hours) that a vehicle can achieve is widely used to describe vehicular fuel economy. To equate across fuel types, measures can be equilibrated to express use in British Thermal Units (BTUs). To specifically address GHG emissions per unit of fuel use requires conversions that reflect the GHG emissions levels associated with different fuel types, blends, and sources. These, as well as the GHG levels for variously sourced electricity, are best evaluated at the local level to capture the large variation across contexts and over time.

Table 1 shows energy use per passenger mile for U.S. transportation modes for 2019. This national average data is published in the Department of Energy, *Transportation Energy Data Book: Edition 40*. Technology performance and vehicle occupancy levels reflect pre-COVID-19 conditions.

TABLE 1: PASSENGER TRAVEL AND ENERGY USE, 2019[A]

		Number of vehicles (thousands)	Vehicle miles (millions)	Passenger miles (millions)	Load factor (persons/ vehicle)	BTU per vehicle mile	BTU per passenger mile	Energy use (trillion BTU)
Cars		108,547.70	1,374,305	2,116,430	1.5	4,292	2,787	5,898.7
Personal trucks		126,769.30	1,293,053	2,353,356	1.8	5,845	3,212	7,558.1
Motorcycles		8,596.30	19,688	23,626	1.2	2,844	2,370	56
Demand response[b]		73.2	1,629	1,823	1.1	17,377	15,527	28.3
Buses	Transit	73.2	2,566	19,311	7.5	34,877	4,634	89.5
	Intercity[d]	[c]	[c]	[c]	[c]	[c]	[c]	39.6
	School[d]	708.8	[c]	[c]	[c]	[c]	[c]	97.1
Air	Certificated route[e]	[c]	6,269	754,981	120.4	270,081	2,243	1,693.1
	General aviation		[c]	[c]	[c]	[c]	[c]	227.1
Recreational boats		12,691.8	[c]	[c]	[c]	[c]	[c]	213.3
Rail	Intercity (Amtrak)	0.4	279	6,479	23.2	34,987	1,506	9.8
	Transit	13.5	843	19,859	23.6	20,040	851	16.9
	Commuter	7.2	382	12,928	33.9	53,587	1,583	20.5

Source: Table 2.13, 3. Stacy C. Davis and Robert G. Boundy, "Transportation Energy Data Book Edition 40," U.S. Department of Energy, Oak Ridge National Laboratory, tedb.ornl.gov, February 2022, https://tedb.ornl.gov/wp-content/uploads/2022/03/TEDB_Ed_40.pdf (September 2023).

Notes: a) Only end-use energy was counted for electricity. b) Includes passenger cars, vans, and small buses operating in response to calls from passengers to the transit operator who dispatches the vehicles. c) Data are not available. d) Energy use is estimated. e) Only domestic service and domestic energy use are shown on this table. These energy intensities may be inflated because all energy use is attributed to passengers–cargo energy use is not taken into account.

While these Department of Energy figures are often considered an authoritative source, there are multiple other estimates for measures of energy efficiency that can vary based on the nature of data collection, the sample or population size, the referenced geography, the quality of source data, the reference period, and other factors. It is not uncommon to see differences. For public transportation, data estimates are dependent upon the multiple hundreds of transit authorities and their contractors compiling and correctly submitting the necessary information. The smallest properties are often exempt from reporting, and analysts use estimates to extrapolate for national totals. Thus, estimates are known to vary across sources and over time. Issues such as average trip length may not be fully reflective of actual conditions during the COVID-19 pandemic period, as exposure risk and staffing shortages may have impacted data collection for some properties, leading to estimating errors in passenger miles of travel and vehicle occupancy.

Operating energy intensiveness incorporates two main components: the operating efficiency of the vehicle/technology and a measure of modal capacity or use. The most common measure is BTUs per passenger mile, as that reflects the average occupancy of the vehicle's capacity over the travel path. Some analysts use measures per trip, as they believe that reflects the energy cost of transportation for carrying out an activity regardless of the length of travel required to access that activity. Measures of energy use per "seat" or per "place" can provide insight into the inherent efficiency of the technology. A more meaningful analysis for understanding the emissions and GHG impacts of travel should reflect the actual operating context by incorporating a measure of average use.

Empirical data to support operating energy intensiveness are derived from actual use and, as such, reflect the technology performance across the context in which it operates. It does not necessarily reflect the operating energy intensiveness comparisons that would be most appropriate if comparative technologies were operated in similar contexts. In the comparison of transit with personal vehicle travel, this means that empirical operating energy intensiveness data compare transit use in the predominately urban and peak period operating environments—where much of the transit mileage is logged—with average private vehicle use that reflects average light vehicle operations over all locations and times. Some analysts recognize the need to adjust or acknowledge this difference in carrying out comparisons; however, technology comparisons often go unqualified. This is discussed more in subsequent sections.

From Table 1, the occupancy weighted average performance of personal vehicles, including cars, trucks, and motorcycles, was 3007 BTUs per passenger mile. This compares to primary transit mode energy intensiveness for operations of 4,635 BTUs for transit buses, 895 for transit rail, and 1,583 for commuter rail with a pre-COVID-19 weighted average of 2,436 BTUs per passenger mile. These findings reflect the fact that the bus mode, based on propulsion energy use, is more energy intensive than average auto vehicle use. Transit's overall propulsion efficiency advantage is enabled by energy efficient heavy rail operations. High ridership and relatively efficient operations in legacy heavy rail systems are responsible for the energy efficient competitiveness of U.S. transit operations in the pre-COVID era. In 2019 the New York metro area accounted for approximately 43 percent of transit trips and passenger miles and approximately 29 percent of the total BTUs for transit agencies submitting data to the National Transit Data (NTD) system.[4] Excluding New York, the calculation of BTUs per transit passenger mile for public transit results in the modal BTU per passenger mile of 3,034 or higher than the national personal vehicle average of 3,007. Removing the top 10 more intensively used transit agencies would result in a

4 Federal Transit Administration, "2019 National Transit Database," https://www.transit.dot.gov/ntd/data-product/2019-database-files, (accessed October 2024).

significant efficiency advantage for auto travel in the vast majority of U.S. metropolitan areas. For example, analysis of the 2019 NTD data set shows that the top 10 metro areas ranked by passenger trips (New York, Chicago, Los Angles, San Francisco, Washington D.C., Boston, Philadelphia, Seattle, Atlanta, and Miami) carry approximately 75 percent of transit trips, 77 percent of passenger vehicle miles, provide 51 percent of revenue service miles, and consume 67 percent of transit agency BTU consumption.[5]

The sensitivity of the national calculations to operations in the top metro areas is a reflection of both how significant those areas are in national totals and an example of the dependence of energy use on operating context–both when analyzing the energy intensiveness of the system operation and how it is used.

The following data describe the characteristics and energy use of U.S. transit over the past several years. As transit buses have added amenities over the decades, especially air conditioning and heating, auxiliary energy uses have become more significant.[6] Power for lighting, cameras and information systems, fare collection, Wi-Fi, kneeling, ramps or lifts, communications, etc., add to the total vehicle energy consumption. Vehicle weight has also increased to accommodate the amenities and the structural modifications to enable low floors and lifts or ramps. More recently, sensitivity to efficiency, hybrid powertrains, and lighter-weight materials have provided efficiency improvements. Tables 2, 3, and 4 provide recent trend data revealing the diversity of fuel types and their evolution.

The decline in diesel vehicles is noticeable in the 10-year period with increases in hybrid vehicles and alternatively fueled vehicles.[7] Battery electric remains included in the other category and constitutes a very small segment of the overall bus fleet in 2020.

Table 3 shows the trends in fuel consumption for the bus fleet. Table 4 shows the fuel sources for the range of public transit modes.

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5 2019 NTD data was analyzed using estimates of PM, VRM, and BTUs for agencies that did not provide full data by using averages per passenger trip for similarly sized properties.

6 Nikiforos Zacharof, Orkun Özener, Stijn Broekaert, Muammer Özkan, Zissis Samaras, Georgios Fontaras, "The impact of bus passenger occupancy, heating ventilation and air conditioning systems on energy consumption and CO2 emissions," *Energy*, Volume 272, 2023, https://doi.org/10.1016/j.energy.2023.127155.

7 "Declining Diesel: What Has Caused The Sharp Fall Of Diesel Vehicles?" Good Car Bad Car, https://www.goodcarbadcar.net/declining-diesel-what-has-caused-the-sharp-fall-of-diesel-vehicles/ (accessed 17 Oct. 2024).

TABLE 2: BUS VEHICLE AND COMMUTER BUS VEHICLE POWER SOURCES (A,B), PERCENT

Year on Jan. 1	CNG, LNG, and Blends	Diesel	Hybrid	Gasoline	Biodiesel	Other (c)	Total
2010	18.6%	65.8%	7.0%	0.7%	7.7%	0.2%	100.0%
2011	18.6%	63.5%	8.8%	0.8%	7.9%	0.4%	100.0%
2013	20.0%	58.4%	13.2%	1.1%	7.0%	0.3%	100.0%
2014	16.8%	56.3%	17.9%	1.0%	7.7%	0.3%	100.0%
2015	23.1%	50.8%	17.3%	1.1%	7.6%	0.2%	100.0%
2016	26.1%	48.0%	17.1%	1.2%	7.4%	0.2%	100.0%
2017	29.9%	42.3%	15.8%	1.7%	9.9%	0.4%	100.0%
2018	28.5%	41.8%	20.9%	1.5%	6.4%	0.9%	100.0%
2019	29.9%	41.8%	17.7%	1.6%	8.2%	0.8%	100.0%
2020	30.2%	42.7%	18.8%	1.5%	5.6%	1.4%	100.0%

(a) Sample data only; "Public Transportation Vehicle Database," American Public Transportation Association, 2013 - 2023, https://www.apta.com/research-technical-resources/transit-statistics/vehicle-database/ (September 2023). Not projected to national total.

(b) Includes bus rapid transit through 2013 and commuter bus until 2013.

(c) Includes battery-electric, hydrogen, and propane powered buses.

TABLE 3: BUS (A) FUEL CONSUMPTION (MILLIONS OF GALLONS)

Year	Diesel Fuel	Compressed Natural Gas (b)	Gasoline	Liquefied Natural Gas	Propane (Liquid Petroleum Gas)	Biodiesel	Other (c)	Total (Fuels Reported Only)
2010	435.4	126.2	8.1	23.0	---	43.5	3.5	639.7
2011	455.1	131.1	8.9	21.6	---	51.1	3.9	671.7
2012	439.0	127.3	12.5	19.6	---	56.5	4.0	658.9
2013	427.5	134.9	12.9	17.6	6.3	66.2	0.4	666.0
2014	413.6	146.0	11.7	15.4	6.2	38.1	1.2	632.2
2015	415.0	158.9	11.1	11.3	8.2	43.9	0.9	649.2
2016	428.9	170.3	11.6	10.7	6.9	43.2	0.7	672.3
2017	432.0	173.8	12.9	4.9	6.7	37.2	0.6	668.3
2018	399.5	181.0	13.3	3.0	2.8	49.4	0.2	649.3
2019	399.9	190.7	13.9	2.7	2.2	41.0	0.2	650.0

(a) Includes all bus modes: bus, commuter bus, and bus rapid transit.

(b) Energy equivalent gallons using energy value of type of fuel each agency would otherwise use, primarily diesel fuel.

(c) Includes bio/soy fuel, biodiesel (through 2006), hydrogen, methanol, ethanol, and various blends.

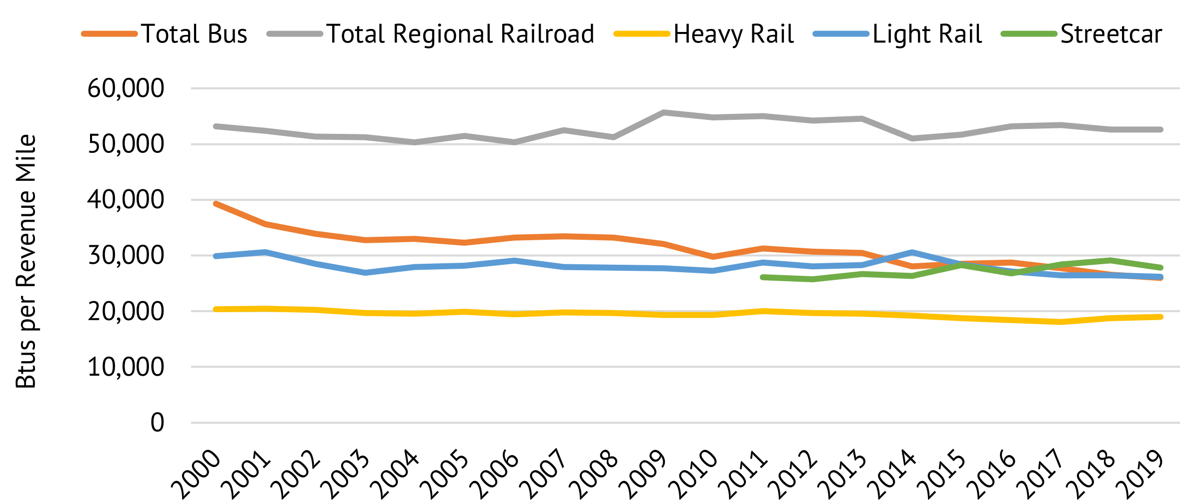
TABLE 4: ALTERNATIVE-POWERED VEHICLES BY MODE (PERCENT OF EACH MODE ALTERNATIVELY FUELED) (A)

Year On Jan. 1	Bus (b)	Commuter Rail Self-Propelled Car (c)	Commuter Rail Locomotive	Demand Response	Heavy Rail	Light Rail (d)	Trolleybus	Vanpool
2010	33.5%	99.5%	11.3%	8.0%	100.0%	98.3%	100.0%	---
2011	36.6%	99.8%	11.6%	7.7%	100.0%	98.4%	100.0%	---
2013	40.4%	99.2%	16.6%	8.3%	100.0%	98.4%	100.0%	---
2014	41.4%	95.0%	4.1%	16.4%	100.0%	100.0%	100.0%	17.0%
2015	46.9%	98.0%	3.2%	17.0%	100.0%	100.0%	100.0%	27.4%
2016	49.1%	98.2%	1.7%	15.9%	100.0%	100.0%	100.0%	29.3%
2017	54.3%	67.9%	4.4%	19.5%	100.0%	100.0%	100.0%	32.1%
2018	53.8%	98.9%	2.5%	14.4%	100.0%	100.0%	100.0%	30.3%
2019	54.5%	98.9%	2.5%	17.0%	100.0%	100.0%	100.0%	0.4%
2020	53.4%	99.5%	6.6%	13.6%	100.0%	100.0%	100.0%	0.2%

(a) Sample data only; "Public Transportation Vehicle Database," American Public Transportation Association, 2013 - 2023, https://www.apta.com/research-technical-resources/transit-statistics/vehicle-database/ (September 2023). Alternative-powered is defined as active vehicles powered by anything other than diesel or gasoline.
(b) Includes bus rapid transit and commuter bus vehicles.
(c) Includes hybrid rail cars.
(d) Includes streetcars.

Figure 2 shows the trends in BTUs per revenue mile for primary transit modes. These trends capture changes in the vehicle sizes and weights, propulsion technologies, and fuel blends.

FIGURE 2: BTUS PER REVENUE MILE

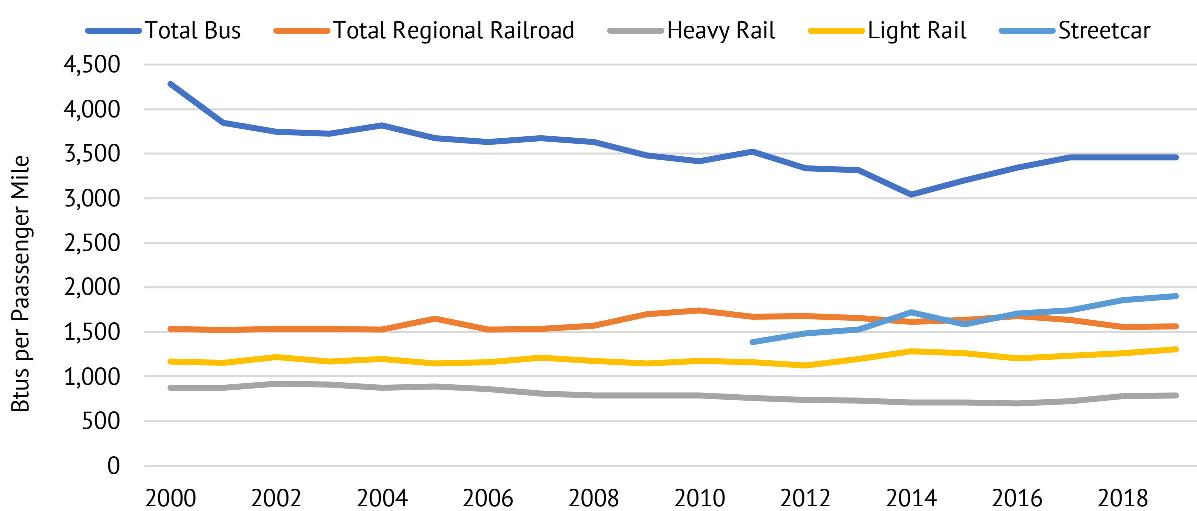


Data sourced from "Public Transportation Fact Book Appendix A," American Public Transportation Association, May 2021, https://www.apta.com/wp-content/uploads/APTA-2021-Fact-Book.pdf (September 2023). Conversion from fuel source to BTUs based on Department of Energy conversion factors.

Bus efficiency has improved meaningfully over time because of the noted changes. Full-size buses tend to be amortized over a 12-year life in U.S. transit properties with an average age of approximately 7-8 years old. Interestingly, the auto fleet now averages over 12.5 years old with scrappage estimated to be at about 17 years of age on average. The changes in BTUs per revenue mile for other modes are relatively modest. In general, newer generations of electric vehicles tend to be more efficient. However, changes in vehicle size and capacity can offset the technology efficiency changes when evaluating BTUs per vehicle revenue mile. Given fleet lives of 25 to 40 plus years for rail, the pace of change in national averages for the rail vehicle fleet efficiency is modest as more efficient replacement vehicles enter the fleet slowly.[8]

Figure 3 factors in passenger miles. In Figure 3, the BTU use per passenger mile efficiency trend for buses is offset beyond 2014 by the declining levels of bus use. Heavy and light rail and streetcar are more modestly affected but show upticks in BTUs per passenger mile as ridership and occupancy declined.

FIGURE 3: BTUS PER PASSENGER MILE



Data sourced from "Public Transportation Fact Book Appendix A," American Public Transportation Association, May 2021, https://www.apta.com/wp-content/uploads/APTA-2021-Fact-Book.pdf (September 2023). Conversion from fuel source to BTUs based on DOE conversion factors.

8 For example "The MBTA adheres to a general standard life cycle of 35 years for rapid transit and light rail vehicles," Boston Region Metropolitan Planning Organization, Program for Mass Transportation, 2009, https://www.bostonmpo.org/data/pdf/studies/transit/pmt/PMT_Ch5.pdf.

As noted in Figure 1, operating energy intensiveness is impacted by the inherent vehicle efficiency and by vehicle use. Table 5, developed from Federal Transit Administration NTD, reflects the trend in vehicle use since 2013 and extends the data to show the impact of the COVID pandemic. Figure 4 shows that trend graphically for transit's primary modes. From a longer-term historical perspective, occupancy levels for modes peaked in the energy crisis in the late 1970s with bus occupancies at 13 and heavy rail occupancy at 29.

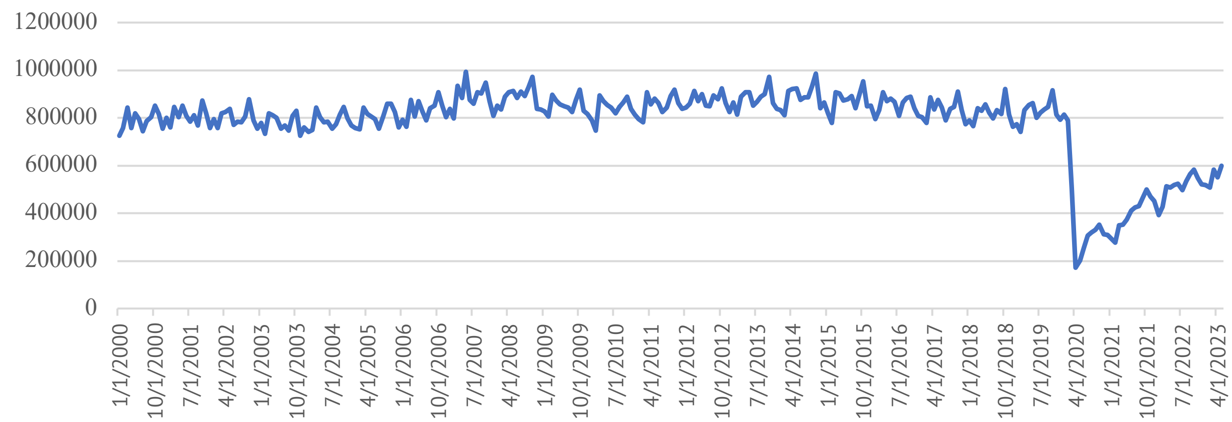
TABLE 5: TRANSIT SERVICE AVERAGE VEHICLE OCCUPANCY TREND

	2013	2014	2015	2016	2017	2018	2019	2020	2021
Commuter rail	35.9	34.3	34.2	34.2	35.3	36.2	36	20.4	13
Heavy rail	27.5	27.9	27.1	27.2	25.7	24.7	24.9	13.9	11.9
Light rail	24.2	24.3	23	23	22	21.5	20.5	15.8	9.6
Streetcar rail	18.2	15.8	18.3	16.1	16.7		15	13.1	6.8
Hybrid rail	29.9	30.2	30.7	28.7	29		20.9	16.8	9.6
Commuter bus	20.8	19.3	12.3	16.9	17.7		16.7	11.0	8.1
Bus	10.9	10.5	10.1	9.7	9	8.2	8.8	6.9	5
Bus rapid transit	24	19.9	18.5	18.3	17.1		15.8	11.3	8.4
Trolley bus	13.8	14.3	13.8	13.6	13.1		12.8	10.2	6.4
Demand Response	1.2	1.1	1.1	1.1	1.1		1.2	1.1	0.9
Vanpool	6	5.9	5.9	5.7	5.6		5.5	5.4	4.7
Ferryboat	122.4	127.8	125.7	133.4	130.1		112.4	99.3	69.1

Source: National Transit Database, National Transit Summaries & Trends, Annual National Transit Summaries and Trends | FTA (dot.gov), https://www.transit.dot.gov/ntd/annual-national-transit-summaries-and-trends.
Notes: Data extracted from respective National Annual Reports. Occupancy is defined as the passenger miles per revenue vehicle mile. Data refers to the agencies' respective fiscal year so in many cases it is not coincident with the calendar year. The FY2020 data likely includes from 2 to 8 pre-COVID months of data depending on the agency.

With the exception of commuter rail and demand response services, all sub-modes of public transit showed declines in occupancy between 2013 and 2019. The declines in recent years were most pronounced for the bus modes. Data from the fiscal year 2021 show the impact of COVID with historically unprecedented declines in transit use and resultant occupancy. While it is premature to estimate post-COVID occupancy levels, continuously reported monthly ridership data suggest improvements. Figure 4 shows the recovery levels for monthly transit ridership through May 2023.

FIGURE 4: PUBLIC TRANSIT MONTHLY RIDERSHIP TREND



Sources: Unadjusted - American Public Transportation Association (APTA) data (2000 through 2009) available at: https://www.apta.com/research-technical-resources/transit-statistics/ridership-report/ and U.S. Department of Transportation, Federal Transit Administration, National Transit Database (2010 to present) available at: https://www.transit.dot.gov/ntd/ntd-data. Accessed 5 Sept. 2023 at https://data.bts.gov/stories/s/Transportation-as-an-Economic-Indicator-Seasonally/j32x-7fku

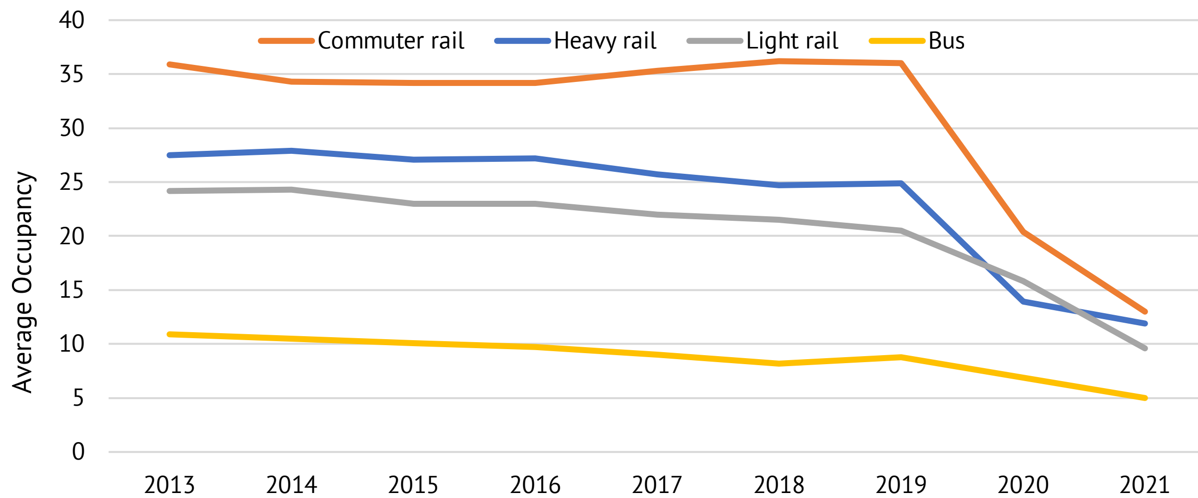
Most systems, especially commuting dependent rail services, are likely to have lower occupancy levels for an extended period. Most experts are predicting substantial levels of telework even when COVID is a more distant memory, and many services are unable or unwilling to cut back service levels because cutbacks in capacity typically require service frequency reductions that discourage ridership and impact those dependent on services.[9] In addition to the strength of the ridership recovery, ultimate post-COVID vehicle occupancies will be dependent upon service levels that transit agencies choose to or can afford to operate as supplemental federal COVID-motivated financial resources are exhausted.

Figure 5 explores the occupancy of transit modes in comparison to their capacity in greater detail. For public transit planning and operating purposes, the industry establishes estimates of operating capacity that use the seating capacity as well as available floor space, as transit vehicles are designed to and regularly operate with significant volumes of standing passengers. This is particularly true for urban services with more modest trip lengths where standing for part of a trip or for a short trip is not an inconvenience. The data in Figure 5 reveals the challenge for domestic transit operations where demand levels fail to utilize a significant share of carrying capacity. This is dramatically evident during the

[9] "Over one-third of private-sector establishments increased telework during the COVID-19 pandemic," Bureau of Labor Statistics, U.S. Department of Labor, at https://www.bls.gov/opub/ted/2022/over-one-third-of-private-sector-establishments-increased-telework-during-the-covid-19-pandemic.htm (accessed 17 Oct. 2024).

COVID-impacted years. Even during pre-COVID conditions U.S. operations seldom leveraged the carrying capacity of transit services.

FIGURE 5: PRIMARY TRANSIT MODES, OCCUPANCY TRENDS



Source: Table 5 data.

TABLE 6: TRANSIT SERVICE AVERAGE VEHICLE OCCUPANCY DERIVATION

	2020				2021			
	Capacity	**Occupancy**	**Percent of Capacity**	**Percent of Seating**	**Capacity**	**Occupancy**	**Percent of Capacity**	**Percent of Seating**
Commuter rail	144.1	13.9	9.6%	27.3%	144.1	11.9	8.3%	23.9%
Heavy rail	174.1	20.4	11.7%	18.5%	173.3	13	7.5%	11.7%
Light rail	185.7	15.8	8.5%	24.2%	188.3	9.6	5.1%	14.8%
Streetcar rail	95.9	13.1	13.7%	28.6%	98	6.8	6.9%	14.9%
Hybrid rail	177.5	16.8	9.5%	20.9%	177.9	9.6	5.4%	11.9%
Commuter bus	65.1	11.0	16.9%	21.6%	64.5	8.1	12.6%	16.2%
Bus	62.5	6.9	11.0%	17.9%	61.6	5	8.1%	13.5%
Bus rapid transit	94.1	11.3	12.0%	23.5%	88.1	8.4	9.5%	18.2%
Trolley bus	73.8	10.2	13.8%	24.8%	73.7	6.4	8.7%	15.5%
Demand response	10.3	1.1	10.7%	11.6%	10.4	0.9	8.7%	9.4%
Vanpool	9.3	5.4	58.1%	57.6%	9.3	4.7	50.5%	50.5%
Ferryboat	609.1	99.3	16.3%	23.0%	628.3	69.1	11.0%	16.0%

Source: Shrey Verma, Gaurav Dwivedi, Puneet Verma, "Life cycle assessment of electric vehicles in comparison to combustion engine vehicles: A review, *Materials Today: Proceedings*, 49, (2022), 217-222, https://doi.org/10.1016/j.matpr.2021.01.666 (accessed March 2023).
Notes: Data extracted from respective National Annual Reports. Occupancy is defined as the passenger miles per revenue vehicle mile. Data refers to the agencies' respective fiscal year so in many cases it is not coincident with the calendar year. The FY2020 data likely includes from 2 to 8 pre-COVID months of data depending on the agency.

Using the BTUs per passenger mile data from Table 1 and adjusting the vehicles' occupancies by the percentage changes in Table 5 provides an estimate of the 2021 BTUs per passenger mile during COVID.

TABLE 7: ESTIMATED 2021 BTUS LEVELS REFLECTING LOWER VEHICLE OCCUPANCIES

	2019			Extrapolated 2021		
	Load factor (persons/ vehicle)	BTUs per vehicle mile	BTUs per passenger mile	Load factor (persons/ vehicle)	BTUs per vehicle mile	BTUs per passenger mile
Cars	1.5	4,292	2,787			
Personal trucks	1.8	5,845	3,212			
Motorcycles	1.2	2,844	2,370			
Buses	7.5	34,877	4,634	4.3	34,877	8,158
Rail Transit	23.6	20,040	851	10.9	20,040	1,846
Commuter Rail	33.9	53,587	1,583	12.2	53,587	4,391

Source: Derived from data in Table 1 and Table 5.
Note: There are differences in DOE and USDOT Btu estimates reflecting differences in methodology and samples. USDOT percent changes in occupancies were used to preserve the robustness of the estimates.

As would be expected, modal comparative energy efficiencies change proportional to occupancies and the auto efficiency advantage is more pronounced relative to transit options. As a new normal in transit demand and supply levels materializes, occupancy levels are expected to improve, but few analysts are expecting them to return to 2019 levels.[10] Telework and other communications substitutions are expected to continue to dampen travel levels, particularly for central business district commuting, which has historically been the strongest market for transit.

As alluded to in reference to the role that New York plays in energy use/emissions, performance with respect to energy efficiency varies across transit properties due to differences in fleets, service characteristics, and especially use levels.

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[10] Abubakr Ziedan, Candace Brakewood, Kari Watkins, "Will transit recover? A retrospective study of nationwide ridership in the United States during the COVID-19 pandemic," *Journal of Public Transportation*, Volume 25, 2023, https://doi.org/10.1016/j.jpubtr.2023.100046

Cautionary Note on Cross-Modal BTU per Mile Comparisons

One often sees comparative measures of BTUs per passenger mile for various modes such as those shown in Table 1 and referenced in this and other reports. Be aware of two important considerations in using these numbers. First, various modes have different trip circuity for completion between an origin and destination.[A] Some modes are inherently more direct; the travel consumes fewer passenger miles to accomplish the desired trip. One might appropriately adjust the BTU comparison table to reflect differences in trip circuity. Personal vehicles driving on our ubiquitous roadway network typically allow for more direct travel and will result in fewer passenger miles per trip. For public transportation, depending on how the network is configured and how the route structure is aligned, these differences can be quite dramatic. Routes commonly weave through neighborhoods to provide convenient stop locations near major attractors, and many transit trips require diversion to a hub location and transfer to a subsequent route that completes the connection. This is particularly true for central business district centric systems, where radial routes might require significant trips circuity traveling into and out of downtown if crosstown connection options aren't available.

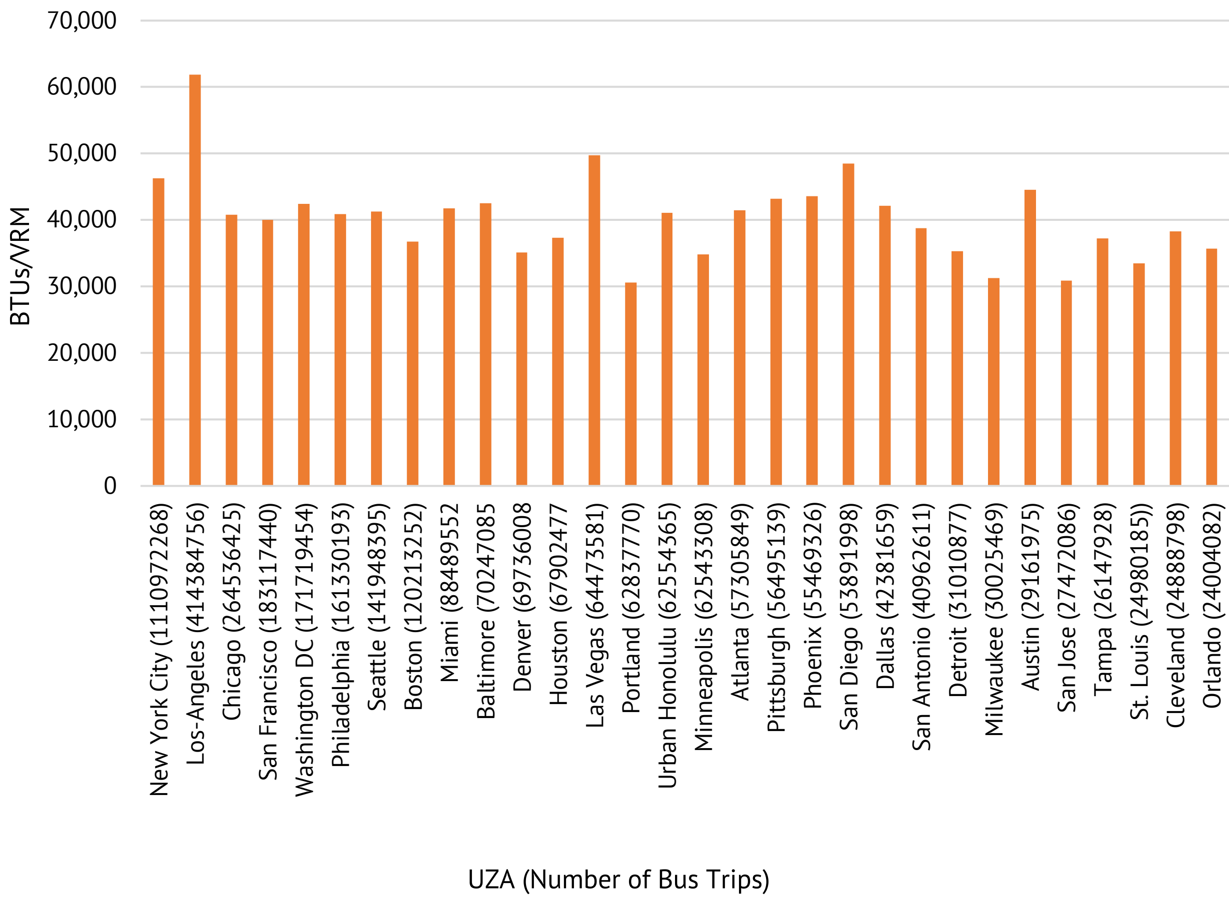
Unfortunately, an appropriate adjustment factor has not been found in the literature. Based on experience evaluating modal accessibility metrics, travel trip time comparisons, and transit service configurations, in this author's opinion, adjustments of 10 to 30 percent would not be surprising. For example, a trip that requires 10 miles of personal vehicle travel might well take 13 miles of travel via bus route(s). Adjustments to account for this would show poorer comparative performance of public transportation with personal vehicle travel. This phenomenon would also be appropriate to evaluate when comparing airline travel to personal vehicle or rail network trips.

A second consideration involves the use of model average efficiency numbers for cross-modal comparisons. Travel on public transportation is typically in urban areas, with a preponderance of travel in larger more congested urban core areas and frequently in peak periods. Thus, using the average energy efficiency of personal vehicles misrepresents the energy consumption or emissions levels that would be most appropriate for comparison to serving the same trip portfolio that occurs on public transportation. Ideally, one would want a congested urban trip profile as the basis for measuring personal vehicle energy consumption/emissions for purposes of comparison with public transportation. This profile would penalize the performance of roadway travel relatively, providing a more favorable comparison for public transportation. After reviewing EPA rating difference for urban versus highway mileage driving cycles for a range of vehicles, in this author's opinion, a 5 to 15 percent adjustment in BTU utilization in urban environments for personal vehicles might be appropriate. With hybridization and electrification this adjustment would diminish. Additional research on these issues would be helpful to more fully understand cross-modal comparisons.

[a] Circuity refers to the door-to-door trip distance of a mode relative to the corresponding distance by automobile. Automobile is used as a base because it is generally the most direct form of urban passenger transportation.

Figures 6-13 provide an indication of the variation in both BTUs per vehicle revenue mile (VRM) and per passenger mile (PM) for larger properties for the various key public transit sub-modes. These graphics are sourced from 2019 NTD. Properties are sorted by ridership levels across the horizontal axis.

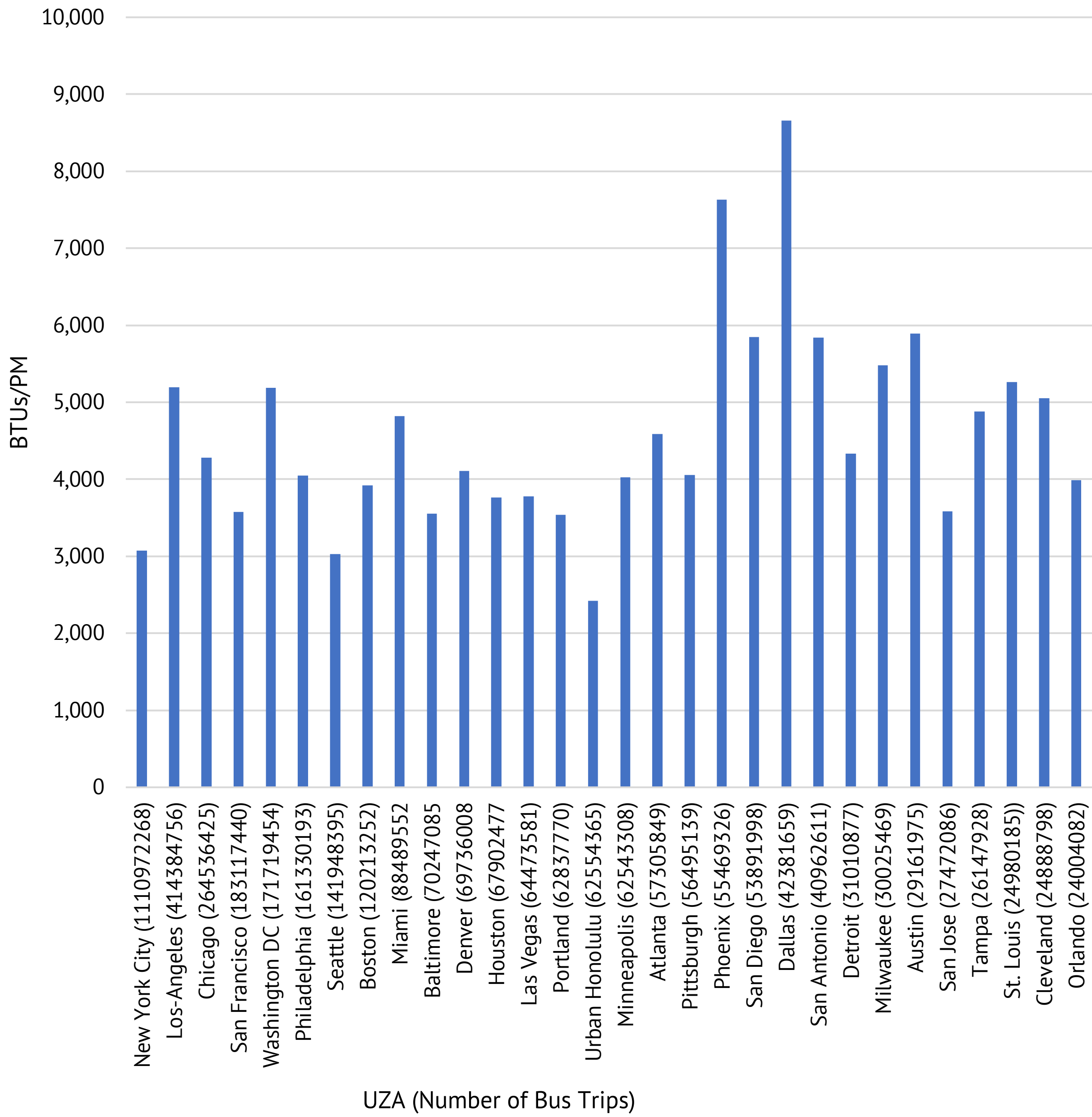
FIGURE 6: BUS BTUS/VRM BY UZA IN 2019



Variations in BTUs per revenue mile are generally modest, with BTUs per revenue vehicle mile ranging from 30,000 to 50,000 BTUs per revenue mile, except in Los Angles with approximately 62,000 BTUs per revenue mile. Vehicle loads and speed/congestion levels may play a role in the lower performance levels for select metro areas.

Figure 7 shows the BTUs per passenger mile for the same large metropolitan systems. Variation in performance is greater for this measure as different occupancy levels result in more variability across contexts. According to this data, the worst performing bus system is Dallas, Texas, which consumes approximately three times as many BTUs per passenger mile as does an average personal car with 1.5 occupants.

FIGURE 7: BUS BTUS/PM BY UZA IN 2019



Figures 8 and 9 provide the same information for heavy rail operations. Estimates of BTUs per vehicle revenue mile indicate that there is variation across properties of more than fourfold, and then an even larger variation in reported BTUs per passenger mile. A careful review of the operating context and the quality of data collection and reporting would be required to fully understand the large variations in performance.

FIGURE 8: HEAVY RAIL BTUS/VRM BY UZA IN 2019

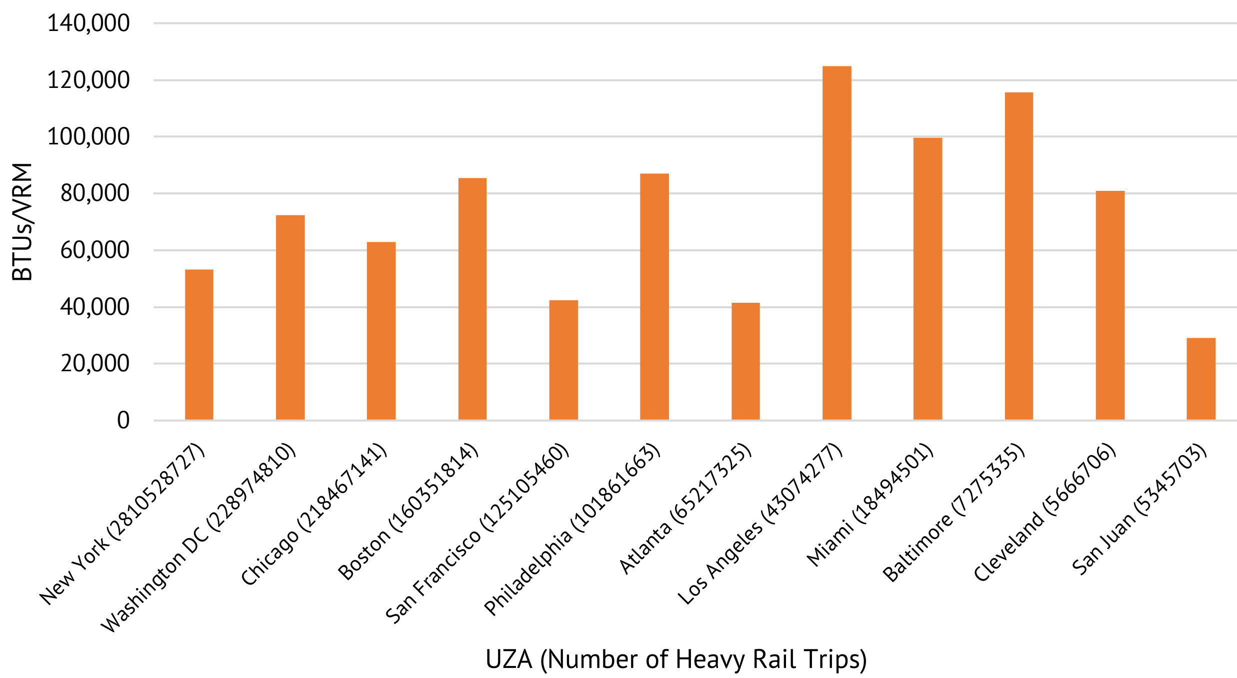
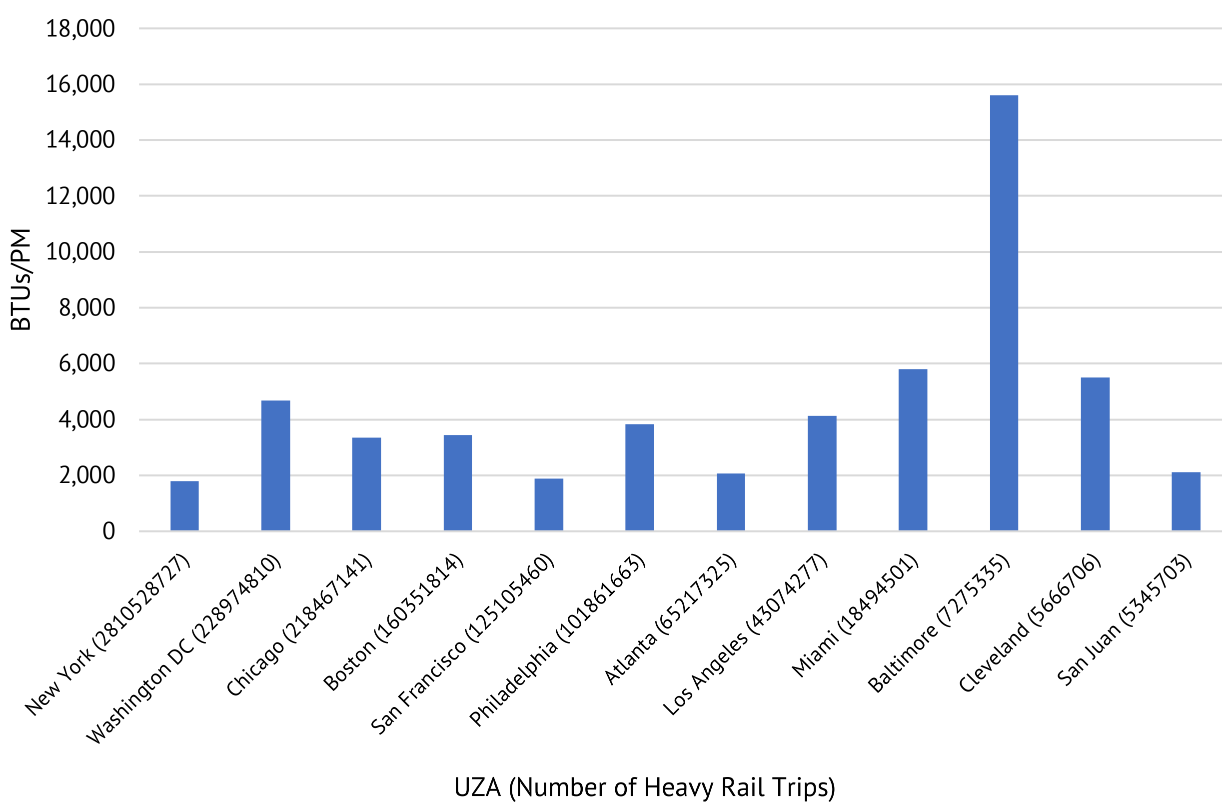


FIGURE 9: HEAVY RAIL BTUS/PM BY UZA IN 2019



With the exception of Baltimore, Figure 9 shows somewhat more consistent performance across heavy rail systems. Figures 10 and 11 provide data for light rail systems and Figures 12 and 13 for commuter rail.

FIGURE 10: LIGHT RAIL BTUS/VRM BY UZA IN 2019

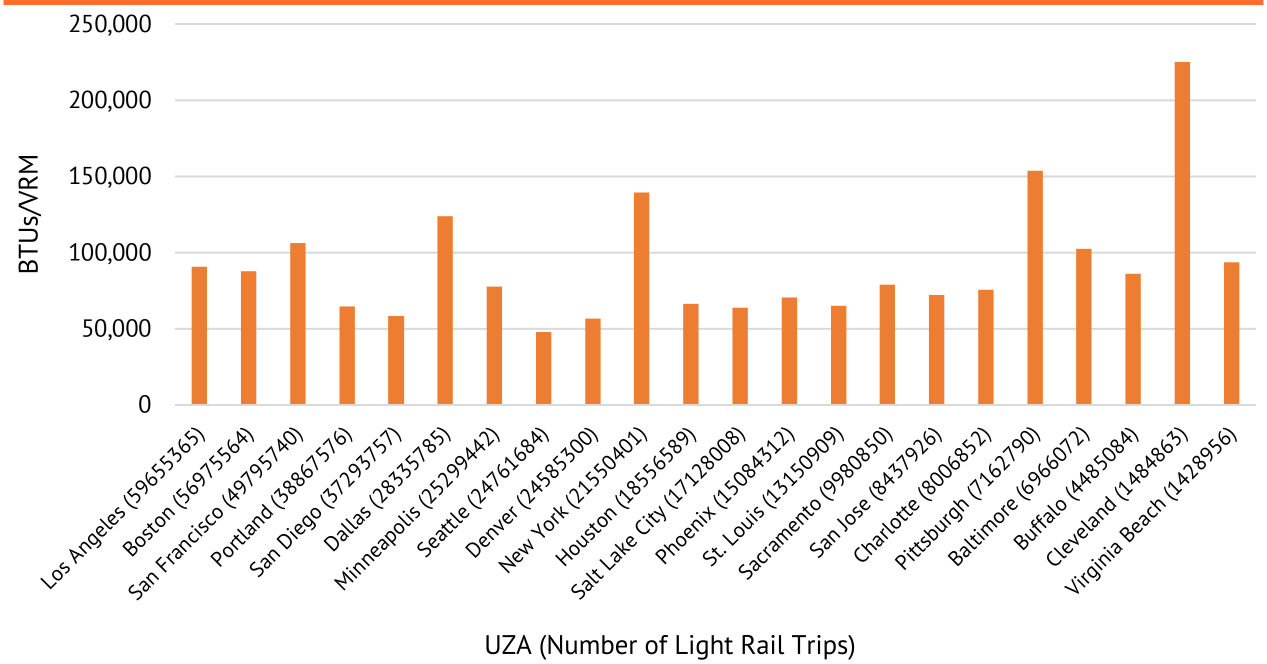
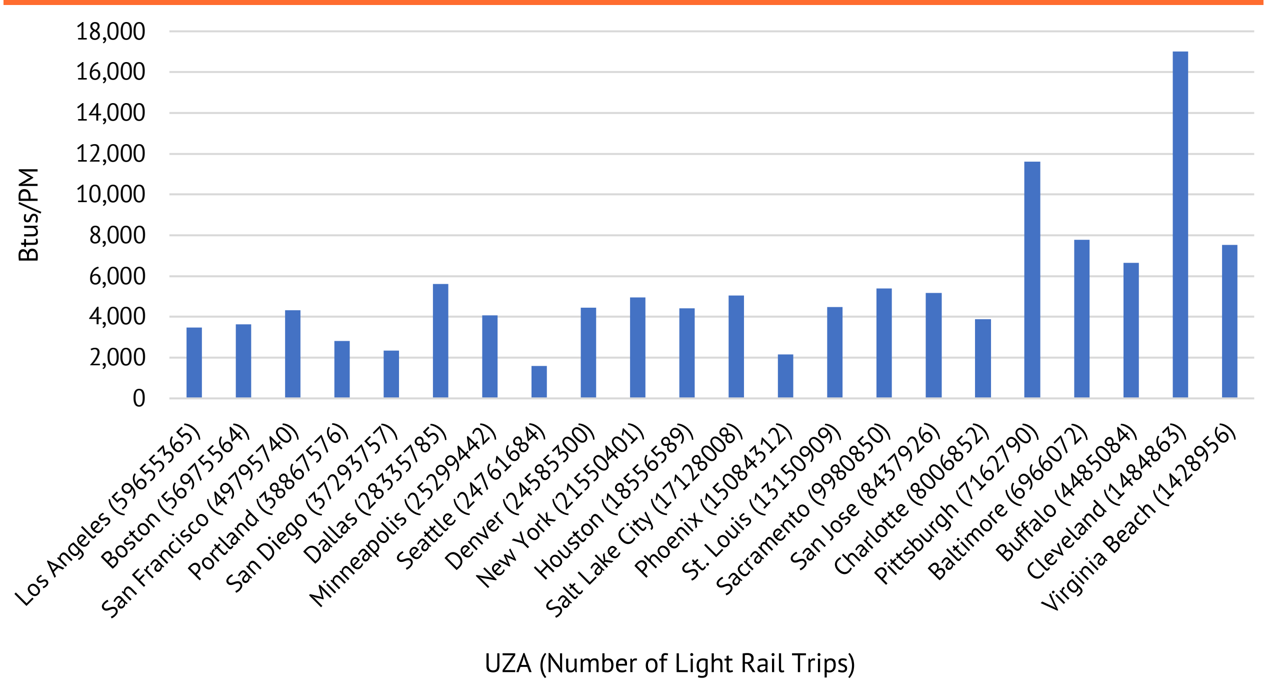


FIGURE 11: LIGHT RAIL BTUS/PM BY UZA IN 2019



The light rail outlier status for Cleveland may be partially attributable to how power use is allocated between heavy and light rail as operations share station and trackage, making it almost impossible to fully discern power use between these two sub modes.

FIGURE 12: COMMUTER RAIL BTUS/VRM BY UZA IN 2019

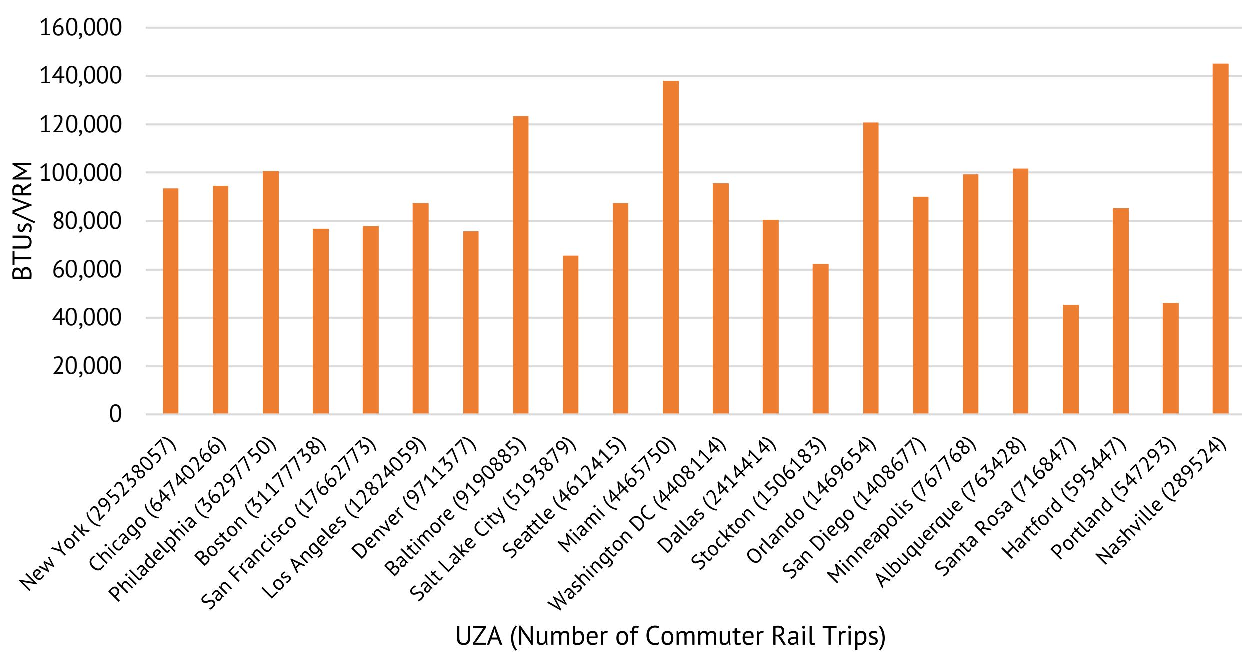
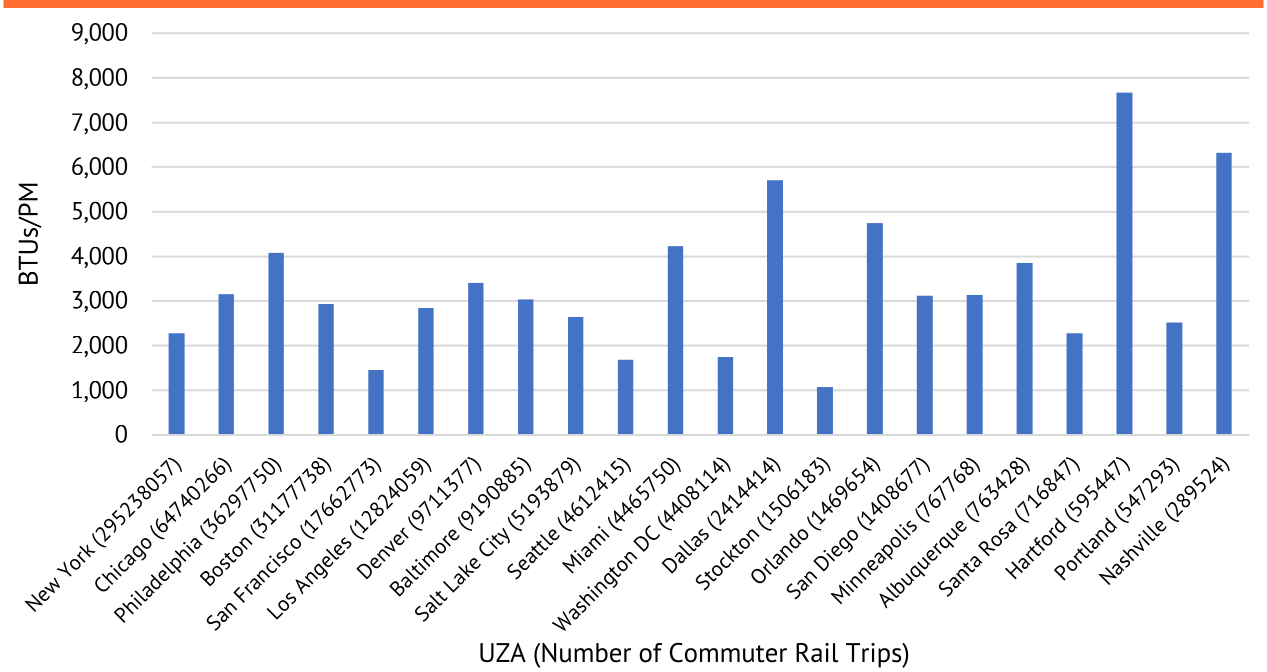


FIGURE 13: COMMUTER RAIL BTUS/PM BY UZA IN 2019



In general, the variations in performance with respect to BTU use is quite dramatic across different operating contexts. These differences reinforce the merits of considering energy or emissions comparisons in the context of the specific set of conditions which apply. While generalizing and producing national averages is an appropriate means of understanding trends and relative comparisons, actual policy and investment decision-making that considers emissions as a factor should be based on actual or anticipated operating conditions.

Another element of operations that merits discussion in the context of energy intensiveness is the logistics efficiency of fleet operations. Logistics efficiency refers to the extent of total vehicle mileage that is in revenue passenger service. Vehicles accrue mileage going to and from the start and end of service and their operating base. Additional miles include operator training and shuttling between facilities for maintenance or other purposes. This mileage consumes fuel and produces emissions impacting the overall efficiency of the service. The occupancy numbers shown in Figure 2 are based on revenue miles. Thus, they overstate the true vehicle operations over all its miles of travel but are a logical metric for using in the context of understanding the passenger use of the capacity of public transit services. Data from the American Public Transportation Association (APTA) from 1995-2019 indicate that revenue service constituted approximately 87 percent of total bus mileage, 97 percent of total heavy rail mileage, 98 percent of light rail mileage, and 92 percent of commuter rail mileage.[11] These numbers remained very stable over the period. Measures of energy use and emissions per passenger mile or per trip are not distorted if total energy and emissions are included in the numerator for calculations. Differences in the treatment of non-revenue vehicle miles is one factor that can cause differences between various estimates of BTUs per passenger vehicle mile.

Logistics efficiency, or what the industry refers to as non-revenue miles or deadhead miles, could become more significant if electric vehicles must return to the garage or a recharging facility more frequently than is the case for liquid refueling of vehicles. Some transit authorities are needing additional electric vehicles to shuttle into service to complete a full day's operating schedule, which increases non-service mileage and reduces overall energy efficiency.[12] This situation may evolve as battery and charging technologies evolve.

11 Developed from APTA data, https://www.apta.com/research-technical-resources/transit-statistics/public-transportation-fact-book/

12 Nathan Bernier, "CapMetro stops shift to all-electric bus fleet," KUT News, July 25, 2024, https://www.kut.org/transportation/2024-07-25/capmetro-stops-shift-to-all-electric-bus-fleet.

PART 3

ENERGY INTENSIVENESS

Referring again to Figure 1 for reference, the preceding narrative focused on energy used for vehicle propulsion. While this is typically the single largest use of energy, a more thorough analysis can be expanded to include energy used to deliver fuel to vehicles.

Different fuels have different amounts of energy consumed in finding or producing, processing, transporting, and storing. As this is both difficult to measure and allocate absent a location-specific energy intensiveness analysis for a given geography, it is not a topic that is addressed in this report. For example, delivering a BTU of Canadian tar sands-extracted diesel fuel to New York may be far more energy intensive than delivering an equivalent number of BTUs of natural gas from Pennsylvania.

The analysis reported in TCRP Research Report 226, *An Update on Public Transportation's Impacts on Greenhouse Gas Emissions*, 2021, does provide a perspective on energy intensiveness and discusses what is referred to as indirect GHG emissions occurring at the power plant when electricity was produced or in the process of producing hydrogen. Upstream emissions, sometimes referred to as "well-to-pump" emissions, are the GHG emissions that occurred during fuel production and distribution. In general, these energy uses or emissions are approximately 20 percent of direct energy/emissions and would not necessarily be expected to vary between modes (electricity generated or fuel used would be expected to have the same proportion of indirect energy use or emissions, regardless of end use in personal or transit vehicles for a given location).[13]

However, it is important to note that analysts do vary in their strategy for treating or attributing emissions to transportation applications as it relates to the trends toward electrification of transportation modes and the absolute emissions impact that should appropriately be attributed to that change. Specifically, while the general practice is to use the average GHG emission characteristics for the respective fuel source and geography, some analysts argue that the shift to electrification of transportation, which will significantly impact the total electric generation and distribution demands across the country, will result in delays in the shift toward green or more sustainable overall electric production. The gist of the argument is that dirtier generating capabilities will be kept in operation longer due to the increase in total demand.[14] Hence emissions associated with that less sustainable energy source should be attributed to, in this case, electric vehicles, as in their absence those less efficient or less clean generating sources would have been retired. This personal vehicle versus public transit travel emissions analysis would only be relevant if one envisioned dramatically different paces of electrification between these modes. In addition, electrification of transportation has significant implications for the production of electricity overall and assigning "ownership" of those implications will inevitably be explored in future research.

> *Energy intensiveness comparisons across geographies for a given mode might vary quite significantly, especially for electrically powered modes, due to differences in the GHG emissions generated by various sources of electrical generation.*

[13] National Academies of Sciences, Engineering, and Medicine. 2021. *An Update on Public Transportation's Impacts on Greenhouse Gas Emissions*. Washington, D.C.: The National Academies Press. https://doi.org/10.17226/26103.

[14] Joyce McLaren, John Miller, Eric O'Shaughnessy, Eric Wood, and Evan Shapiro, "Emissions Associated with Electric Vehicle Charging: Impact of Electricity Generation Mix, Charging Infrastructure Availability, and Vehicle Type." National Renewable Energy Laboratory, Technical Report NREL/TP-6A20-64852, April 2016.

Energy intensiveness comparisons across geographies for a given mode might vary quite significantly, especially for electrically powered modes, due to differences in the GHG emissions generated by various sources of electrical generation. Specifically, sustainably generated electricity would have lower GHG emissions than might coal-fired or other carbon-based fueled electricity production. Thus, the GHG emissions calculations should appropriately be based on power source characteristics of specific geography.

PART 4

LIFE CYCLE ENERGY INTENSIVENESS

Life cycle energy intensiveness is more comprehensive than energy intensiveness because it includes the energy used to operate stations and maintain vehicles as well as the energy used to construct travel ways and supporting infrastructure and manufacture the vehicles. For transit, propulsion energy is the largest single component of life cycle energy, with station and maintenance energy usually second. More recently, some analysts have included the energy cost of recycling or disposing of the assets after their useful life in their calculations. Life cycle energy intensiveness is computed by adding to propulsion energy the energy needed to operate stations and maintain vehicles and roadways and the energy needed to construct facilities and manufacture vehicles. Energy for construction and manufacturing is converted to a per-mile basis using the estimated life, in vehicle miles, of roadways and vehicles, respectively. Computations are transformed to a passenger-mile basis by applying the average number of occupants used to compute energy intensiveness.

As the U.S. moves toward the electrification of transportation vehicles, the issue of life cycle energy intensiveness has gotten increased attention due to the energy intensiveness of actions required in the mining, refining, processing, and transporting of the materials used to produce batteries. Various studies have evaluated the extent to which this characteristic of electrified vehicles offsets some of the GHG efficiency that might be associated with operations. Estimation of this influence is both somewhat variable and rapidly changing. As the movement toward electrification continues, experts anticipate substantial changes in battery chemistry and production processes and the sources, methods, locations, and impact of securing the necessary raw materials. One would expect changing estimations of the energy intensiveness of electric vehicle production over time. Similarly, the disposal and/or recycling of components used in electric vehicles is a rapidly developing aspect of electrification, and the GHG emissions implications of disposal of electric vehicles at the end of their useful life are similarly likely to evolve.[15, 16]

The "break-even point" is the point when an electric vehicle makes up for the incremental emissions produced during its manufacturing stage in its operations stage. This break-even point can vary widely depending on several factors, most of which is the energy mix of the state or country of manufacture and use. Reuters carried out a study using Argonne's Greenhouse Gases, Regulated Emissions and Energy Use in Technologies (GREET) model. The data showed that a Tesla Model 3 in the United States would need to be driven for 13,500 miles before it does less harm to the environment than a Toyota Corolla.[17] In a study conducted by the University of Michigan, the break-even point is between 1.4 to 1.5 years for sedans, 1.6 to 1.9 years for SUVs and about 1.6 years for pickup trucks, based on the average number of vehicle miles traveled in the United States.[18, 19] In another study, an electric car and electric truck would need to drive 21,300 miles and 17,500 miles respectively to reach the break-even points with their gas counterparts. Considering most vehicles are driven nearly 200,000 miles in their lifetime, that means the break-even point arrives after 1.5-2 years of driving.[20]

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15 Shrey Verma, Gaurav Dwivedi, Puneet Verma, "Life cycle assessment of electric vehicles in comparison to combustion engine vehicles: A review," *Materials Today: Proceedings*, 49, (2022), 217-222, https://doi.org/10.1016/j.matpr.2021.01.666 (accessed March 2023).

16 Yusuf Bicer, Ibrahim Dincer, "Life cycle environmental impact assessments and comparisons of alternative fuels for clean vehicles," *Resources, Conservation and Recycling*, 132, (2018),141-157, https://doi.org/10.1016/j.resconrec.2018.01.036 (accessed March 2023).

17 Paul Lienert, "Analysis: When do electric vehicles become cleaner than gasoline cars?", Reuters, July 7, 2021, reuters.com, https://www.reuters.com/business/autos-transportation/when-do-electric-vehicles-become-cleaner-than-gasoline-cars-2021-06-29/ (accessed March 2023).

18 Woody M, Vaishnav P, Keoleian G A, De Kleine R, Kim H C, Anderson J E, Wallington T J, "The role of pickup truck electrification in the decarbonization of light-duty vehicles," *Environmental Research Letters*, 17 034031, (2022), https://doi.org/10.1088/1748-9326/ac7cfc. (March 2023). M, Vaishnav P, Keoleian G A, De Kleine R, Kim H C, Anderson J E, Wallington T J (2022) The role of pickup truck electrification in the decarbonization of light-duty vehicles Environ. Res. Lett. 17 034031. https://doi.org/10.1088/1748-9326/ac7cfc.

19 Eric Taub, "E.V.s Start with a Bigger Carbon Footprint. But That Doesn't Last," *The New York Times*, October 19, 2022, nytimes.com, https://www.nytimes.com/2022/10/19/business/electric-vehicles-carbon-footprint-batteries.html (accessed March 2023).

20 Kelly Shin, " Lifecycle Emissions of Electric Cars vs. Gasoline," Green Energy Consumer Alliance, January 5, 2023, https://tinyurl.com/y3b3rv4w. (accessed March 2023).

In Brief:

- ☒ Electric bus technology continues to evolve, and most transit agencies have yet to go all in on electrification.
- ☒ Electric buses present issues with charging infrastructure, storage space, reliability, range and cost.
- ☒ Some say improving service and attracting more riders is a bigger climate benefit than vehicle electrification.[21]

Thus, as both personal vehicles and public transit vehicles move toward electrification and as battery technologies, the grid, and generation capabilities evolve, one would expect some changes in the comparative GHG impacts. There will inevitably be other unanticipated energy consequences associated with changes in fuel source and propulsion technologies over time that may have impacts on the energy intensiveness or GHG emissions associated with the delivery of public transportation services. Examples of these unanticipated consequences include the realization by one transit property that the energy consumption associated with compressing natural gas to the high pressures required for fueling buses offset the anticipated energy/emissions savings associated with that fuel used in vehicle propulsion. Similarly, other properties have needed to build and heat overnight storage facilities for electric vehicles to maintain satisfactory battery charge levels and performance, thus offsetting some of the operational benefits of electrically propelled vehicles. Others have chosen to install diesel generator powered air conditioning in electric buses in order to extend the battery life to support the propulsion system and provide adequate range.[22]

Another aspect of life cycle energy intensiveness involves accounting for the energy use associated with building and operating the supportive facilities to enable the mode to function. In the case of public transportation, this would include energy used for stations, stops, parking facilities for vehicles, and customers accessing the mode by vehicle and other auxiliary functions. Energy use and related GHG emissions become more significant

21 Jared Brey, "The Rocky Road to Bus Electrification," *Governing*, June 6, 2023, governing.com, https://www.governing.com/transportation/the-rocky-road-to-bus-electrification (April 2023).

22 Tom Krisher, "In Chicago, adapting electric buses to winter's challenges," Associated Press, March 4, 2023, apnews.com. https://apnews.com/article/chicago-electric-bus-cold-weather-eea4314383f4678c01d78ff202936d68 (accessed April 2023).

as these facilities become more significant. The physical size of these facilities, as well as the amenity levels (heating, cooling, lighting, security, elevators, escalators, hot water, etc.), affects the energy use levels both in the construction and the ongoing operation. Construction energy use is related to the magnitude of the construction effort. Huge quantities of energy are needed to dig tunnels, make and haul concrete, and perform the thousands of other tasks that go into building transportation facilities. Since construction energy is expended only once, its use is amortized over the total mobility provided by the facility over its life. Thus, greater efficiency is realized when the asset scale is in proportion to the volume of travel accomplished on the facility. As public transit has attempted to become more attractive and accessible to more travelers and travelers' expectations have increased, there has been a tendency to increase the levels of infrastructure for passenger serving facilities such as stops and stations. Elevators and escalators, restroom facilities, enhanced ventilation, heating and air conditioning, lighting, security systems, information and mobile connection capabilities, and other features can increase energy use.

“*As public transit has attempted to become more attractive and accessible to more travelers and travelers' expectations have increased, there has been a tendency to increase the levels of infrastructure for passenger serving facilities such as stops and stations. Elevators and escalators, restroom facilities, enhanced ventilation, heating and air conditioning, lighting, security systems, information and mobile connection capabilities, and other features can increase energy use.*”

There are no databases appropriate for measuring or discerning the trend in these supportive energy uses and emissions for public transit or auto modes. In the case of rail systems, it may not be possible to separate the propulsion power from the power used to support station operations and maintenance facilities, as billing is integrated to optimize rate efficiency.

To the extent that one can use the amount of infrastructure as a surrogate for the energy and hence GHG impact to build and operate capital facilities, then the trend for growing infrastructure per passenger mile of travel is suggestive of greater life cycle energy intensiveness. Comparing older rail stations on, for example, the Chicago and New York rail systems with those of the Washington, D.C., and San Francisco Bay area rail systems provide a perspective for someone who has experienced those systems on the greater infrastructure intensiveness of modern facilities as they seek to enhance accessibility and meet other current design standards and expectations.

PART 5

MODAL ENERGY INTENSIVENESS

Modal energy intensiveness supplements the consideration of energy and emissions impacts by including the consideration of access and trip circuity. Combining the additional energy consumed in access and circuity with either life cycle energy or energy intensiveness can sometimes result in shifts in relative modal energy efficiency. Many of the characteristics needed to estimate modal energy (for example, the consideration of access distance and circuity) are highly variable, context specific, and poorly documented. Nevertheless, a balanced view of overall modal energy use must take these factors into account.

Trip circuity is a very important and potentially significant factor and is discussed in the breakout box on page 15 of this report.

Most short transit trips are made by walking to a bus stop or transit station, riding to another stop, and then walking to a destination. Long transit trips frequently involve making a trip by automobile or feeder bus to reach the line haul part of the system. In such cases, the access mode can both add trip circuity and often contributes more energy consumption per distance traveled and higher emissions than the principal or line-haul mode. For analysis of a proposed project one can compare the total energy use or emissions of the travelers choosing to use the proposed project compared to those travelers' energy consumption or emissions contributions if the new project is not implemented. To capture dynamic conditions or induced travel behavior changes one might compare the totality of energy and emissions between the build and no-build scenarios.

To give perspective on the potential impact of access modes, a 2017 report by the American Public Transportation Association compiled on-board surveys from across the country that indicated that 69 percent of transit users walk to their stop or station. Another 11 percent drive to their stop, 10 percent transfer from another transit vehicle, and the remaining travelers are either dropped off, 6 percent, or use another mode. On alighting from their transit vehicles, 76 percent walk to their destination, 16 percent transfer to another transit vehicle, 4 percent drive, 3 percent get a ride, and 1 percent use other means.[23] Short, cold start, and sometimes round-trip personal vehicle trips to drop off or pick up passengers could influence overall project energy efficiency or emissions calculations, particularly for park-and-ride and drop-off intensive services, such as commuter rail and long-distance commuting bus trips.

The magnitude of access trips that incur energy consumption and produce emissions is relatively modest and unlikely to be significant in aggregate measurement. However, there may be project types where this contribution becomes significant.

The magnitude of access trips that incur energy consumption and produce emissions is relatively modest and unlikely to be significant in aggregate measurement. However, there may be project types where this contribution becomes significant. This is particularly true for those longer distance commutes or other trips to central business districts where the access shed for suburban travelers can be quite large and park-and-ride and drop off access modes can be significant.

23 "Who Rides Public Transportation", American Public Transportation Association, January 2017, apta.com. https://www.apta.com/wpcontent/uploads/Resources/resources/reportsandpublications/Documents/APTA-Who-Rides-Public-Transportation-2017.pdf (accessed September 2023).

PART 6

TRANSPORTATION ENERGY IMPACT

The next to last energy use category shown in Figure 1 is used to measure "transportation energy impact." This category is added to capture secondary benefits associated with the presence of public transportation that impact transportation energy use and emissions above and beyond the actual use on a given transit trip. This category is significant because some analyses attribute the totality of positive energy and emissions benefits associated with public transportation to its influence on travel behavior and location decisions. As the discussion above indicates and as the data has indicated for years, claims of transit providing energy and emissions efficiency based on per passenger mile of travel comparisons are not always positive or compelling, particularly for bus transit. This was true even before the market disruption of COVID and adjustments for transit trip circuity enter into calculations.

This finding is reinforced in recent research sponsored by the National Academy of Sciences. The Transit Cooperative Research Program, "Research Report 226, An Update on Public Transportation's Impacts on Greenhouse Gas Emissions," updated the national analysis of public transportation's influence on climate change by documenting public transportation's 2018 GHG impacts.[24] That analysis included an evaluation of the

[24] John Mc Graw, Peter Hass, Reid Ewing and Sadegh Sabouri, "An Update on Public Transportation's Impacts on Greenhouse Gas Emissions," Transit Cooperative Research Program Report 226, 2021, https://nap.nationalacademies.org/read/26103/chapter/1 (accessed August 2023).

consumption of energy and GHG emissions associated with the provision of public transportation compared to an estimate of the additional emissions associated with increased personal vehicle operation should transit service not be available. This initial part of their overall evaluation, carried out with 2018 data, produced the two national estimates shown below:

Estimated transit vehicle GHG emissions = 12 MMT of CO_2e[25]

Estimated GHG emissions saved by passengers riding transit rather than using personal vehicles = 9 MMT[26]

These estimates indicate that annual transit operations produce 3 million more metric tons of CO_2 equivalent emissions than would have been produced had those individuals foregone trips or used alternative means of travel.

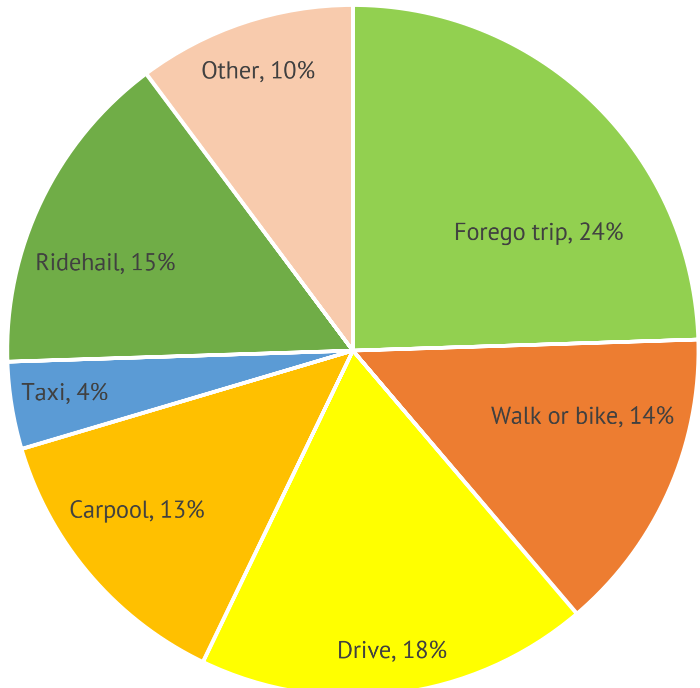
This type of analysis uses onboard survey data from transit travelers to determine what riders would do in the absence of public transit services. Information in the 2017 publication by The American Public Transportation Association, "Who Rides Public Transit 2017," was updated in 2020 to reflect the availability of ride-hailing services and some new data to produce a national estimate of what travelers would do in the absence of public transit.[27] The analysis produced the response summary shown in Figure 14 below, which was refined to produce an estimate that 33 percent of prior transit trips would be producing additional VMT in the absence of the transit option.

[25] MMT is Millions of Metric Tons. CO_2e is CO_2 equivalent emissions where other greenhouse gas emissions are converted to equivalent CO_2 emissions based on their greenhouse gas impacts.

[26] Ibid.

[27] "Economic Impact of Public Transportation Investment 2020 Update," American Public Transportation Association, February 2020, https://www.apta.com/wp-content/uploads/APTA-econ-impact-transit-investment-2020-ES.pdf (accessed August 2023).

FIGURE 14: REPORTED ALTERNATIVE MEANS OF TRAVEL IN THE ABSENCE OF TRANSIT



"Economic Impact of Public Transportation Investment 2020 Update," American Public Transportation Association, February 2020, https://www.apta.com/wp-content/uploads/APTA-econ-impact-transit-investment-2020-ES.pdf (August 2023)

This type of analysis reveals the energy use and emissions consequences of individual decisions to use public transportation. Most obviously, if new trips are induced by public transportation, their energy and emissions impacts are nonexistent, as those trips otherwise would not have been made. While they may provide quality of life and economic benefits for the travelers, they do not reduce emissions and might arguably slightly increase it. Each additional passenger could provide a tiny incremental energy and emissions impact as they may be introducing additional vehicle stops or boarding delays and potentially tiny increases in vehicle propulsion and auxiliary energy use. Similarly, trips shifted to public transit from bike and walk would not reduce energy use or emissions.

More importantly, additional travel demand may necessitate increased transit service and the associated energy consumption and emissions. For example, if free fares induced additional new trips that used transit—not trips that would have otherwise been made by an energy-consuming, emissions-emitting mode—and those trips necessitate additional transit service miles, they would have a negative energy use and emissions impact.

Alternatively, one could speculate that many trips attracted to improved transit would be trips shifting from vehicle modes as most individuals with no access to personal vehicles might already be using transit services and thus have more impact on VMT.

The most current *Energy Data Book* from the U.S. Department of Energy and the newest exploration by the Transit Cooperative Research Program, published by the National Academy of Science, Engineering and Medicine, both indicate that public transportation does not provide a direct energy or emissions savings.[28, 29] The logic behind claims of transit being a sustainable and climate-supportive mode of travel is dependent on estimates of secondary effects associated with the presence of public transportation. The TCRP report badges these as land use efficiency GHG savings.

These savings estimates, developed by a complex statistical analysis of demographic and transportation characteristics of a sample of metropolitan areas, result in an estimated reduction in emissions associated with the presence and the level of public transit services and use. The magnitude of this emissions impact is five-and-a-half times the estimated emissions of transit operations and over seven times the estimated direct emissions reductions associated with reduced VMT attributable to travelers using transit in lieu of driving personal vehicles.

Estimated transit vehicle GHG emissions	*= 12 MMT of CO_2e*
Estimated GHG emissions saved by passengers riding transit rather than using personal vehicles	*= 9 MMT of CO_2e*
Estimated GHG emissions saved by virtue of Land Use Efficiency	*= 66 MMT of CO_2e*
Estimated net savings	*= 63 MMT of CO_2e*

This widely cited document provides multipliers for metropolitan areas to enable them to determine the emissions reductions that, by virtue of the methodology, can be attributed to the presence of public transportation in the respective community.

The environmental benefits attributable to public transit are dependent upon its ability to influence behaviors and land use. The report's authors note, "The main effect of transit is not due to modal shifts from auto use to transit use but rather is due to changes in the built environment that are well served by transit." At the national level, each mile of reduced

28 *Transportation Energy Data Book: Edition 400*—2022, U.S. Department of Energy, June 2022.

29 John Mc Graw, Peter Hass, Reid Ewing and Sadegh Sabouri, "An Update on Public Transportation's Impacts on Greenhouse Gas Emissions," Transit Cooperative Research Program Report 226, 2021, https://nap.nationalacademies.org/read/26103/chapter/1 (accessed August 2023).

auto travel shifted to transit results in an additional 7.43 miles of reduced auto travel by virtue of the multiplier intended to capture the land use impact and subsequent behavior changes.

Thus, this analysis indicates that the emissions benefit attributable to public transportation is wholly dependent upon its ability to induce land use and travel behavior changes.

PART 7

PUBLIC TRANSPORTATION'S IMPACT ON LAND-USE PATTERNS AND TRAVEL BEHAVIOR

To understand the potential of public transportation to influence emissions, one must evaluate the causal relationship between public transportation and urban form. There are two key issues: 1) to what extent can public transit influence land use; and 2) to what extent does altering land use influence emissions of GHG?

Addressing the first question: While the historical influence of transportation on land use and of public transit on land use is acknowledged, what is most relevant for developing policy is understanding the strength of that relationship currently and its strength going forward in response to incremental changes in transit service and use.

The role that transit has played in shaping major metro areas across the globe and in the U.S. is well understood. This understanding, however, is shaped by the historical context that existed when major metropolitan areas were developing. Transit's influence was leveraged by the compelling case for activity agglomeration, particularly in central business districts that were the dominant activity location for commerce, business, governance, and often a critical transfer location for both local and regional travel for both persons and commodities. The era was also characterized by rapid growth in population and per capita travel, often resulting in capacity constraints creating congestion, which subsequently leveraged the accessibility enhancement provided by public transportation, particularly guideway-based systems. This development also occurred during an era where auto availability was far less prevalent than today, giving further competitive opportunities for public transportation accessibility to influence travel and development patterns.

These characteristics are potentially undermined by current and emerging conditions. First, the power of agglomeration−the desire to concentrate activities to leverage the productivity and efficiency advantage historically attributed to agglomeration of activity−is arguably significantly diminished in the evolution toward an information-based economy and the presence of powerful communication and information-sharing capabilities not dependent on face-to-face personal interaction. As the presence of COVID-induced dramatic adoption of work-at-home and information-sharing capabilities through digital media has shown, many information-based employment activities can function productively absent the historical reliance on geographic proximity.[30]

While the ultimate post-COVID telework participation share remains in flux, experts across disciplines acknowledge that a substantial share of the workforce will not be present in workplaces a significant amount of the time.[31] As the work trip has historically been significant in residential location choice decision-making, the new workplace flexibility opportunity for what could well be over 20 percent of the workforce not commuting on an average workday lessens the appeal of concentrating near employment clusters. Similarly, the preponderance of growth in information-based economic activities also undermines the criticality of businesses to locate near large concentrations of other businesses.

In addition to the diminished draw of workplaces, virtual communication enables other activity functions that historically required travel to be carried out remotely via communications. Telework, telemedicine, distance learning, e-commerce, online worship services, online banking, online business transactions, and document exchange, etc., all diminish the criticality of proximity to destinations in location choice. While COVID has accelerated the maturation of these options for carrying out activities, continued enhancement of communication capabilities, increased proliferation of customer-friendly software and connection capabilities, and aging out of the generation less experienced with or reluctant to embrace digital media, suggest continued penetration of these

30 Katherine Haan, “Remote Work Statistics and Trends in 2024,” *Forbes Advisor*, https://www.forbes.com/advisor/business/remote-work-statistics/ (accessed 18 October 2024).

31 Ibid.

capabilities. There are expectations that the comparability of digital to in-person experiences will continue to be enhanced with features such as virtual reality.

> *People choose where to live based on a few underlying factors: proximity to where they work, preferred amenities like school quality or climate, and connections to social networks of family and friends. But the pandemic may have fundamentally changed some of these factors—loosening the need to live within daily commuting distance of workplaces and increasing preference for larger homes to accommodate telework.*[32]

Another feature of the current economy relative to conditions that existed during the formative stages of most of the major metropolitan areas is the fact that in today's economy, often with multiple adult household workers, individuals often may forego the time cost of personal travel to carry out household and household member care functions. Individuals can instead procure vendors or service providers to carry out those activities, contracting out the activity and associated travel. Delivery of food and groceries is a common example of this. However, multiple other functions that historically were carried out by household members and often incurred travel for materials and supplies to carry out those functions can now be procured. Painting, cleaning, handyperson repairs, yard work, pest treatment, pet grooming and walking, and other functions are often procured. While this does not necessarily reduce total travel, it diminishes the importance of the time cost of travel to households who choose this option to carry out activities. This can accordingly diminish the importance of proximity in residential location decision making.

A second and critical aspect that is now different relates to the relative growth in travel demand. The ability of transportation to influence growth is leveraged in conditions where demand is growing rapidly, and new development seeks opportunities where accessibility is

[32] Source: Joseph W. Kane, Mona Tong, and Jenny Schuetz, "Pandemic-Fueled Suburban Growth Doesn't Mean We Should Abandon Climate Resiliency," brookings.edu, Brookings, April 12, 2022, https://www.brookings.edu/articles/pandemic-fueled-suburban-growth-doesnt-mean-we-should-abandon-climate-resiliency/ (August 2023).

available. In the period between 1945 and 1990, VMT in the U.S. grew at 4.9 percent per year, a combination of robust population growth and robust VMT growth per capita.[33] This rapid growth provided an opportunity for transportation capacity improvements to attract development, hence shaping growth. Currently, per capita VMT growth has been flat for nearly two decades, and there is no compelling case for growth going forward with several reasonable hypotheses for diminished per capita local travel.[34] Census-reported population growth is at its lowest level in decades, well below one percent per year, with natural growth very low and future growth highly dependent on immigration policy decisions.

Between 1945 and1990, interstate highways significantly shaped urban growth patterns, and several major metropolitan areas were planning and implementing guideway systems. The foundational influence of these major systems remains in place with most areas seeing only incremental and non-transformative changes in their transportation systems. Given the slower demand growth and existing maintenance and operating burdens, many metropolitan areas are unlikely to see significant macro-scale development influence from transportation system investments. In some communities, extensions of guideway systems into distant suburban or exurban areas may facilitate sprawl.

Putting transit use in perspective, before COVID, the American Community Survey indicated that about 5 percent of commuters relied on public transportation. The 2017 National Household Travel Surveys indicate approximately 2 to 2.5 percent of all household trips occurred on public transportation. The 2022 NHTS showed the usual commuting mode being 4.1 percent and the overall public transit use at 1.5 percent of household trips.[35] Given household travel constitutes approximately 60 percent of all travel and transit trips are shorter than average trips, estimates indicate that public transit carries about 1 percent or less of passenger miles of surface vehicle travel. To give a historical perspective, in 1955 public transit ridership levels were nearly 20 percent higher than levels in 2019, whereas roadway vehicle miles of travel in 1955 was less than 18 percent of its value in 2019.[36] Thus, the role, scale, and potential travel influencing ability of public transportation was far

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33 Richard Weingroff, "President Dwight D. Eisenhower and the Federal Role in Highway Safety. Appendix," U.S. Department of Transportation, https://rosap.ntl.bts.gov/view/dot/76415.

34 Steven Polzin, Irfan Batur, Ram Pendyala, "Changing Travel Behavior Insights from the 2021 ACS, ATUS, and CE Surveys," A TOMNET Policy Brief, (October 2022). https://tomnet-utc.engineering.asu.edu/briefs/ (accessed August 2023).

35 "Summary of Travel Trends 2022 National Household Travel Survey," Federal Highway Administration Office of Policy and Governmental Affairs, Washington, DC 20590, January 2024.

36 "US Urban Personal Vehicle & Public Transport Market Share from 1900," *Urban Transportation Factbook*, https://www.publicpurpose.com/ut-usptshare45.pdf (accessed October 2024)

more modest in 2019. As transit ridership remains approximately 30 to 40 percent below 2019 levels as of spring 2023, its influence on overall travel and hence its influence on land use, is now further dampened by the impact of COVID.

It is prudent to consider the extent to which incremental changes in public transportation today or in the future can realistically be expected to induce land-use changes and/or associated travel behavior changes that will reduce VMT, and hence emissions to the extent captured in statistical analysis of historically influenced land use conditions.

A theoretical foundation for how public transportation can influence land use was laid out in the paper "Transportation/Land Use Relationship: Public Transit's Impact on Land Use," *ASCE Journal of Urban Planning and Development.*[37]

The set of considerations, outlined in Figure 15, points out the contextual conditions under which one would expect a land-use impact associated with transportation investments. It identifies the conditional nature of the relationships and the components that must align to result in impacts. The figure categorizes three causal conditions of transportation infrastructure or service required to produce a land use response: direct, indirect, and secondary.

Direct Influence on Land Use Via Improved Accessibility: First, there should be a market demand for additional development. The "build it and they will come" logic doesn't follow if there is no reason to build or no reason to come; building subways in North Dakota or 10-lane freeways in rural Alaska would not be expected to create demand.

Second, and also necessary, there must be existing transportation capacity or performance constraints for new services to offer a more competitive choice. Thus, new transportation capacity is of value in stimulating demand only if the existing capacity or performance is not adequate to meet demand.

Third, the new investment has to offer real accessibility improvements–it has to offer some attributes that make it competitive for some segments of the market. Investment without meaningful improvements in performance might not be expected to generate additional development demand.

[37] Steven Polzin, "Transportation/Land-Use Relationship: Public Transit's Impact on Land Use," *ASCE Journal of Urban Planning and Development*, 125, (December 1999). 135-151.

Indirect Influence on Land Use by Complimentary Initiatives: Indirect land-use impacts may be more significant as a form of influence. Transit investments can be a catalyst for a host of planning, investment, and policy commitments that encourage development. Thus, the transit investment may be leveraged by a community to create a land-use response greater than might be achieved based solely on the changes in regional accessibility that the transit investment provides. The nature of the complementary changes is enumerated in Figure 15. These complementary actions and investments do not necessarily require transportation investment to occur but can be motivated by those investments. It has been argued that policy initiatives alone may be a far more cost-effective strategy for influencing land use independent of major investments in facilities or services.

Secondary Impacts on Land Use: This refers to development activities that are motivated by marketing and promotion and the momentum that can accompany real estate development. This category may be less significant than the preceding two categories but nonetheless is relevant in today's planning and development environment. This category is intended to acknowledge the influence of momentum, development synergies, and the impacts of promotion associated with development near major transportation investments. For example, if rail accessibility or developer inducements can attract an office building, one may get a print shop, restaurant, day care center, or other complementary development because of the natural market forces at work in the development community. To the extent that a trend can be started in development, there is often continuing momentum after the initial motivation for development has been fulfilled.

The Pace of Land Use Change: As Figure 15 suggests, the relationship between transit and land use and travel behavior impacts is complex and most probably not linear or uniform across incremental changes in transit availability. Even if one is to ignore the possibility that recalibration of the TCRP 226 Report analysis with post-COVID ridership data would produce meaningfully different answers and historic relationships between transportation and development patterns may no longer be as powerful in a world with very high levels of auto availability and nearly ubiquitous communication capabilities as a substitute for travel, one must still recognize that land use changes are incremental and slow at a metropolitan scale. The country currently has an estimated 128 million residential dwelling units and produces about 1.5 million new dwelling units annually. This pace of new dwelling unit development, recognizing that some are replacement units, provides little opportunity for dramatic shifts in residential development patterns. For example, even if all new units were in 5+ unit structures and none were replacements, it would take two decades for the share of 5+ unit dwelling households to double its modest share. Figure 16 shows trends in housing development.

FIGURE 15: THREE LAND USE RESPONSES TO TRANSPORTATION INVESTMENT

Transportation Investment

and/or

(1) Direct Transportation Impact on Land Use if:

A. Compelling market for additional development,

and

B. Existing transportation capacity or performance constraints,

and

C. Real accessibility improvements provided by investments.

TRANSPORTATION INVESTMENT

The market responds to transportation capacity and/or level of service improvements.

and/or

(2) Indirect Impact on Land Use if:

A. Reduces developer cost by:

1. Increasing allowed densities,
2. Reducing impact fees, parking requirements, etc.
3. Expecting approvals, permitting, etc.
4. Assembling land

and/or

B. Increases attractiveness via complementary enhancements such as

1. Upgraded infrastructure
2. Enhanced urban amenities, etc.,
3. Improved security.

and/or

C. Serves as a catalyst for policy change:

1. Alters land planning, zoning, site development guidelines, etc.,
2. Alters parking requirements, pricing, competing mode investments, or other transportation policies.

POLICY INCENTIVES

The market responds to policies intended to complement a transportation investment.

(3) Secondary Impacts on Land Use if:

A. Development community, households, and individuals respond to the momentum from direct and indirect impacts.

and/or

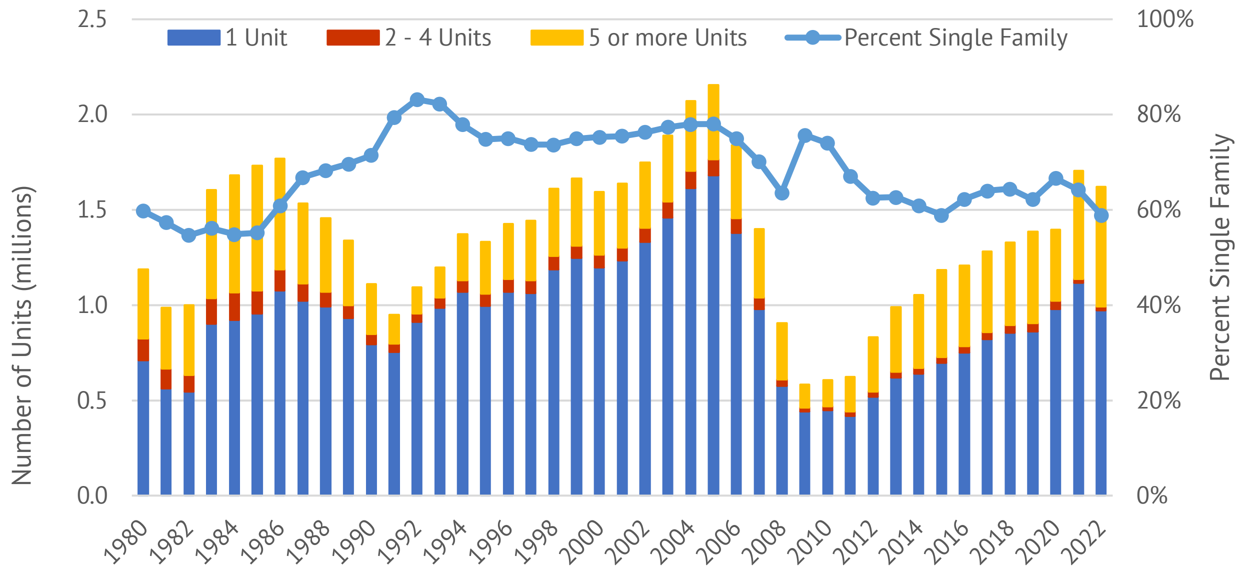
B. Development community, households or individuals respond to the expectation of direct or indirect impacts.

MOMENTUM AND PROMOTION

The market responds to the momentum of other development or to expectations not necessarily validated by investments or policy benefits.

Sources: Steven Polzin, "Transportation/Land-Use Relationship: Public Transit's Impact on Land Use," *ASCE Journal of Urban Planning and Development*, 125, (December 1999). 135-151.

FIGURE 16: U.S. HOUSING COMPOSITION TRENDS



Total Inventory 2021 ACS	
Single Family/Manufactured	75.2%
2-4 Units	6.6%
5+ Units	18.1%
128,504,000 occupied units	

Sources: "Building Permits Survey," US Census Bureau, census.gov, 2022, https://www.census.gov/construction/bps/stateannual.html (August 2023).

The second consideration, the extent by which altered land use influences emissions of GHG, is explored in numerous studies. The premise is that greater density and urban design characteristics can enable both shorter trip lengths and altered mode choices that reduce vehicle travel and subsequent emissions. While there is a substantial body of literature addressing the relationships between urban design, density, and transportation, perhaps the definitive resource that addresses the aggregate consequence at the metropolitan level is a National Academies report, “Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and CO2 Emissions — Special Report 298.”[38] This report includes a synthesis of existing research and an extensive discussion of methodological challenges associated with discerning the impacts of self-selection versus

[38] National Research Council. 2009. “Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and CO2 Emissions — Special Report 298.” Washington, D.C.: The National Academies Press. https://doi.org/10.17226/12747.

causality and the methodological, study scale, and data challenges of both aggregate and disaggregate studies.

This effort evaluated 2050 scenarios of development that included substantial changes in density. The extensive reporting was summarized: "Thus, under a wide range of conditions, reductions in VMT, energy use, and CO2 emissions resulting from compact, mixed-use development are estimated to be in the range of less than 1 percent to 11 percent."[39]

Extensive discussion addressed the challenges of influencing land use to the magnitude referenced in the scenarios. Additionally, this study, like most currently published transportation research into future travel behavior and its subsequent consequences, failed to anticipate the impact that communications and computer access is having on travel behaviors. Nor did it explore what's anticipated to be a more substantial change in energy use and emissions impacts of vehicle travel resulting from the currently forecast pace of electrification in response to current sensitivities to climate change.

Initiatives to leverage land-use changes as a strategy in emissions reductions must be considered in the context of rapid changes that are influencing travel behaviors. These other changes may significantly diminish the importance, relevance, or cost effectiveness of land-use changes as personal travel technologies move toward electrification and sustainable generation of propulsion electricity. Both the time frame for influencing land-use and travel behavior and the level of confidence that estimated impacts materialize are such that policymakers will have to weigh these issues against alternative tactics and strategies for accomplishing emissions reduction goals. For example, one might want to be cautious in estimating the magnitude of emissions reductions associated with transit improvements whose energy and emissions savings are premised on induced ridership and land-use changes in situations where there is stable or shrinking urban population or areas where there is not the political or market forces to make the policy and regulatory changes necessary to enable or incentivize complementary land use changes.

The financial and political capital required to have a meaningful land-use impact will be substantial and merit careful analysis and full disclosure of the risks, uncertainty, scale, and time frame for impacts. Not all communities have the geographic, economic, or cultural characteristics that make densification appealing. There is a substantial body of literature

[39] Ibid, page 156.

addressing all aspects of transit-oriented development that can give insight into the issues, opportunities, and potential impacts of such initiatives.

Transit can enable and support densification and reconfiguration of land use but counting on it to independently induce those changes is highly uncertain. This is particularly true in an era where the core motivation for activity concentration is diminished in a highly information-based economy with strong communications capabilities.

PART 8

NON-TRAVEL ENERGY CONSEQUENCES OF TRANSPORTATION

The final category of analysis, shown in Figure 1, is the non-travel energy consequence of transportation. In the case of public transportation, this category refers to impacts from investments in public transportation facilities and services that affect other aspects of infrastructure and people's lives that change the amount of energy use and emissions. In the case of transportation, the most obvious potential implication is the intensiveness or density of settlement patterns and its subsequent consequence on non-transportation energy consumption associated with that pattern of development. Very few analyses explore this relationship due to the uncertainty of relationships and the inadequacy of available data. The logical hypothesis would be that public transportation enables and/or induces more dense development, which may be less infrastructure intensive and by virtue of denser development patterns, utilizes less energy in building the infrastructure and providing services and building operations.[40] For example, a household living in a 2,500-square-foot suburban single family residential structure may have greater energy use to

40 Masayuki Morikawa, "Population density and efficiency in energy consumption: An empirical analysis of service establishments," *Energy Economics*, Volume 34, Issue 5, 2012, https://doi.org/10.1016/j.eneco.2012.01.004.

maintain the home than the same couple induced by transit to live in a 1,700-square-foot multifamily urban residence.

There is a body of literature on the cost of sprawl that can give some insights into perspectives on the magnitude of this impact.[41] There remain unresolved research issues, new technologies, and other considerations, including the sources and nature of energy transmission and utility system operations, that impact the energy and emissions implications of various development intensities and patterns. The referenced TCRP Report 226 did not include this consideration, nor is there available scenarios of indirect emissions implications of scenarios of land development density and patterns in light of the evolving technologies.

41 Todd Litman, "Analysis of Public Policies That Unintentionally Encourage and Subsidize Urban Sprawl," Victoria Transport Policy Institute, 2015, https://ssti.us/wp-content/uploads/sites/1303/2015/03/public-policies-encourage-sprawl-nce-report-2015-1.pdf.

PART 9

SUMMARY OBSERVATIONS

Public transportation has the opportunity to be an energy- and emissions-efficient means of moving people through two principal avenues of influence. First, by carrying large volumes of people in shared vehicles, it has the potential to reduce energy use and emissions per passenger mile of service delivered. Second, public transportation can enable more concentrated development patterns that have been shown to result in shorter trips and/or a greater propensity to use alternatives to single occupant vehicles. These characteristics continue to fuel the expectation amongst some of the broader public and many planning professionals that public transportation currently is an important contributor to resource efficiency and can play a more substantial role in the future.

However, these expectations are frustrated by empirical data that does not support the argument that public transportation, in aggregate, is operating as an energy and emissions efficient means of moving people. Use levels are simply not sufficient to support that claim. Fixed route bus services have not been operating in a manner that is more efficient on a BTUs per passenger mile basis for years. Adjusting for transit trip circuity or post-COVID ridership levels would further widen the performance gap relative to personal vehicles. Rail transit remains more efficient and is generally already electrified, but it has suffered more significantly from COVID impacts, substantially weakening its competitive advantage. Rail's national average advantage is strongly dependent on productive operations in a small number of stronger transit markets.

Given empirical data on the efficiency of transit operations, the case for transit reducing emissions is then premised on transit's influence on land use and travel behavior. Transit can enable development patterns that reduce vehicle transportation levels. However, this is premised on public transportation continuing to have the land-use- and behavior-influencing attributes that occurred during the formative years of metropolitan areas.

Uncertainty includes:

1) The diminished power of agglomeration in light of the changing nature of economic activities and the ability to substitute communications for travel;

2) The diminished competitive position of public transit relative to vehicle use given the near ubiquitous availability of vehicles and the diminished role and influence of public transportation today;

3) Increased flexibilities of employees as information jobs enable telework and work-hour flexibility reducing pressure for travel in the rush hours when transit is most competitive;

4) The diminished influence of transportation in shaping land use in an era where per capita travel demand has plateaued, and population growth is very modest; and

5) the presence of additional choices available to individuals to forgo travel, contracting products and service delivery, and the availability of additional options such as ride-hailing, short-term car rental, ebikes, scooters, and emerging micro-mobility choices.

In addition to these factors challenging the relevance of historical data as a basis for estimating public transportation's land-use influence, the modest pace of growth in residential infrastructure suggests benefits would take decades to materialize, and the electrification of vehicle travel and the movement towards sustainable electrical generation undermine the fundamental emissions-related expectations for leveraging transit as a significant tool in addressing climate change.

Public transportation's greatest opportunity for contributing to emissions reduction involves: 1) attracting personal vehicle trips to existing public transportation services or new services that operate with high levels of use; 2) scaling the vehicle capacities and service levels of transit to more closely corresponding to the scale of demand; and 3) aggressively insuring that commitments to expand transit services are coupled with policy and investment commitments to influence development patterns. The challenges and opportunities associated with a path forward are addressed in the subsequent report, “The Path Forward: Urban Mobility in a Climate Change Sensitive Post-COVID World.”

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