NORTHERN VIRGINIA TRANSPORTATION COMMISSION

Climate Benefits of Transit in Northern Virginia

March 2024

Executive Summary

The transportation sector is a major source of air pollution and one of the leading causes of greenhouse gas emissions. While personal vehicles are a major cause of air pollution, transit is an inherently climate friendly alternative that can mitigate these emissions. The purpose of this report was to explore the climate benefits of transit in Northern Virginia. Specifically, this report explored regional policies that connect transit to the climate before quantifying the climate impacts of Northern Virginia transit.

Key Findings

- ✓ The use of public transit in Northern Virginia reduces 120,000 to 160,000 metric tons of CO_2 annually.
- ✓ All bus fuel types, even diesel buses, are a much greater climate option than using cars.
- ✓ While electric cars might eventually produce fewer emissions per mile than fossil fuel buses, electric cars need to make up a much larger proportion of on-road vehicles before other bus fuel types become better options.
- ✓ There are opportunities for the region's jurisdictions and transit agencies to learn from each other when it comes to developing policies that consider how transit could benefit the climate.

Recommendations

The region can use transit to reduce Northern Virginia emissions through the following actions:

1. Increase ridership (*shorter-term)*
2. Reduce miles and hours when a transit vehicle is not taking passengers ("deadheading") where possible (*shorter-term)*
3. Increase the amount of transit in the region (*medium-term)*
4. Speed up buses using bus priority infrastructure and policies (*medium-term)*
5. Transition to zero emission buses (*longer-term)*

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Acknowledgements

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1.0 Introduction

Transportation is the number one source of greenhouse gas emissions in the United States (US), contributing 28% of all emissions, with over half of transportation emissions generated by passenger cars, SUVs and pickup trucks[1] (see **Figure 1**). Increases in vehicle miles traveled (VMT) impacted by increases in population, the economy and urban sprawl, heavily influence the growth in emissions[1]. Although improvements in vehicle fuel efficiency have helped slow the growth, transportation emissions have been creeping steadily upward for decades. Pollution from vehicles has a detrimental effect on society and the economy, worsening health outcomes and exacerbating climate change and other environmental issues[2]. And, as highways were historically built near and through low-income neighborhoods and communities of color, these effects disproportionately impact historically marginalized populations[2].

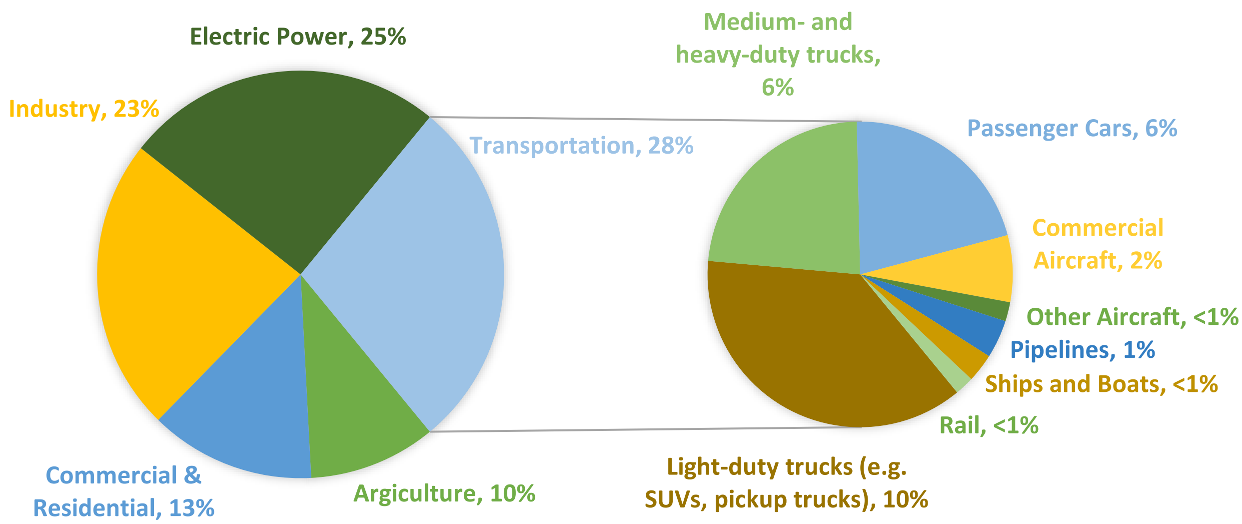

Figure 1: US greenhouse gas emissions by economic sector (EPA 2021)

While increases in vehicle fuel efficiency and electric vehicles adoption could help mitigate the issue, one of the most important ways to reduce the impact of transportation-generated pollution is through reducing demand for driving[1]. Public transportation is a critical part of this, providing a more climate friendly alternative to driving. The Washington, DC region, one of the most populated regions in the country with one of the highest levels of traffic

[1] https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions#transportation
[2] https://www.nrdc.org/stories/air-pollution-everything-you-need-know; Hajat, A., Hsia, C. and O'Neill, M.S., 2015. Socioeconomic disparities and air pollution exposure: a global review. *Current Environmental Health Reports*, 2, pp.440-450.

congestion[3], can particularly benefit from increases in transit. In this region, transportation produces over a third of the region's greenhouse gas emissions[4]. Northern Virginia warrants an even greater focus given it is the fastest growing part of the region[5] and produces a disproportionate amount of transportation emissions[6].

Considering the impact of transportation emissions, the purpose of this report is to better understand how Northern Virginia transit benefits the climate. The report begins with an overview of how transit generally benefits air quality and climate, focusing on different types of emissions, national trends and trends in the transit industry. Following the background is a summary of Northern Virginia policies that intersect transit and climate. This provides a regional understanding as to how transit is perceived to benefit the climate as well as what actions are currently being considered to improve transit's climate impact. Next, the climate benefits of transit are quantified. Finally, the report concludes with recommendations for the region.

2.0 Background

Before evaluating the climate benefits of transit in Northern Virginia, context is needed to understand what emissions are and what larger geographic and industry trends may affect or influence regional trends. This section briefly provides an overview of different types of transportation emissions, national emission trends and transit industry trends that may influence the climate benefits of transit in Northern Virginia.

2.1 Emission Types

Road vehicles produce two main types of emissions. First, there are greenhouse gas emissions like carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) that contribute to climate change[7]. CO_2 is the most abundant of these gases, making up almost 80% of US greenhouse gas emissions with 35% of CO_2 coming from transportation[8]. The second main types of emissions are air pollutants like carbon monoxide (CO), nitrogen oxides (NO_X), particulate matter (PM) and volatile organic compounds (VOC). These emissions can produce smog, which negatively impacts the environment as well as human health.

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[3] https://inrix.com/scorecard/

[4] Metropolitan Washington Community-Wide Greenhouse Gas Emissions Inventory Summary https://www.mwcog.org/documents/2022/12/27/community-wide-greenhouse-gas-emissions-inventory-summaries-featured-publications-greenhouse-gas/

[5] "Northern Virginia leads growth in Washington region" https://www.insidenova.com/headlines/northern-virginia-leads-growth-in-washington-region/article_7e4a25b2-4c7f-11ec-bc88-cb3bef339aaf.html

[6] The MWCOG Virginia GHG Emissions Inventory Summary documents show that transportation accounts for ~42% of all greenhouse gas emissions in Virginia jurisdictions, higher than the regional average of ~38%.

[7] https://www.greenvehicleguide.gov.au/pages/UnderstandingEmissions/VehicleEmissions

[8] https://www.epa.gov/ghgemissions/overview-greenhouse-gases

There are a variety of ways these emissions are mitigated. For example, air pollutants from diesel trains can be reduced using different after-exhaust technologies like diesel particulate filters or exhaust gas recirculation[9]. Electrically powered vehicles are particularly effective at reducing or eliminating the production of most of these types of emissions. However, changes to power type cannot reduce or remove all emissions. For example, electric cars can produce more non-exhaust emissions (like PM) than gasoline cars[10]. Electric cars, like all cars, also require much more space per person for transportation compared to non-automobile modes[11], increasing the environmental impacts of infrastructure and land use even as emissions per mile driven are lower. These points reinforce the importance of reducing VMT by taking fewer trips or switching to other modes like walking, bicycling, or transit where possible.

This report primarily focuses on greenhouse gas emissions, especially CO_2. This is because CO_2 is one of the most widely measured forms of emissions, making comparisons between transportation modes easier, but also because CO_2 is produced in especially large quantities and thus has one of the largest climate impacts.

2.2 National Trends

In 2021, the US produced 6.3 billion metric tons of CO_2 emissions[8]. Although there are many current approaches to reducing CO_2, including the use of new technologies and incentivizing behavior change, CO_2 emissions have only decreased by about 2% since 1990[8]. While overall CO_2 emissions have decreased over the past three decades, transportation CO_2 emissions have *increased* by almost 20% since 1990[12]. This problem is also likely to get worse.

Larger vehicles emit more pollution per mile than smaller vehicles because of their greater size and weight. This includes both exhaust emissions, as larger vehicles are less fuel efficient, as well as non-exhaust emissions, like tire and road wear. Larger vehicles also generate more emissions during manufacturing. Concerningly, trucks, SUVs and other large vehicles are becoming a greater share of US on-road vehicles. In Virginia, for example, the share of trucks (including pickups, vans, SUVs, crossovers and commercial vehicles) increased from 52% of all road vehicles in 2012 to 60% by 2021[13].

Switching modes is one of the key solutions for reducing transportation emissions. **Figure 2** shows commute mode share since 1970. As the graph shows, over the last half century drive-

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[9] The Virginia Railway Express (VRE) uses technologies like these to meet environmental Protection Agency (EPA) Tier 4 standards for diesel train locomotives https://www.epa.gov/regulations-emissions-vehicles-and-engines/regulations-emissions-locomotives

[10] Woo, S.H., Jang, H., Lee, S.B. and Lee, S., 2022. Comparison of total PM emissions emitted from electric and internal combustion engine vehicles: An experimental analysis. *Science of The Total Environment*, 842, p.156961.

[11] https://sensibletransport.org.au/project/transport-and-climate-change/

[12] https://cfpub.epa.gov/ghgdata/inventoryexplorer/#transportation/entiresector/allgas/category/all

[13] "The real reason trucks have taken over U.S. roadways" https://www.washingtonpost.com/business/2023/04/07/trucks-outnumber-cars/

alone commuting increased while all other more environmentally friendly transportation modes decreased[14]. During this period, transit fell from 8.5% of commutes to about 3.1% of commutes. Consequently, there is much that could be done to change transportation mode shares.

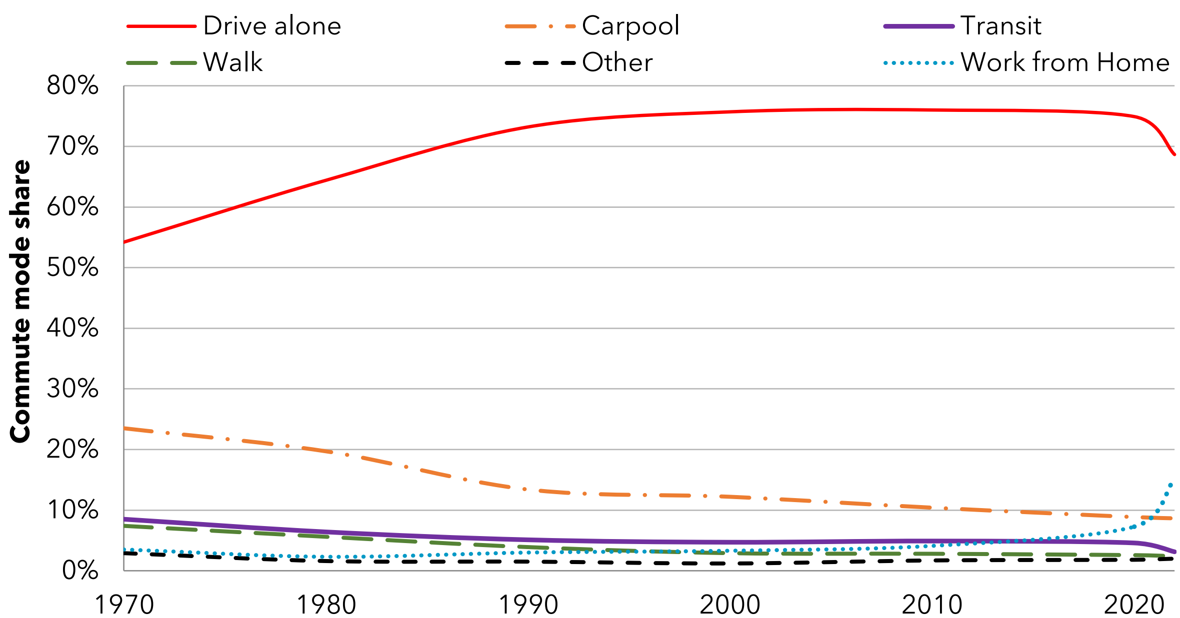

Figure 2: US commute mode share over time[15]

2.3 Transit Industry Trends

While transit is generally considered inherently greener than cars, the industry has also been working on increasing its environmental benefits through lower emission vehicles. Fuel type makes a large difference in bus emissions, for example. Compared to diesel buses, natural gas buses produce 12% fewer emissions per mile and diesel-hybrid buses produce 17% fewer emissions per mile[16]. Electric vehicles have much lower greenhouse gas emissions than vehicles that use fossil fuels and transit agencies have been taking advantage of that to reduce their vehicle emissions[16,17].

Figure 3 shows the trends in transit bus fuel types in the US. The figure shows diesel buses have been steadily decreasing, from 90% of all buses in 2001 to just 43% in 2020. Conversely, buses using natural gas have slowly been increasing over the same period, now

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[14] The only exception to this was between 2020 and 2022 when pandemic effects decreased driving alone and increased teleworking.

[15] US census data; decennial and American Community Survey 1-year estimates

[16] https://blog.ucsusa.org/jimmy-odea/electric-vs-diesel-vs-natural-gas-which-bus-is-best-for-the-climate/

[17] Intergovernmental Panel on Climate Change – Chapter 10: Transport https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_Chapter10.pdf

making up about 30% of buses by 2020. Although hybrid buses have been the fastest growing type of bus in the US over the last two decades, the share of zero emission buses, including electric and hydrogen buses, are likely to grow faster in the coming years. While it is difficult to see the change in **Figure 3**, the "Other" category, which includes electric and hydrogen buses, increased by 80% between 2019 and 2020, the largest change of any bus fuel type (hybrid buses saw the second largest change with a 5% increase). Thanks in part to federal grants aimed at low or zero emission buses[18], there is more money available to help transit agencies transition their buses away from diesel.

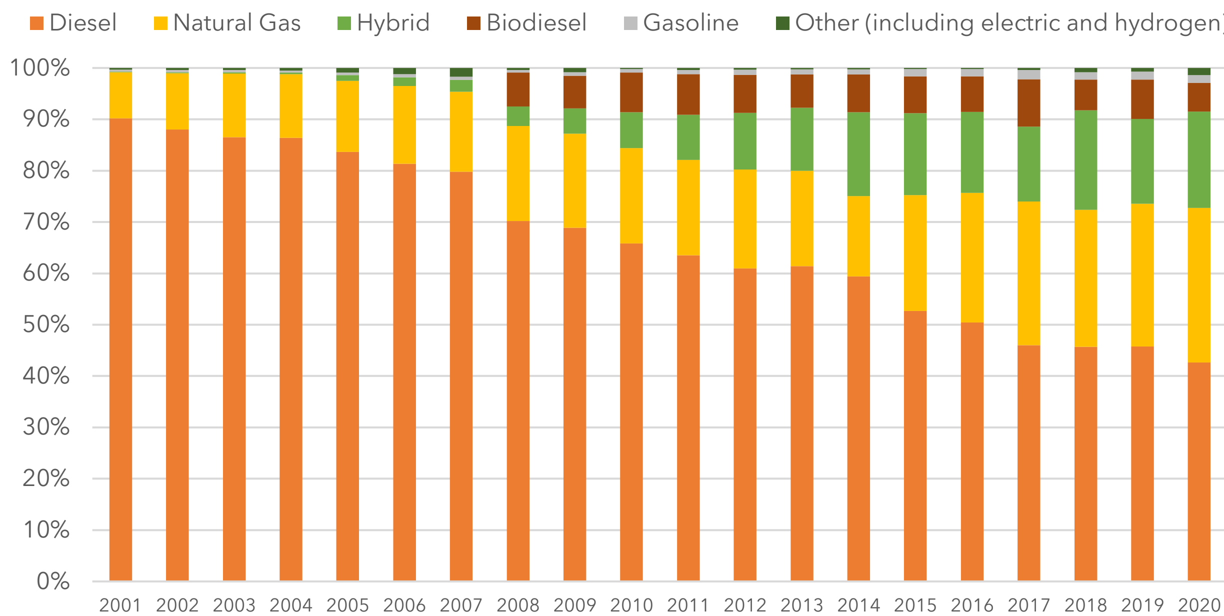

Figure 3: US transit buses by fuel type[19]

Through changes in fuel types and other technologies aimed at reducing emissions, the average transit vehicle produces 10% less CO_2 per passenger mile in 2018 than it did in 2008[20]. This trend is likely to increase over time as more electric buses are put on the street. As electricity becomes less carbon intensive[21], these benefits will be even greater. Overall, these data provide evidence of an environmentally friendly alternative to driving becoming even greener.

[18] https://www.transit.dot.gov/lowno

[19] American Public Transportation Association 2022 Public Transportation Fact Book Appendix A; *Note: Biodiesel was part of Other before 2008*

[20] McGraw J., P. Haas, R. Ewing, and S. Sabouri. 2021. TCRP Research Report 226: An Update on Public Transportation's Impacts on Greenhouse Gas Emissions. https://nap.nationalacademies.org/catalog/26103/an-update-on-public-transportations-impacts-on-greenhouse-gas-emissions

[21] US electricity was 29% less carbon intensive in 2018 compared to 2005 (TCRP Research Report 226)

3.0 Northern Virginia Transit Climate Policies

Northern Virginia transit agencies and jurisdictions have broadly recognized the relationship between transit and the climate. The region is transit rich with eight transit agencies serving over 1.5 million weekly transit riders[22,23]. However, regional jurisdictions and transit agencies vary significantly in defining what climate goals transit can help with, how transit might be able to be used to achieve climate goals and how transit's impacts can be measured. This section synthesizes Northern Virginia policies that connect transit to climate. **Appendix A** includes all goals or policies that connect transit to climate for each of Northern Virginia's jurisdictions and transit agencies[24]. Regional policies are categorized in three ways:

- **Climate Goals** –In what ways transit benefits the climate.
- **Transit Actions** – What explicit actions or steps a jurisdiction/agency is taking or plans to do to increase transit's climate benefits.
- **Performance Measures** – How a jurisdiction/agency intends to track transit's climate impacts.

There is large variation in both the types of content as well as the breadth of content each jurisdiction or agency includes in their policies. Overall, most jurisdictions/agencies identified advancing environmental sustainability as an important goal. Reducing emissions or greenhouse gases was also mentioned by half of the included organizations. Outside of these two goals, transit was associated with a variety of climate goals including improving air quality and helping mitigate climate change. The path to achieving different climate goals also varied significantly. Different transit actions were grouped under seven subheadings, described below. **Table 1** provides examples of many of the transit actions mentioned in regional policies.

- **Increase Ridership** – Policies designed to get people to use transit.
- **Transit Vehicles** – Actions to reduce environmental impacts of transit vehicles.
- **Transit Operations** – Operational strategies to benefit the environment.
- **Transit Facilities** – The buildings, stops and other facilities that transit agencies build, maintain or operate.
- **Other Transit Infrastructure** – Infrastructure other than buildings and stops.
- **Studies** – Areas where further study might be required before actions can be undertaken.
- **Other** – Anything not captured in the other categories.

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[22] https://novatransit.org/transit-dashboard/

[23] Northern Virginia is defined as the counties of Fairfax, Arlington and Loudoun and the cities of Alexandria, Fairfax and Fals Church. Northern Virginia transit agencies include Arlington Transit (ART), Loudoun County Transit, DASH, Fairfax Connector, City-University Energy Saver (CUE), the Virginia Railway Express (VRE) and the Washington Metropolitan Area Transit Authority (Metro).

[24] Source documents are listed in **Appendix B**. This list is not comprehensive as transit agencies and jurisdictions may have policies that are not captured in publicly accessible documents.

Table 1: Climate friendly transit actions in Northern Virginia policies

#	Transit Actions	Examples
1	Increase Ridership	Improve equity, improve rider experience, incentivize transit-oriented development
2	Vehicle	Zero-emission buses, electric paratransit or staff vehicles, renewable natural gas
3	Operations	Increase service, utilize regenerative braking
4	Facilities	Energy efficient lighting, solar panels
5	Other Infrastructure	Bus priority infrastructure, on-route charging
6	Studies	Zero-emission bus implementation, transit facilities
7	Other	Increase education, energy audits

One of the largest climate benefits of transit comes from people using transit rather than a car. Policies focusing on increasing ridership are an important strategy for increasing environmental sustainability. As **Appendix A** shows, finding ways to encourage people to use transit was the most mentioned policy action. However, other actions like making transit easier to use or improving the rider experience, implicitly achieve the same outcome. While generally out of the control of transit agencies[25], incentivizing transit-oriented development (TOD) is another way to help increase transit ridership.

> *"…the environmental benefits of transit only arise from many people riding the bus rather than driving, taking a taxi, or otherwise getting a ride in a private vehicle."*
>
> *– Alexandria Transit Vision Plan*[26]

As **Section 2.3** demonstrated, one of the most significant climate trends in transit is the move towards more environmentally friendly vehicles. Thus, it is not surprising that transit vehicles feature heavily in policies considering both transit and climate. As **Appendix A** shows, every jurisdiction or agency with bus service is testing, has tested or is considering using zero or low emission buses. These primarily include electric buses, with all but one agency trying them, as well as natural gas and hybrid buses. Although Metrorail is already electric, their trains have been retrofitted with technologies to reduce energy consumption and thus produce fewer emissions while in operation.

[25] Metro is an exception here as they have a dedicated group focusing on TOD. https://www.wmata.com/business/real-estate/transit-oriented-development.cfm

[26] Alexandria Transit Vision Plan https://media.alexandriava.gov/docs-archives/tes/alexandria-transit-vision-final-report-=2020-02-24.pdf

Vehicles are not the only way transit agencies can reduce emissions. As **Appendix A** shows, transit operations can also help reduce emissions. The policies appear to focus on two strategies. First, increasing or improving transit service can help increase ridership and incentivize people to switch from a car to a bus or train, decreasing emissions. Second, Metro describes operational strategies that reduce train emissions when in operation.

Although transit operations are a unique way transit agencies can help benefit the climate, they have buildings and facilities that can leverage strategies to reduce emissions and pollution shared by a variety of other industries. For example, using green building practices, using solar panels and implementing energy efficient lighting. Given electric vehicles are so prevalent in transit climate strategies, it is unsurprising installing electric vehicle chargers is the most popular action mentioned.

Transit agencies can also use on-route infrastructure to improve the environmental sustainability of their operations. First, on-route bus charging is widely being considered to improve the range of electric buses. Second, increasing bus priority infrastructure, like transit signal priority and bus only lanes, are another way to improve the climate benefits of transit. Bus priority infrastructure helps because vehicles produce more emissions at lower speeds[27]. Consequently, bus emissions per mile increase when they are slowed in congestion.

Not all transit agencies or jurisdictions have the requisite knowledge to start funding actions that help transit benefit the climate. Several jurisdictions/agencies are considering studies to help them make more climate conscious decisions. Zero emission bus studies are the most popular study option with regional studies on the topic also coming from NVTC[28] and the Virginia Department of Rail and Public Transportation (DRPT)[29].

There are also a variety of other actions transit agencies can take that don't fit into one of the other sub-categories. **Appendix A** demonstrates several of them including energy audits, increasing education and awareness of the climate impacts of transit and learning from others through reviewing best practices.

The final category of transit and climate policies in **Appendix A** focused on performance measures. This category contained the least content in the reviewed documents. Of the measures listed, the most popular focused on measuring or estimating greenhouse gas emissions, followed by quantifying energy use and financial savings. Although financial savings do not explicitly demonstrate climate benefits, they can be used to help make the case as to why investment in climate actions are beneficial.

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[27] Barth, M. and Boriboonsomsin, K., 2008. Real-world carbon dioxide impacts of traffic congestion. *Transportation Research Record*, 2058(1), pp.163-171.
[28] https://novatransit.org/programs/transit-technology/
[29] https://drpt.virginia.gov/work/modernizing-transit-fleets/

4.0 Northern Virginia Transit and Greenhouse Gas Emissions

Northern Virginia jurisdictions and transit agencies do more for the climate than propose policies and strategies. The services in operation are already helping the climate. Consequently, it is useful to understand how much of an impact transit has in the region and could have in the region as transit trends described earlier (see **Section 2.3**) progress. This section quantifies the climate effects of Northern Virginia transit policies and actions. A recent Transit Cooperative Research Program (TCRP) report[20] highlighted different ways the greenhouse gas emissions of transit can be analyzed:

- **Avoiding Personal Vehicle Emissions** – The emissions saved or reduced by switching from cars to transit.
- **Transit Vehicle Greenhouse Gas Emissions** – The impact different types of transit vehicles and different transit fuel types have on emissions.

The following sections analyze transit's climate impact using each of these methods.

4.1 Avoiding Personal Vehicle Emissions

One of transit's largest climate benefits comes from reducing the number of personal vehicles on the road. Thus, the first evaluation estimates the CO_2 emissions avoided by using fixed-route transit instead of driving a personal vehicle. Two data sources were used to estimate avoided personal vehicle emissions. The first uses the Metropolitan Washington Council of Governments (MWCOG) Transportation Planning Board (TPB) Regional Travel Survey (RTS) while the second uses the Federal Transit Administration (FTA) National Transit Database (NTD). **Appendix C** describes both methods. Using 2017 as an estimate year, the year of the most recent RTS data, transit in Northern Virginia avoided approximately 120,000 to 160,000 metric tons of CO_2. **Figure 4** provides CO_2 equivalencies[30] to further demonstrate transit's impact.

The RTS data allows us to see how the personal vehicle emissions savings vary through the region. **Table 2** shows the estimated CO_2 emissions avoided between different jurisdictions in the region[31]. As the table shows, while a substantial number of emissions are avoided for trips going to other parts of Virginia, Maryland, or the District of Columbia, many emissions are also avoided within Northern Virginia.

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[30] Equivalencies from the EPA Greenhouse Gas Equivalencies Calculator https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

[31] The table sums to more than 160,000 metric tons cited earlier because it also includes emissions from trips that enter Northern Virginia from Maryland, the District of Columbia, or other parts of Virginia.

13,500,000 gallons of gasoline

27,000 cars driven for one year
(cars end-to-end would go from Washington, DC to Richmond, VA)

33 wind turbines running for a year

Over **15,000** homes' energy use for one year

Almost **2,000,000** tree seedlings grown for 10 years

Figure 4: Northern Virginia transit CO_2 equivalents

Table 2: Personal CO_2 emissions (metric tons) avoided by using transit disaggregated by origin-destination pair

		Destination								
		Alexandria City	Arlington County	Fairfax City	Fairfax County	Falls Church City	Loudoun County	Other Virginia	District of Columbia	Maryland
Origin	Alexandria City	969	1,610	-	1,045	-	-	4,002	6,777	1,235
	Arlington County	1,595	3,474	263	9,996	158	2,259	9,776	12,745	9,166
	Fairfax City	-	105	61	253	-	-	-	461	255
	Fairfax County	1,054	9,506	152	21,863	35	1,131	2,154	29,373	3,761
	Falls Church City	-	159	-	2	117	-	-	890	-
	Loudoun County	-	2,489	-	962	-	5,571	56	10,028	1,733
	Other Virginia	4,051	8,066	-	1,137	-	-	24,753	28,405	1,056
	District of Columbia	6,478	12,653	378	27,977	880	9,838	27,556	-	-
	Maryland	1,391	8,126	-	4,295	-	1,770	1,056	-	-

Note: darker shading indicates more CO_2 emissions avoided

While the use of transit in the region can avoid a substantial level of emissions, the large drop in regional ridership driven by the COVID-19 pandemic has also had an impact on how many emissions are avoided. **Figure 5** shows how much emissions have changed over time. As the figure shows, emissions in FY 2021 dropped to less than 20% of pre-pandemic emissions. However, avoided emissions are on an upward trend, doubling between FY 2021 and FY 2022.

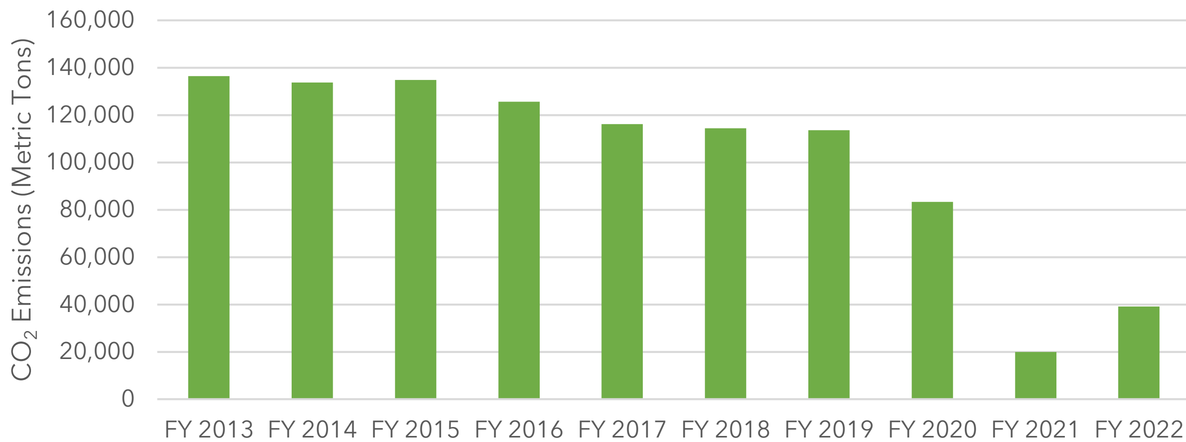

Figure 5: Personal CO_2 emissions avoided by taking transit in Northern Virginia

Not all modes of transit avoid emissions in the same way. Avoided emissions are directly related to the length of the trip taken by transit. **Figure 6** shows the proportion of avoided emissions sorted by each of the region's transit modes. As the figure shows, commuter-oriented transit, that typically serves longer trips, saves a disproportionate amount of carbon emissions. For example, while commuter rail made up just 0.5% of regional transit ridership in FY 2022, it was responsible for almost 9% of CO_2 emissions avoided.

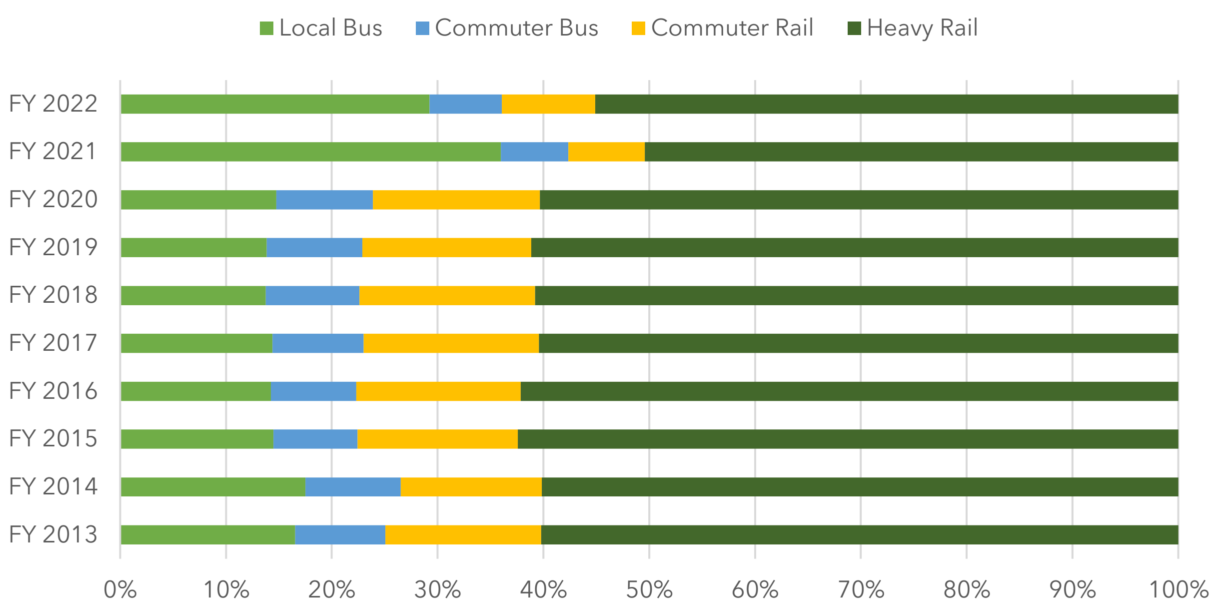

Figure 6: Proportion of CO_2 emissions avoided by transit mode in Northern Virginia

4.2 Transit Vehicle Greenhouse Gas Emissions

As noted by Metro in the quote below, transit is inherently sustainable when compared to cars. However, there are still opportunities to reduce transit emissions, further increasing the environmental benefits of transit in the region. **Section 2.3** demonstrated the evolution of bus fuel types in the national transit industry. Consequently, this section focuses on the impact different transit vehicles have on greenhouse gas emissions in the region.

> *"Metro's core business—moving people on public transportation—is inherently sustainable. Every trip taken with Metro instead of a car reduces the region's carbon footprint."*
>
> *– Metro 2020-2021 Sustainability Report*[32]

As **Figure 7** shows, Northern Virginia transit agencies primarily operate diesel buses. Almost three-quarters of the region's bus miles are diesel; however, **Figure 3** demonstrated earlier that only about 43% of US transit buses use diesel. This suggests the region may be lagging national trends when it comes to transitioning buses away from diesel. This may be because of the relative lack of hybrid buses in Northern Virginia and because the region has a greater focus on long-distance commuter routes which currently rely more on diesel buses. As **Appendix A** demonstrated, most transit agencies in the region are considering fully electric buses rather than hybrids. However, the inherently sustainable attributes of transit mean even diesel buses can benefit the climate.

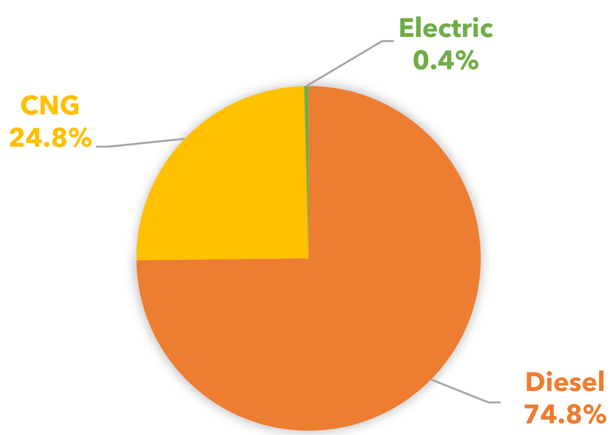

Figure 7: Northern Virginia transit agency bus miles by fuel type (FTA NTD 2021)

[32] https://www.wmata.com/initiatives/sustainability/upload/2020-2021-Sustainability-Report_final.pdf

Transit vehicles have greater capacity than cars, meaning much lower emissions per passenger mile. However, an empty bus has higher emissions than a car. A breakeven analysis provides a way to estimate when a bus becomes a better option for travel than a car[33]. **Appendix D** explains the calculation process for determining when transit CO_2 emissions are equivalent to car CO_2 emissions. **Figure 8** shows how full a transit vehicle needs to be to have lower emissions per passenger mile than a car. The calculations used account for non-revenue transit miles ("*deadheading*") and assume cars carry an average of 1.67 people per car[34], 42 people per bus[35], 878 people per VRE commuter train[36], and 880 per Metrorail train[37].

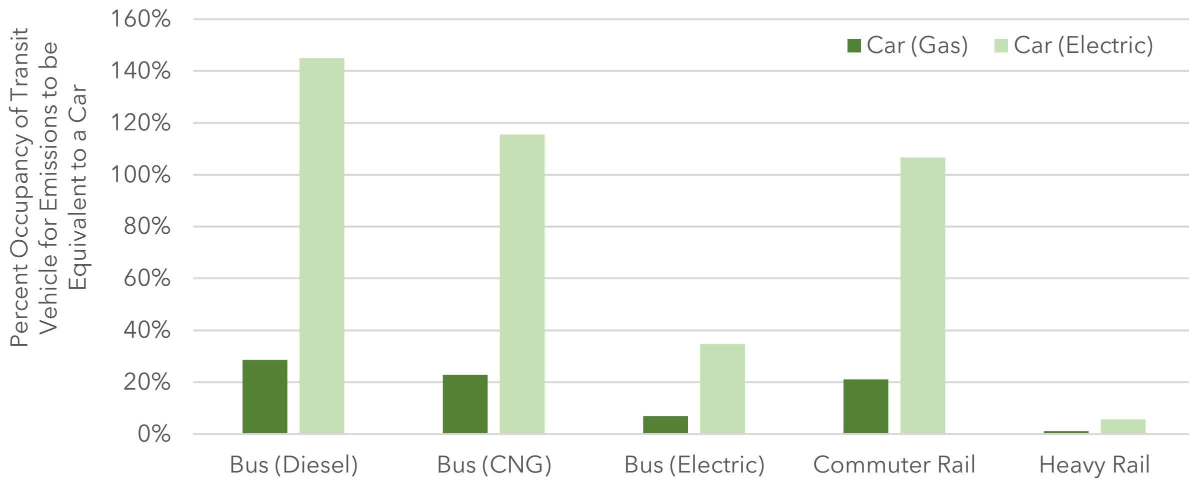

Figure 8: Transit and car emissions per passenger mile breakeven analysis

As the figure shows, all transit vehicle types used in Northern Virginia can operate less than half empty and still have lower emissions than personal vehicles using gasoline. However, when considering just the emissions produced per mile of travel, fully electric cars may have lower emissions than transit vehicles that use fossil fuels.

While transit vehicles are more efficient than cars on a passenger mile basis, manufacturing transit vehicles produce more emissions than manufacturing cars. Electric vehicles also have more manufacturing emissions than fossil fuel vehicles. Consequently, an emission

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[33] As mentioned earlier, this analysis does not consider the other environmental benefits of transit over cars including particulate matter and the lower infrastructure and land use emissions required to support transit over cars.

[34] Average vehicle occupancy https://www.energy.gov/eere/vehicles/articles/fotw-1040-july-30-2018-average-vehicle-occupancy-remains-unchanged-2009-2017

[35] https://www.codot.gov/programs/innovativemobility/assets/commuterchoices/documents/trandir_transit.pdf

[36] Estimated with consultation from VRE staff.

[37] https://dcist.com/story/23/04/20/metros-8000-series-trains-will-have-new-seating-configurations-and-d-c-icons-new-renderings-show/

breakeven analysis was also performed considering manufacturing emissions[38]. The results are shown in **Figure 9**. As the figure shows, buses need to have many more people per trip to be competitive to cars earlier in their life cycle. However, the more a bus is used, the lower the number of passengers required to replace a gasoline car. This relationship changes for electric cars and fossil fuel buses. For fossil fuel buses, the more a bus is used, the greater the average number of passengers required to replace an electric car.

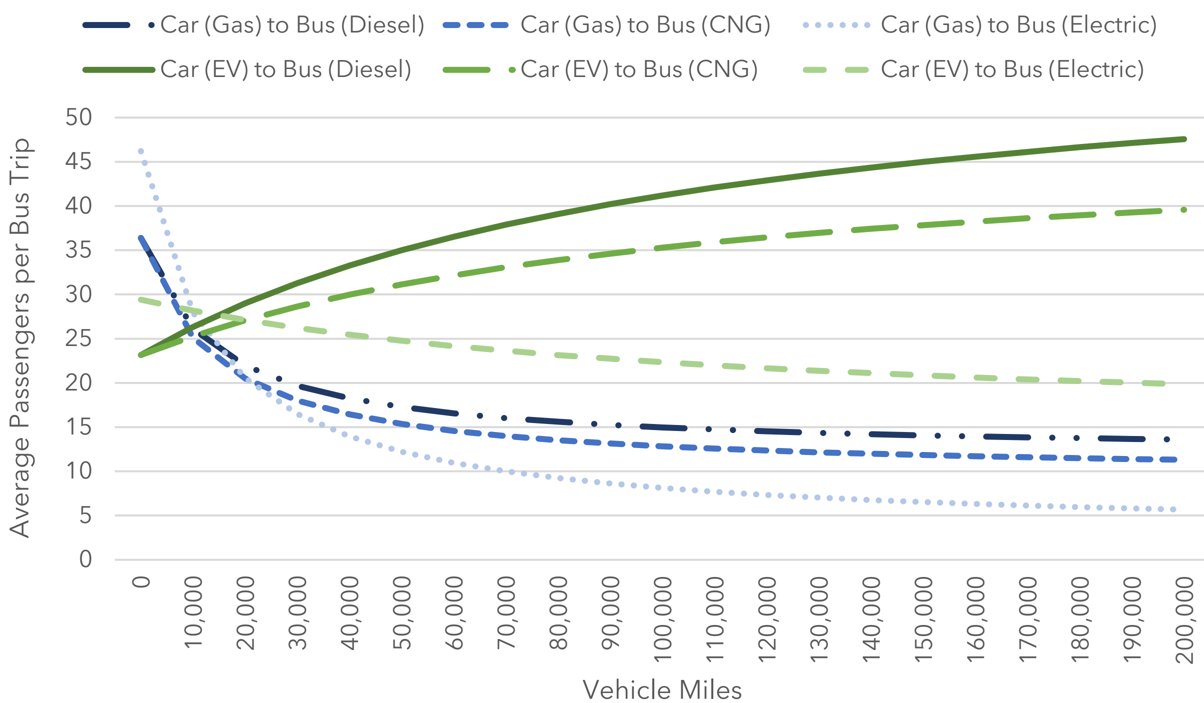

Figure 9: Bus and car breakeven analysis

Both **Figures 8 and 9** demonstrated that electric cars are much more competitive compared to transit when it comes to lowering transportation emissions. However, less than 1% of current road vehicles are fully electric or electric hybrids[39]. **Figure 10** shows how the emissions breakeven analysis for different bus fuel types changes as the proportion of on-road vehicle fuel types changes (i.e., the number of electric cars increase). As the figure shows, the trend away for fossil fuel buses is slow. Even if electric cars increase from 1% to 10% of all cars, an average diesel bus needs only to carry one additional person to be a better environmental option. Further, 85% of all on-road vehicles need to be electric for electric buses to have a similar breakeven to diesel buses today. A conservative estimate

[38] Data for rail vehicle manufacturing emissions was not available so all emission calculations are for buses only

[39] Number of electric vehicles (https://www.eia.gov/todayinenergy/detail.php?id=60422) divided by all road vehicles (https://www.bts.gov/content/number-us-aircraft-vehicles-vessels-and-other-conveyances)

suggests it may take more than 20 years to reach that point (see **Appendix E**), enough time to fully turnover an average bus fleet 1.8 times[40].

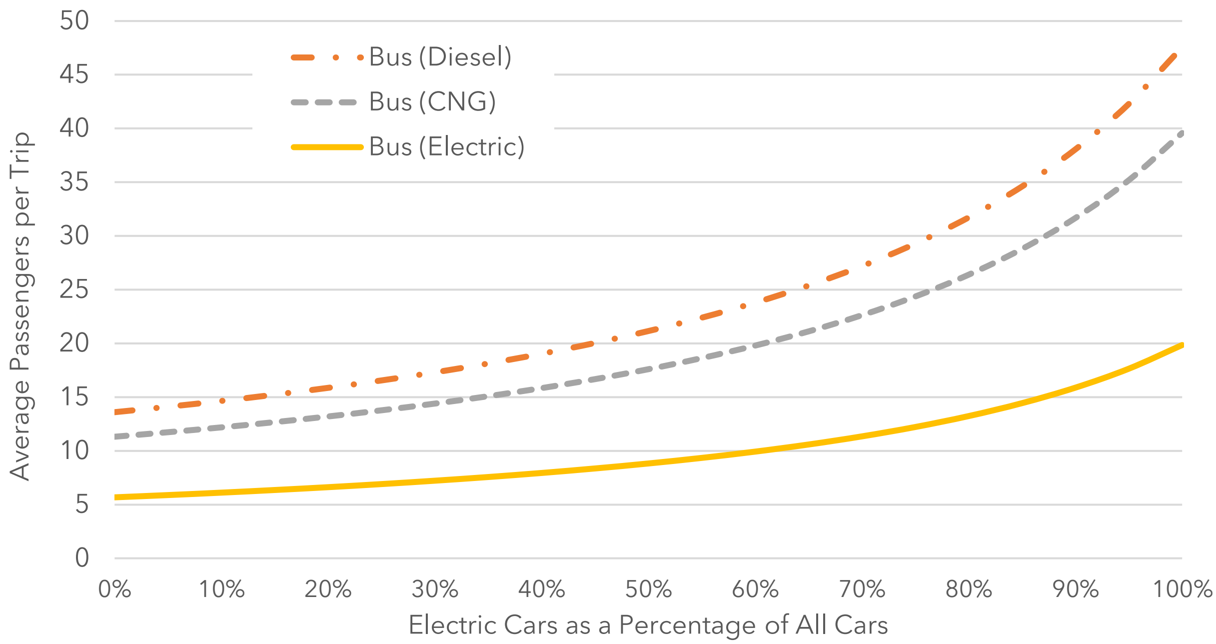

Figure 10: Breakeven analysis considering EV car composition

5.0 Conclusions and Recommendations

Transportation is a major source of air pollution and one of the leading causes of greenhouse gas emissions. While personal vehicles are a major cause of pollution, transit is an inherently climate friendly alternative that can be used to mitigate these emissions. Consequently, this report explores the climate benefits of transit in Northern Virginia. Specifically, this report reviewed regional policies that connect transit to the climate before quantifying the climate impacts of Northern Virginia transit.

The transit and climate policies were evaluated to find themes. These themes reflected policy goals, policy actions and different measures of success. Overall, the lack of policy consistency is a regular theme in regional policies that consider both transit and the climate. In Northern Virginia, coordination and collaboration is one of the region's strengths, both of which are an integral part of providing a useful transit network. Thus, as Loudoun highlights in the quote below, there are opportunities for the region's jurisdictions and transit agencies to learn from their own experiences as well as each other when it comes to developing policies that consider how transit could benefit the climate.

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[40] Assuming an average bus has a useful life of 12 years https://drpt.virginia.gov/wp-content/uploads/2023/07/useful-life-chart.pdf

> *"Leverage lessons from […] systems currently installed at County transit maintenance and operations facility and apply those to […] other transit maintenance facilities."*
>
> *– Loudoun County Energy Strategy*[41]

The climate impacts of Northern Virginia transit were quantified in two ways. First, this report estimated the amount of greenhouse gas emissions avoided by using transit. Using the most recent year of regional travel survey data from 2017, it is estimated the use of transit in the region reduces 120,000 to 160,000 metric tons of CO_2 annually. Although the COVID-19 pandemic has significantly reduced that number, the trend is reversing with transit use in FY 2022 saving twice as many emissions as transit use in FY 2021.

In the background, this report demonstrates the transit industry is working on making an already environmentally friendly industry even more sustainable by using lower emission vehicles. Northern Virginia is following this trend. Consequently, the second evaluation of Northern Virginia transit considered the tradeoff in vehicle fuel types. This analysis demonstrated that even diesel buses are a much greater climate option than using cars. While electric cars might eventually produce fewer emissions per mile than fossil fuel buses, electric cars need to make up a much larger proportion of on-road vehicles before other bus fuel types become better options.

Overall, transit is inherently an climate friendly mobility alternative in Northern Virginia. However, there are opportunities to increase the climate benefits of the region's transit. This report concludes with some recommendations for improving the climate benefits of transit in Northern Virginia.

1. Increase ridership (*Shorter-Term)*

As noted earlier, "the environmental benefits of transit only arise from many people riding the bus." The more people who ride transit, the more climate friendly transit becomes. **Figure 5** demonstrated COVID-19 related ridership impacts[42] have resulted in a drop in the greenhouse gas emissions avoided through transit. Consequently, increasing transit ridership should be one of the key focuses of increasing the climate benefits of transit. As **Appendix A** demonstrated, ridership can be encouraged by making transit easier to use, improving the rider experience, increasing transit equity and access, or incentivizing transit-friendly land use

[41] https://www.loudoun.gov/DocumentCenter/View/174600/Loudoun-County-Energy-Strategy-Final-Report---2023

[42] Northern Virginia Transit through the COVID-19 Pandemic (2022) https://novatransit.org/uploads/studiesarchive/2022NoVaCOVIDTransitReport.pdf

and development. As noted by Fairfax County, improving transit services through network redesigns and schedule adjustments are another way to help increase ridership.

> *"Optimizing bus schedules and connecting transit to where people live, work, and play is good for emission reduction"*
>
> *– Fairfax County*
> *Office of Environmental and Energy Coordination*[43]

2. Reduce deadheading where possible (*Shorter-Term*)

Deadheading is the distance a transit vehicle covers when not in revenue service. For example, a bus might deadhead between where it is stored at night and the beginning of the route to start service. The more distance transit vehicles cover without passengers, the lower the climate benefits of the service. This is because each deadhead mile is equivalent to a revenue mile for a completely empty bus. Consequently, reducing deadhead mileage can increase transit climate efficiency. While the region's buses average 22% deadhead hours for every revenue hour, this varies significantly by agency. Regional deadheading ranges from 3% to 43% for buses and is 4-5% for rail (FTA NTD data). Just a 1% reduction in deadheading (going from 22% deadhead miles to just under 21%) would save almost an average of 30g of CO_2 for every revenue mile traveled. If bus deadheading was similar to rail deadheading, for example, a diesel bus would need to be 4% less full to still be a better climate option than a gasoline car.

3. Increase the amount of transit in the region (*Medium-Term*)

As the EPA notes[1], reducing travel demand for personal vehicles are one of the major opportunities for reducing transportation emissions. More transit choices make it easier for people to use transit instead of driving for their regular mobility needs. Consequently, making transit more frequent and ubiquitous is another opportunity to reduce regional emissions.

> *"Building public transportation, sidewalks, and bike paths […] increases lower-emission transportation choices."*
>
> *– US Environmental Protection Agency (EPA)*[1]

[43] https://www.fairfaxcounty.gov/environment-energy-coordination/reduce-vehicle-miles-traveled

As ridership is still recovering post pandemic, and there are current pressing financial needs for existing transit services, this is a difficult recommendation to implement immediately. However, this is still a goal the region should work towards.

4. Speed up buses using bus priority infrastructure and policies (*Medium-Term*)

Slower vehicles cause more emissions than faster vehicles[26]. While a bus is generally more climate friendly than a car, a faster bus is more climate friendly than a slower bus. Congestion is a major cause of slower buses[44] and the region should increase investment in bus priority infrastructure to make buses faster and more reliable. This is expected to be a medium-term goal because of the processes and resources required for implementation. However, regional partners are already working towards making faster buses a priority[45].

5. Transition to zero emission buses (*Longer-Term*)

Both electric and hydrogen buses have significantly lower emissions per mile than other bus fuel types. However, transit agencies are still deciding which might be better in the long term. As **Section 4.2** demonstrates, diesel buses are still a much better option than cars today. However, as electric cars become an increasingly large share of on-route vehicles, transit should also transition away from fossil fuels. Thus, while a longer-term strategy should consider transitioning to zero emission buses, like electric or hydrogen, this does not need to be an immediate priority.

[44] Advancing Bus Priority in Northern Virginia (2023) https://novatransit.org/uploads/studiesarchive/NVTC%20Report%20-%20Advancing%20Bus%20Priority.pdf

[45] https://www.wmata.com/initiatives/plans/bus-priority/index.cfm

Appendix A: Northern Virginia Transit Climate Policies

Table 3: Northern Virginia transit environmental policies

Category	Policies	Jurisdiction/ Transit Agency							
		Arlington County/ ART	City of Alexandria/ DASH	OmniRide	Loudoun County	City of Fairfax/ CUE	Fairfax County	Metro (WMATA)	VRE
Climate-related Goals	*Advance environmental sustainability*	✓	✓		✓			✓	✓
	Carbon neutrality	✓					✓		
	Climate change mitigation/resilience							✓	
	Improve air quality		✓				✓	✓	
	Increase energy efficiency	✓						✓	
	Land use efficiency/ conserve land		✓						
	Make transportation greener		✓			✓			
	Reduce dependence on fossil fuels						✓		
	Reduce emissions and greenhouse gasses	✓	✓	✓			✓	✓	
	Reduce single occupancy vehicle usage and vehicle miles traveled (VMT)		✓		✓		✓		
Transit Actions	**Increase Ridership**								
	Develop mobile transit app/payment		✓					✓	
	Encourage transit use	✓	✓				✓		
	Improve rider experience		✓					✓	
	Improve transit equity							✓	
	Incentivize/build transit-oriented development (TOD)						✓	✓	
	Transit Vehicles								
	Test or Pilot Hybrid buses					✓			
	Minimize use of petroleum-based fuels						✓		
	Prioritize low emission buses	✓			✓				
	Retrofit railcars with energy efficiency technologies							✓	
	Test/buy zero emission buses/ electric buses/ hydrogen buses	✓	✓	✓	✓		✓	✓	

Category	Policies	Jurisdiction/ Transit Agency							
		Arlington County/ ART	City of Alexandria/ DASH	OmniRide	Loudoun County	City of Fairfax/ CUE	Fairfax County	Metro (WMATA)	VRE
	Buy electric vehicles for paratransit vehicles			✓					
	Buy electric vehicles for staff vehicles			✓		✓			
	Transition fleet to zero-emission buses	✓	✓	✓			✓	✓	
	Use renewable natural gas	✓							
	Transit Operations								
	Increase/ improve transit service		✓				✓	✓	
	Use pocket tracks and turn backs to increase train operation efficiency							✓	
	Utilize regenerative braking							✓	
	Transit Facilities								
	Efficient switch heaters, third rail heaters and controls for heaters and transformers							✓	
	Energy efficiency lighting upgrades							✓	
	Incorporate green building practices in all transit facilities including bus shelters	✓						✓	
	Install electric vehicle chargers	✓	✓	✓			✓	✓	
	Leverage lessons from geothermal exchange systems installed at transit maintenance and operations facilities				✓				
	Solar panels (e.g. bus stops, car ports)	✓	✓					✓	
	Other Transit Infrastructure								
	Build bus priority infrastructure		✓					✓	
	Evaluate on-route bus charging		✓						
	Study								
	Consider the environmental impacts of transit facilities	✓							
	Compare the efficiencies and environmental	✓							

Category	Policies	Jurisdiction/ Transit Agency							
		Arlington County/ ART	City of Alexandria/ DASH	OmniRide	Loudoun County	City of Fairfax/ CUE	Fairfax County	Metro (WMATA)	VRE
	impacts of alternative fuel options								
	Research new technologies and maintenance practices	✓							
	Study zero emission buses	✓	✓	✓				✓	
	Other								
	Buy climate bonds							✓	
	Increase education and awareness							✓	
	Increase use of renewable energy							✓	
	Innovate							✓	
	Personalized rider emissions impact reporting							✓	
	Regular energy audits							✓	
	Review Best Practices with peer agencies and other industries							✓	
Performance Measures	*Energy use*							✓	✓
	Financial savings							✓	✓
	Fuel consumption (as measured in BTUs) of transit vehicle operations	✓							
	Greenhouse gas emissions avoided by using transit							✓	✓
	Greenhouse gas emissions related to transit operations	✓						✓	
	Miles of dedicated bus infrastructure		✓						
	Mode share		✓						
	Reductions in weather-related delays								✓

Appendix B: Transit Climate Policy Reference Documents

Table 4: Northern Virginia transit and climate policy sources

Agency	Year	Title	Link
Arlington County/ ART	2023	ART Zero-Emissions Bus Study	https://www.arlingtonva.us/files/sharedassets/public/v/1/transportation/documents/zero-emissions-buses/art-zeb-study-final-report-nov2023.pdf
Arlington County/ ART	2023	Arlington Transit Purchases Electric Buses (Press Release)	https://www.arlingtonva.us/About-Arlington/Newsroom/Articles/2023/Arlington-Transit-Purchases-Electric-Buses
Arlington County/ ART	2021	ART Operations and Maintenance Facility Community Meeting	https://www.arlingtonva.us/files/sharedassets/public/v/1/projects/documents/20210615-aomf-community-mtg-3.pdf
Arlington County/ ART	2020	Arlington Projects	https://www.arlingtonva.us/Government/Projects/Project-Types/Transportation-Projects/ZEB
Arlington County/ ART	2016	Master Transportation Plan	https://arlingtonva.s3.amazonaws.com/wp-content/uploads/sites/31/2017/03/2016.12.5-MTP-Transit-Update-Board-Report-Attachment-B.pdf
City of Alexandria/ DASH	2021	Alexandria Mobility Plan	https://media.alexandriava.gov/docs-archives/tes/info/alexandriamobilityplan=full-document=3=.pdf
City of Alexandria/ DASH	2020	Alexandria Transit Vision Plan	https://media.alexandriava.gov/docs-archives/tes/alexandria-transit-vision-final-report-=2020-02-24.pdf
City of Alexandria/ DASH	2019	Environmental Action Plan 2040	https://media.alexandriava.gov/docs-archives/tes/eap2040v25.pdf
City of Fairfax/ CUE	*No date*	Green Transportation	https://www.fairfaxva.gov/government/environment-sustainability/green-transportation
City of Fairfax/ CUE	*No date*	Greening the City Fleet	https://www.fairfaxva.gov/government/environment-sustainability/climate-and-air/greening-the-city-fleet
City of Fairfax/ CUE	*No date*	Fairfax City Welcomes Its First Electric Fleet Vehicle	https://www.fairfaxva.gov/Home/Components/News/News/12018/18
Fairfax County	*No date*	Climate Action - Transportation	https://www.fairfaxcounty.gov/environment-energy-coordination/climate-action/transportation
Fairfax County	*No date*	Climate Plans, Policies, and Initiatives	https://www.fairfaxcounty.gov/environment-energy-coordination/policies-and-initiatives
Fairfax County	2023	On the Road to Zero: Fairfax Connector Introduces Battery-Electric Buses	https://www.fairfaxcounty.gov/news/road-zero-fairfax-connector-introduces-battery-electric-buses

Agency	Year	Title	Link
Fairfax County	2023	Fairfax Countywide Strategic Plan (Revised)	https://www.fairfaxcounty.gov/strategicplan/sites/strategicplan/files/assets/documents/countywide%20strategic%20plan.pdf
Fairfax County	2021	Fairfax County Operational Energy Strategy	https://www.fairfaxcounty.gov/environment-energy-coordination/sites/environment-energy-coordination/files/assets/documents/fairfax-county-operational-energy-strategy-2021.pdf
Loudoun County	2023	Loudoun County Energy Strategy	https://www.loudoun.gov/DocumentCenter/View/174600/Loudoun-County-Energy-Strategy-Final-Report---2023
Loudoun County	2019	Loudoun County 2019 Countywide Transportation Plan	https://www.loudoun.gov/DocumentCenter/View/152287/CTP---Combined-with-small-maps-bookmarked
Metro (WMATA)	*No date*	2025 Energy Action Plan	https://www.wmata.com/initiatives/sustainability/upload/WMATA-Energy-Action-Plan-Final-4_18.pdf
Metro (WMATA)	*No date*	More Metro. Less CO_2.	https://www.wmata.com/initiatives/sustainability/metro-sustainability-summary-calculator.cfm
Metro (WMATA)	2023	Sustainability	https://www.wmata.com/initiatives/sustainability/
Metro (WMATA)	2023	Zero-Emission Buses	https://www.wmata.com/initiatives/plans/zero-emission-buses.cfm
Metro (WMATA)	2022	2020–2021 Metro Sustainability Report	https://www.wmata.com/initiatives/sustainability/upload/2020-2021-Sustainability-Report_final.pdf
OmniRide	2022	Zero Emissions Bus Study – Draft Study Overview	https://prtctransit.civicweb.net/document/18064/
OmniRide	2017	PRTC Strategic Plan	https://omniride.com/omniride/assets/File/Strategic-Recomendations-Report.pdf
VRE	2023	System Plan 2050 - Vision and Goals	https://storymaps.arcgis.com/stories/b48acdc8c80b4fc4bdaa79f3435a9fdf
VRE	2019	Transit Development Plan FY2020 - 2025	https://www.vre.org/sites/vre/assets/File/VRE%20FY2020-FY2025%20Transit%20Development%20Plan%20FINAL.pdf

Appendix C: Calculations for Personal Vehicle Emissions Avoided

Method 1: Metropolitan Washington Council of Governments (MWCOG) Regional Travel Survey (RTS) Data

There are three steps for estimating the avoided personal vehicle emissions:

1. Estimate the number of avoided personal vehicle miles

$$Avoided\ Personal\ Vehicle\ Miles = PMT \times Mode\ Shift\ Factor$$

Where PMT estimated is from MWCOG RTS bus or rail trips with an origin or destination in Virginia[46] and mode shift factor is an estimate of how many transit passenger miles would be replaced by car miles[47].

2. Using the avoided personal vehicle miles, estimate the avoided gallons of fuel

$$Avoided\ Gallons\ of\ Fuel = \frac{Avoided\ Personal\ Vehicle\ Miles}{Miles\ per\ Gallon_{Car}}$$

Miles per gallon calculations are discussed in more detail in **Appendix C**.

3. Using the estimated avoided gallons of fuel, estimate avoided CO_2 emissions

$$Avoided\ CO_2\ Emissions = Avoided\ Gallons\ of\ Fuel \times Emissions\ per\ Fuel\ Unit$$

Emissions per fuel unit calculations are discussed in more detail in **Appendix C**.

Method 2: Federal Transit Administration (FTA) National Transit Database (NTD) Data

There are three steps for estimating the avoided personal vehicle emissions:

1. Estimate the number of avoided personal vehicle miles. In this case, PMT is FTA NTD passenger miles traveled (see **Table 5**).
2. Using the avoided personal vehicle miles, estimate the avoided gallons of fuel
3. Using the estimated avoided gallons of fuel, estimate avoided CO_2 emissions

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[46] RTS data is for an average weekday. According to National Household Travel Survey data (https://nhts.ornl.gov/), about 16% of weekly trips happen on an average weekday. Consequently, to estimate annual vehicle miles avoided, divide by 0.16 and multiply by 52, the number of weeks in a year.

[47] Some transit passenger miles would be replaced by other modes like bicycling, walking, carpooling, or not taking a trip at all. Explained in more detail in the TCRP Research Report cited earlier[20]. The mode shift factor is assumed to be 0.329, meaning less than one third of transit passenger miles are assumed to be translated to personal vehicle miles.

Table 5: FTA NTD Northern Virginia passenger miles traveled ('000s)

Agency Name	Mode	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
ART	Local Bus	5,554	5,759	5,731	6,316	7,150	6,288	5,941	5,181	2,923	3,723
DASH	Local Bus	10,408	9,537	9,607	9,229	7,450	7,321	7,390	5,966	2,876	5,707
CUE	Local Bus	3,088	3,059	2,854	2,512	2,189	2,052	2,040	1,655	1,108	1,817
Fairfax Connector	Local Bus	80,190	80,209	49,638	41,388	42,567	41,657	42,436	34,407	19,618	37,887
Loudoun County	Commuter Bus	42,267	46,709	38,137	36,177	36,369	39,228	39,606	28,769	1,776	4,597
Loudoun County	Local Bus	0	3,014	5,971	7,345	6,345	2,224	2,175	2,406	1,435	1,455
OmniRide	Commuter Bus	44,449	43,216	41,596	39,189	38,055	36,340	37,151	28,004	7,660	15,341
OmniRide	Local Bus	12,927	15,133	15,336	13,462	9,707	8,833	8,145	6,280	3,845	5,594
VRE	Commuter rail	149,745	132,624	152,273	145,777	143,469	141,567	135,051	97,935	10,751	25,720
Metro*	Heavy Rail	612,337	599,356	627,381	581,995	523,064	518,229	518,035	374,777	74,722	160,569
Metro*	Local Bus	56,188	57,699	56,578	53,299	49,292	48,955	49,097	35,735	21,529	28,996

FTA NTD data is provided at the agency level and does not provide an estimate of PMT by state. Consequently, for Metro, Virginia PMT was estimated to be proportional to ridership (Table 6** shows how much of Metro's ridership is in Virginia). As trips are expected to be shorter on average in Washington, DC, Metro's primary geographic area, the estimate for Virginia PMT is conservative.*

Table 6: Proportion of Metro ridership in Virginia

	NVTC Dashboard		FTA NTD		Percent	
Fiscal Year	Bus Ridership	Rail Ridership	Bus Ridership	Rail Ridership	Bus Ridership	Rail Ridership
2022	9,162,772	30,183,438	79,512,639	76,077,714	11.5%	39.7%
2021	6,920,441	13,677,941	52,325,667	36,550,201	13.2%	37.4%
2020	12,588,125	66,347,907	97,210,648	174,540,714	12.9%	38.0%
2019^	16,474,263	90,305,329	123,333,115	228,974,810	13.4%	39.4%

^ FY 2019 split was used for all Table 3 data prior to FY 2019 as it was assumed to be more similar than data that was affected by the COVID-19 pandemic.

Appendix D: Calculations for Transportation Emissions Breakeven Analysis

There are two main steps for calculating emissions breakeven analysis. First, the emissions per mile of travel need to be calculated for each transportation mode and fuel type. Second, the values from the emissions calculations become inputs for the breakeven calculation. Each process is described below. For simplicity, maintenance emissions are ignored.

Emissions per Mile of Travel

Total vehicle emissions is a combination of fixed emissions, the emissions from manufacturing, as well as a variable emissions calculation, the emissions per mile of travel primarily generated through the use of different fuels. The steps below outline the process for calculating emissions per mile of travel.

1. Estimate fuel need per mile of travel (Table 1).
2. Estimate emissions generated through fuel use (Table 2).
3. Estimate emissions per mile of travel (Table 2):

$$Emissions\ per\ Mile = \frac{Emissions\ per\ Fuel\ Unit}{Miles\ per\ Fuel\ Unit}$$

Table 7: Northern Virginia transit fuel use (2021 FTA NTD data)

Mode	Fuel	Fuel Units	Quantity	Miles	Miles per Fuel Unit
Bus	Diesel	Gallons	10,782,071	45,618,051	4.23
	CNG	Gasoline Gallon Equivalent[1]	3,569,840	12,108,554	3.39
	Electric	kWh	58,048	28,934	0.50
Rail	Electric	kWh	544,182,367	68,218,296	0.13
	Diesel	Gallons	1,118,627	266,867	0.24

[1]https://epact.energy.gov/fuel-conversion-factors

Table 8: Emission calculations for major vehicle fuel types

Fuel Type	Unit	Emissions (*g of CO_2 per unit*)	Miles per Gallon (or Equivalent)			Emissions per Mile (*g of CO_2*)		
			Car[3]	Bus[4]	Rail[5]	Car	Bus	Rail
Gasoline[1]	Gallon	8,887.00	21.79	-	-	407.9	-	-
Electric[2]	kWh	290.20	3.60	0.50	0.13	80.6	578.6	2,314.7
CNG[6]	Gallon Equivalent	6,512.46	-	3.39	-	-	1920.0	-
Diesel	Gallon	10,190.00	-	4.23	0.24	-	2,408.5	43,171.1

[1] https://www.eia.gov/environment/emissions/co2_vol_mass.php; [2] https://www.epa.gov/egrid/power-profiler#/SRVC; [3] https://afdc.energy.gov/vehicles/electric_emissions_sources.html; [4] Table 1; [5] WMATA Metrorail uses electricity while VRE Commuter Rail uses diesel; [6] https://www.transit.dot.gov/regulations-and-programs/environmental-programs/fta-transit-bus-electrification-tool

Breakeven Calculation – Excluding Manufacturing

The breakeven calculation finds the required bus productivity for a bus to have lower CO_2 emissions per passenger mile than cars.

To begin, a mile traveled with a passenger is called a revenue mile. However, buses also travel when not carrying passengers (e.g., from the route end point to the bus garage). These additional miles are called deadhead miles. Thus, deadhead miles need to be accounted for in the calculation of total bus emissions. This can be achieved by using a Deadhead Multiplier (DHM). A DHM is estimated by dividing all miles (revenue and deadhead), by vehicle revenue miles.

$$DHM = \frac{(Vehicle\ Revenue\ Miles + Deadhead\ Miles)}{(Vehicle\ Revenue\ Miles)} = \frac{(Total\ Transit\ Miles)}{(Vehicle\ Revenue\ Miles)}$$

This means bus vehicle revenue miles can be used to estimate total bus vehicle miles. This calculation can then be used to estimate the emissions per person on a bus. Emissions per person in a car is simpler as deadhead miles are not needed. The calculations for both are below.

$$(Transportation\ Emissions\ per\ Person\ per\ Mile)_{Transit} = \frac{(DHM)(Vehicle\ Revenue\ Miles)(ED_{Bus,x})}{(Passenger\ Mile_{Bus})}$$

$$(Transportation\ Emissions\ per\ Person\ per\ Mile)_{Car} = \frac{(Car\ Miles)(ED_{Car,x})}{(Passenger\ Mile_{Car})}$$

Where, ED is Emissions per Distance (miles) and x is fuel type. This estimates the emissions per person by mode by fuel type. We can then use a breakeven analysis to find when bus emissions per person are equivalent to car emissions per person.

$$\frac{(DHM)(Vehicle\ Revenue\ Miles)(ED_{Transit,x})}{(Passenger\ Mile_{Transit})} = \frac{(Car\ Miles)(ED_{Car,x})}{(Passenger\ Mile_{Car})}$$

First, we rearrange the equation to isolate the passenger metrics.

$$\frac{(DHM)(Vehicle\ Revenue\ Miles)(ED_{Transit,x})}{(Car\ Miles)(ED_{Car,x})} = \frac{(Passenger\ Mile_{Transit})}{(Passenger\ Mile_{Car})}$$

As passenger miles is the number of passengers per vehicle trip multiplied by the number of miles, the formula can be rewritten as:

$$\frac{(DHM)(Vehicle\ Revenue\ Miles)(ED_{Transit,x})}{(Car\ Miles)(ED_{Car,x})} = \frac{(Occupants_{Bus})(Miles_{Transit})}{(Occupants_{Car})(Miles_{Car})}$$

To calculate the breakeven emissions per mile traveled, we would assume bus miles and car miles are the same and can thus be canceled out of the right side of the equation. We can then rearrange the formula to solve for the average transit occupancy per trip needed for transit emissions and car emissions per passenger mile to be equivalent.

$$\frac{((DHM)(Vehicle\ Revenue\ Miles)(ED_{Transit,x}))(Occupants_{Car})}{(Car\ Miles)(ED_{Car,x})} = (Occupants_{Transit})$$

Breakeven Calculation – Including Manufacturing

The breakeven calculations can be modified to account for emissions generated through manufacture of different transportation vehicles. The equations below follow a similar process to the previous equations. The only difference is that manufacturing emissions are included in the calculation process:

$$(Transportation\ Emissions\ per\ Person\ per\ Mile)_{Bus} = \frac{(DHM)(Vehicle\ Revenue\ Miles)(ED_{Bus,x}) + ME_{Bus,x}}{(Passenger\ Mile_{Bus})}$$

$$(Transportation\ Emissions\ per\ Person\ per\ Mile)_{Car} = \frac{(Car\ Miles)(ED_{Car,x}) + ME_{Car,x}}{(Passenger\ Mile_{Car})}$$

Where, ED is Emissions per Distance (miles), ME is Manufacturing Emissions and x is fuel type. Like before, we can then use a breakeven analysis to find when bus emissions per person are equivalent to car emissions per person.

$$\frac{(DHM)(Vehicle\ Revenue\ Miles)(ED_{Bus,x}) + ME_{Bus,x}}{(Passenger\ Mile_{Bus})} = \frac{(Car\ Miles)(ED_{Car,x}) + ME_{Car,x}}{(Passenger\ Mile_{Car})}$$

Rearrange the equation to isolate the passenger metrics:

$$\frac{(DHM)(Vehicle\ Revenue\ Miles)(ED_{Bus,x}) + ME_{Bus,x}}{(Car\ Miles)(ED_{Car,x}) + ME_{Car,x}} = \frac{(Passenger\ Mile_{Bus})}{(Passenger\ Mile_{Car})}$$

Split out passenger miles:

$$\frac{(DHM)(Vehicle\ Revenue\ Miles)(ED_{Bus,x}) + ME_{Bus,x}}{(Car\ Miles)(ED_{Car,x}) + ME_{Car,x}} = \frac{(Occupants_{Bus})(Miles_{Bus})}{(Occupants_{Car})(Miles_{Car})}$$

Rearrange the formula to solve for the average bus occupancy per trip needed for bus emissions and car emissions per passenger mile to be equivalent:

$$\frac{((DHM)(Vehicle\ Revenue\ Miles)(ED_{Bus,x}) + ME_{Bus,x})(Occupants_{Car})}{(Car\ Miles)(ED_{Car,x}) + ME_{Car,x}} = (Occupants_{Bus})$$

Appendix E: Electric and Hybrid Vehicle Projection Estimates

Table 9 provides public projections of how many on-road vehicles will be electric or hybrids in the US.

Table 9: Electric and hybrid vehicle projection data

Year	Percent EVs	Source
2022	0.75%	*Footnote 39*
2030	10%	https://www.eei.org/resources-and-media/energy-talk/Articles/2022-06-eei-projects-264-million-electric-vehicles-will-be-on-us-roads-in-2030
2045	50%	https://www.cnbc.com/2022/04/04/electric-and-hybrid-vehicles-will-account-for-nearly-half-the-cars-on-the-road-by-2040-goldman-predicts.html

These data points were used to estimate a polynomial equation to project EVs as a proportion of all on-road vehicles. The equation is as follows:

$$EV\% = 0.1528x^2 - 618.02x + 624{,}917.1$$

Where x is a given year. **Table 10** gives EV projections for the US using this equation.

Table 10: Projected electric and hybrid vehicles as a percentage of all on-road vehicles

Year	Percent EVs
2022	1.0%
2030	10.0%
2040	48.8%
2041	54.3%
2042	60.2%
2043	66.4%
2044	72.8%
2045	79.6%
2046	86.7%
2047	94.1%
2048	~100.0%

Note: These projections are only estimates and are subject to error. They are based on only three data points, optimistic projections, and simple assumptions on the rate of growth.