
# TPB Climate Change Mitigation Study of 2021

## Technical Appendix

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# Transportation Climate Change Mitigation Scenarios Analysis: Technical Appendix

This document provides supplemental information on the analysis methods and assumptions used as part of the scenario analysis conducted for the TPB's Climate Change Mitigation Study of 2021. It describes processes used to develop the baseline emissions forecast and to estimate the emissions levels associated with each of the ten scenarios analyzed as part of the "bottom-up" analysis.

## Baseline Emissions Forecast

The ICF team calculated baseline 2030 and 2050 greenhouse gas (GHG) emissions using the most recent 2005-2045 reference annual vehicle miles traveled (VMT) and MOVES on-road GHG emission estimates provided by the Metropolitan Washington Council of Governments (COG), used for COG's Metropolitan Washington 2030 Climate and Energy Action Plan (CEAP).[1] [2] The 2045 passenger VMT projections were extrapolated to 2050 based on the projected population growth rate between 2040 and 2045 as reported in the TPB Round 9.1a Cooperative Forecast along with trends in VMT per capita. The VMT projections were then integrated with vehicle-specific fuel economy values and grid electricity emissions to obtain GHG emissions according to the step-process described below.

### Step 1. Population Forecasts

A population forecast estimate for 2050 was needed to estimate 2050 VMT and GHG emissions in later steps. Population estimates for 2005, 2018, 2030, and 2045 were compiled here for VMT per capita reference reporting purposes only. The population estimate for 2018 was calculated using linear interpolation between the 2015 and 2020 estimates reported in the Round 9.1a Cooperative Forecast.[3] The forecasted estimates for 2030 and 2045 were taken directly from the Round 9.1a Cooperative Forecast. The percent change in regional population between 2040 and 2045 (3.17%) from the Round 9.1a Cooperative Forecast was used to extrapolate population estimates to 2050. All population estimates used are shown in Table 1.

[1] "Metropolitan Washington 2030 Climate and Energy Action Plan" (Washington, D.C.: Metropolitan Washington Council of Governments, November 18, 2020), https://www.mwcog.org/documents/2020/11/18/metropolitan-washington-2030-climate-and-energy-action-plan/

[2] As part of developing the 2030 CEAP, the historic GHG estimates were updated using MOVES2014b, and so the baseline estimates of on-road GHGs differ from the figures presented in the Visualize 2045 plan released in 2018.

[3] Metropolitan Washington Council of Governments. "Cooperative Forecasts: Employment, Population, and Household Forecasts by Transportation Analysis Zone," December 2, 2021. https://www.mwcog.org/documents/2021/12/02/cooperative-forecasts-employment-population-and-household-forecasts-by-transportation-analysis-zone-cooperative-forecast-demographics-housing-population/

**Table 1. Regional Population Estimates**

| | 2005 | 2018 | 2030 | 2045 | 2050 |
|---|---|---|---|---|---|
| Population total (thousands) | 4,758.4 | 5,570.2 | 6,249.0 | 6,925.7 | 7,145.3 |

### Step 2. VMT Forecasts

Baseline VMT by vehicle type was provided for 2005, 2018, 2030, and 2045 by COG, using the data underlying COG's 2030 CEAP. These figures reflect estimates developed using the Regional Travel Demand Model Version 2.3.75 and MOVES2014b for 2005, 2018, and 2030, using assumptions in the Visualize 2045 plan from 2018. Baseline VMT for 2045 was estimated using the Regional Travel Demand Model Version 2.3.78 and MOVES2014b, using assumptions in the 2020 Amendment to Visualize 2045.[4]

VMT projections through 2050 were calculated as follows for the various vehicle classes. For light-duty passenger cars and passenger trucks, the VMT for 2050 was obtained from the forecasted growth in population multiplied by the estimated VMT per capita, using the forecast trend in VMT per capita from 2030 to 2045 extended through 2050. VMT per capita is shown in Table 2. The resulting VMT growth between 2045 and 2050 for light-duty vehicles was 2.5%. For light-duty commercial trucks, heavy-duty trucks, and combination trucks, VMT was assumed to continue increasing at the same annual rate as the period between 2030 and 2045, resulting in a VMT increase of 2.7%, 3.4%, and 3.5%, respectively, between 2045 and 2050. The VMT growth for the bus categories (transit bus and other bus) was kept at 0% because of minimal change forecast in VMT between 2030 and 2045. The results of the VMT projections through 2050 are shown in Table 3.

**Table 2. Baseline VMT per Capita Projections**

| Per Capita Projections | 2005 | 2018 | 2030 | 2045 | 2050 |
|---|---|---|---|---|---|
| Total VMT per capita (annual) | 8,730 | 8,245 | 8,158 | 8,005 | 7,954 |
| Total VMT per capita (daily) | 23.92 | 22.59 | 22.35 | 21.93 | 21.79 |

[4] The assumptions used in the Gen2/Version 2.3.78 Travel Model do not differ substantially from those used in the Gen2/Version 2.3.75 Travel Model. For details, see "User's Guide for the COG/TPB Travel Demand Forecasting Model, Version 2.3.78." Washington, D.C.: Metropolitan Washington Council of Governments, National Capital Region Transportation Planning Board, April 14, 2020. https://www.mwcog.org/transportation/data-and-tools/modeling/model-documentation/

**Table 3. Baseline Annual Total VMT Projections (billion miles) through 2050**

| Vehicle Category | 2005 | 2018 | 2030 | 2045 | 2050 | VMT Growth Assumed 2045-2050 |
|---|---|---|---|---|---|---|
| Pass. Cars + Pass. Trucks | 35.04 | 38.11 | 42.23 | 45.87 | 47.01 | 2.5% |
| Transit Buses | 0.11 | 0.14 | 0.14 | 0.14 | 0.14 | 0.0% |
| Other Buses | 0.16 | 0.13 | 0.13 | 0.13 | 0.13 | 0.0% |
| Light Duty Comm. Trucks | 4.14 | 5.30 | 5.89 | 6.41 | 6.59 | 2.7% |
| Heavy Duty Trucks | 1.03 | 1.21 | 1.39 | 1.54 | 1.60 | 3.4% |
| Combination Trucks | 1.06 | 1.04 | 1.20 | 1.34 | 1.38 | 3.5% |
| Total VMT | 41.54 | 45.93 | 50.98 | 55.43 | 56.85 | 2.5% |

## Step 3. Tailpipe and Electricity-Related GHG Emissions Forecasts

Next, the research team calculated tailpipe-related GHG emissions from on-road sources for 2050, and estimated electricity-related GHG emissions for each of the analysis years. Similar to the source of the baseline VMT estimates by year, baseline $CO_2e$ GHG emissions were provided for 2005, 2018, and 2030, estimated using MOVES2014b and the Regional Travel Demand Model Version 2.3.75. Baseline $CO_2e$ GHG emissions for 2045 were estimated using MOVES2014b and the Regional Travel Demand Model Version 2.3.78. These figures were used to calculate a GHG emissions rate per mile for internal combustion engine (ICE) vehicles. The ICE emissions rates per vehicle mile traveled were assumed to be the same in 2050 as in 2045, generally reflecting that the improvements in vehicle fuel economy of conventional vehicles already would be in place with limited further improvements. These figures were then multiplied by estimated "ICE-only" VMT in 2050 (described below) to obtain estimated tailpipe emissions of ICE vehicles in 2050, as shown in Table 4.

**Table 4. Baseline Tailpipe Only On-Road GHG Emissions Estimates (million metric tons, MMTCO2e)**

| GHG Emissions by Vehicle Category (MMT CO2e) | 2005 | 2018 | 2030 | 2045 | 2050 |
|---|---|---|---|---|---|
| Pass. Cars | 8.35 | 7.57 | 5.83 | 5.53 | 5.62 |
| Pass. Trucks | 6.69 | 7.42 | 5.81 | 5.57 | 5.71 |
| Transit Buses | 0.20 | 0.24 | 0.23 | 0.23 | 0.23 |
| Other Buses | 0.21 | 0.21 | 0.20 | 0.20 | 0.20 |
| Light Duty Comm. Trucks | 2.17 | 2.44 | 1.95 | 1.89 | 1.94 |
| Heavy Duty Trucks | 1.13 | 1.32 | 1.44 | 1.60 | 1.66 |
| Combination Trucks | 2.00 | 1.90 | 2.10 | 2.28 | 2.36 |
| Total GHG Emissions | 20.75 | 21.10 | 17.56 | 17.30 | 17.72 |

In the calculation of electric vehicle-related emissions and in order to calculate the GHG emissions factors for ICE vehicles for 2030 and 2045 (used for 2050 as well), the EV percent of VMT for each year and vehicle type was assumed to be at levels anticipated by the National Renewable Energy Laboratory (NREL)[5] reference case, displayed in Table 5. Note that the term EV is typically used to include both battery electric EVs (BEVs) and plug-in hybrid EVs (PHEVs). The baseline emission calculations described in this section assume that all EVs are BEVs.

**Table 5. % VMT by EVs Assumed in Baseline (Based on NREL study, Reference Scenario)**

| Vehicle Type | 2005 | 2018 | 2020 | 2030 | 2045 | 2050 |
|---|---|---|---|---|---|---|
| Pass. Cars | - | 1.49% | 2.26% | 11.41% | 17.62% | 18.35% |
| Pass. Trucks | - | 0.33% | 0.39% | 1.28% | 1.87% | 1.87% |
| Transit Buses | - | 0.12% | 0.30% | 1.00% | 1.00% | 1.00% |
| Other Buses | - | 0.00% | 0.01% | 0.12% | 0.80% | 0.91% |
| Light Duty Comm. Trucks | - | 0.00% | 0.01% | 0.12% | 0.80% | 0.91% |
| Heavy Duty Trucks | - | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| Combination Trucks | - | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |

To calculate additional emissions from electricity generation for EVs for each year, the EV percent of VMT reported by NREL was multiplied by each year's predicted total VMT (Table 2) by vehicle type to isolate "EV-only" VMT by vehicle type, reported in Table 6.

**Table 6. Baseline EV Only VMT Estimated (million miles)**

| Vehicle Type | 2005 | 2018 | 2030 | 2045 | 2050 |
|---|---|---|---|---|---|
| Pass. Cars | - | 342.0 | 2,901.3 | 4,858.1 | 5,183.4 |
| Pass. Trucks | - | 49.2 | 214.4 | 342.0 | 3,51.1 |
| Transit Buses | - | 0.2 | 1.4 | 1.4 | 1.4 |
| Other Buses | - | 0.005 | 0.2 | 1.0 | 1.2 |
| Light Duty Comm. Trucks | - | 0.2 | 7.0 | 51.5 | 60.2 |
| Heavy Duty Trucks | - | - | - | - | - |
| Combination Trucks | - | - | - | - | - |
| **Total** | **-** | 391.6 | 3,124.3 | 5,254.0 | 5,597.3 |

The vehicle-specific EV energy economy data estimated for 2018 were obtained from the Argonne National Laboratory's Alternative Fuel Life Cycle Environmental and Economic Transportation (AFLEET) tool[6] for commercial and heavy-duty vehicles. Industry data[7] was used to obtain EV energy economy estimates for 2018 for passenger cars and trucks. The energy economy values through 2050 were obtained by assuming a 15%

[5] National Renewable Energy Laboratory. (2018). Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States.
[6] Argonne National Laboratory (2021). Alternative Fuel Life Cycle Environmental and Economic Transportation (AFLEET). Available at https://afleet.es.anl.gov/home/
[7] Kane, Mark. InsideEVs, "Electric Pickup Trucks: What Energy Consumption Should We Expect?" April 16, 2020, https://insideevs.com/news/409923/energy-consumption-ev-pickups-kwh-per-mile/

energy economy improvement in 2050[8] compared to the 2018 energy economy of EVs, and linearly interpolating between 2018 and 2050.

**Table 7. EV Energy Economy (kWh/mi)**

| Vehicle Type | 2005 | 2018 | 2030 | 2045 | 2050 |
|---|---|---|---|---|---|
| Pass. Cars | - | 0.30 | 0.28 | 0.26 | 0.26 |
| Pass. Trucks | - | 0.60 | 0.57 | 0.52 | 0.51 |
| Transit Buses | - | 2.50 | 2.36 | 2.18 | 2.13 |
| School Buses (type C) | - | 1.50 | 1.42 | 1.31 | 1.28 |
| Light Duty Comm. Trucks | - | 0.86 | 0.81 | 0.75 | 0.73 |
| Heavy Duty Trucks | - | 1.70 | 1.60 | 1.48 | 1.45 |
| Combination Trucks | - | 3.80 | 3.59 | 3.32 | 3.23 |

Table 8 shows the full set of GHG emission factor values for ICE vehicles in $gCO_2e$/mi. The ICE gCO2/mi values were obtained from the MOVES output provided by COG by dividing total tailpipe GHG emissions by ICE-only VMT, after subtracting out VMT associated with Baseline levels of EV vehicle penetration.

ICF also developed a Reference Case electricity power generation emissions factor through 2050, using ICF's Integrated Planning Model (IPM). The process for developing electricity power generation emissions factors is described in the next section of this document, Electric Grid Emissions Factors under Three Different Future Cases, below. These electricity power generation emissions factors, expressed in metric ton of $CO_2e$ per megawatt-hour ($MTCO_2e$/MWh) (Table 11), were multiplied by the "EV-only" VMT by vehicle type (Table 6) and assumed vehicle energy economy (kWh per VMT) of each vehicle type (Table 7) to obtain EV emissions factor equivalents in $gCO_2$/mi (Table 9).

**Table 8. ICE GHG Emissions Factors Used in Analysis ($gCO_2e$/mile)**

| Vehicle Type | 2005 | 2018 | 2030 | 2045 | 2050 |
|---|---|---|---|---|---|
| Pass. Cars | 354.45 | 334.68 | 258.83 | 243.71 | 243.71 |
| Pass. Trucks | 583.13 | 492.10 | 349.87 | 310.21 | 310.21 |
| Transit Buses | 1,744.75 | 1,678.53 | 1,631.69 | 1,617.22 | 1,617.22 |
| Other Buses | 1,312.48 | 1,650.75 | 1,593.04 | 1,594.65 | 1,594.65 |
| Light Duty Comm. Trucks | 526.05 | 461.40 | 331.78 | 296.58 | 296.58 |
| Heavy Duty Trucks | 1,095.47 | 1,096.65 | 1,040.15 | 1,036.76 | 1,036.76 |
| Combination Trucks | 1,875.35 | 1,824.62 | 1,721.76 | 1,708.23 | 1,708.23 |

[8] Burke, Andrew and Hengbing Zhao (2017) Fuel Economy Analysis of Medium/Heavy-duty Trucks: 2015-2050. Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-17-49 https://itspubs.ucdavis.edu/publication_detail.php?id=2863

**Table 9. EV GHG Emissions Factors, under Reference Case Electric Grid Assumptions ($gCO_2e$ /mile)**

| Vehicle Type | 2018 | 2030 | 2045 | 2050 |
|---|---|---|---|---|
| Pass. Cars | 101.23 | 70.44 | 36.57 | 34.96 |
| Pass. Trucks | 202.47 | 140.87 | 73.15 | 69.91 |
| Transit Buses | 843.62 | 586.98 | 304.79 | 291.30 |
| Other Buses | 506.17 | 352.19 | 182.87 | 174.78 |
| Light Duty Comm. Trucks | 290.20 | 201.92 | 104.85 | 100.21 |
| Heavy Duty Trucks | 573.66 | 399.14 | 207.25 | 198.09 |
| Combination Trucks | 1,282.30 | 892.20 | 463.28 | 442.78 |

Note: These values assume the Reference Case Grid. 0 emissions from EVs were assumed for 2005.

These emissions were added to the COG provided emissions projections through 2050 to obtain the total baseline scenario emissions, reported in Table 10.

**Table 10. Baseline GHG Emissions by Vehicle Category for Tailpipe + Electricity Generation ($MMTCO_2e$)**

| Vehicle Category | 2005 | 2018 | 2030 | 2045 | 2050 |
|---|---|---|---|---|---|
| Pass. Cars | 8.35 | 7.61 | 6.03 | 5.71 | 5.80 |
| Pass. Trucks | 6.69 | 7.43 | 5.84 | 5.6 | 5.73 |
| Transit Buses | 0.20 | 0.24 | 0.23 | 0.23 | 0.23 |
| Other Buses | 0.21 | 0.21 | 0.20 | 0.21 | 0.20 |
| Light Duty Comm. Trucks | 2.17 | 0.24 | 1.95 | 1.90 | 1.94 |
| Heavy Duty Trucks | 1.13 | 1.32 | 1.44 | 1.60 | 1.66 |
| Combination Trucks | 2.00 | 1.90 | 2.06 | 2.28 | 2.36 |
| Total | 20.75 | 21.16 | 17.77 | 17.52 | 17.93 |

## Electric Grid Emissions Factors under Three Different Future Cases

The grid factor projections are from ICF's proprietary power sector model, the Integrated Planning Model (IPM).[9] IPM is a multi-regional, dynamic, deterministic linear programming model of the U.S. electric power sector with zonal representation of capacity expansion and generator dispatch. It produces least-cost capacity expansion forecasts and associated generation, emissions, and costs based on energy demand as well as environmental, transmission, dispatch, and reliability constraints. IPM provides projected grid emission factors that consider the changing generation mix over time. The analysis performed with IPM provided grid emission factors that were applied to calculate EV-related GHG emissions. As a starting point for this analysis, ICF used 2019 eGRID values[10] for Virginia and Maryland, and 2019 RFCEast values[11] for Washington DC and then shifted to IPM projected emission factors.

[9] ICF, Integrated Planning Model, https://www.icf.com/technology/ipm
[10] The Emissions and Generation Resource Integrated Database (eGRID) is a source of data from the U.S. Environmental Protection Agency on the environmental characteristics of almost all electric power generated in the United States. https://www.epa.gov/egrid
[11] RFCEast is an eGRID subregion generally reflecting the Mid-Atlantic area.

Emission factors were provided for three cases, with resulting values shown in Table 11 below:

1. A Reference Case, based on current on-the-books policies in the District, Maryland, and Virginia;
2. A Modified Reference Case, which is slightly more aggressive than the Reference Case; and
3. A Clean Grid Case, assuming a 100% clean grid by 2035.

**Table 11. ICF Electricity Generation Emissions Factors (MTCO$_2$e/MWh)**

| Electric Power Generation Assumption | 2018 | 2030 | 2045 | 2050 |
|---|---|---|---|---|
| Reference Case | 0.337 | 0.249 | 0.140 | 0.137 |
| Modified Grid | 0.337 | 0.224 | 0.084 | 0.082 |
| Clean Grid Case | 0.337 | 0.050 | 0.000 | 0.000 |

The Reference Case emissions factor represents current policies. In IPM, enacted policies in DC, Maryland and Virginia were modeled, including Virginia's Clean Economic Act (100% by 2045, assuming Dominion as the dominant utility), Maryland's Renewable Portfolio Standard (RPS) (50% by 2030) and DC's RPS (100% by 2032). IPM's grid factor projections include not only the impact of state RPS policies, but also the changes in fossil emission intensity over time as coal retires and is replaced by natural gas. The grid factor projections also factor in the emission intensity of imports to the states based on each state's imports in 2019 (from EIA data).

The Modified Reference Case emissions factor represents a slightly more aggressive Reference Case. In this scenario, ICF assumes a more aggressive policy for Maryland: a zero-carbon grid by 2040. This assumption aligns with Governor Hogan's legislative proposal. In this scenario, ICF assumes that the 100% by 2040 requirement would have to be met in-state, as opposed to the current policy where eligible sources can be located anywhere in Pennsylvania, New Jersey, and Maryland (PJM). This helps to increase the penetration of clean electricity in the state, resulting in a lower emissions factor. The emissions factor is not 0 in 2040 due to the weighting in of imports.

The Clean Grid Case emissions factor is the most aggressive, representing the Biden Administration's plan for a 100% clean grid by 2035. This policy would be applied nationally, so the emission intensity of imports by 2035 is assumed to be zero.

## Vehicle Technology and Fuels Scenarios Analysis

This section discusses the calculations and assumptions used to simulate the impacts of the vehicle technology and fuels scenarios (VT.1 and VT.2).

### Analysis of Shifts to Electric Vehicles

The analysis for the VT scenarios used a combination of the Argonne National Laboratory VISION model and Excel-based sketch modeling. The VISION model allows the user to model different vehicle technologies and fuels, including several types of conventional fuels (diesel, gasoline, CNG) and technologies (EV, PHEV, ICE). VISION was used to calculate the estimated fleet penetration,[12] expressed as percentage of VMT, for four vehicle classes corresponding to the following MOVES categories as provided by MWCOG:

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[12] Although market simulation is not by default a user-facing capability, the VISION spreadsheet tool contains internal calculations that estimate fleet makeup by fuel type based on asserted fuel type sales ratios. ICF modified the spreadsheet

| VISION Vehicle Classes | MOVES Vehicle Categories |
|---|---|
| Light-duty passenger cars | Passenger cars |
| Light-duty passenger pickup trucks | Passenger pickup trucks |
| Medium-duty vehicles | Light duty commercial trucks |
| Heavy-duty vehicles | Heavy-duty trucks, combination trucks |

Note that while MWCOG reported combined VMT from MOVES for light-duty passenger cars and pickup trucks, ICF conducted a separate analysis for the two vehicle classes due to their different fuel economies. The split was based on MWCOG vehicle population data (60% of the light duty VMT from passenger cars, and 40% from pickup trucks). Furthermore, the fleet turnover for transit and school buses was not modeled with VISION because the targets for zero-emission buses in 2030 and 2050 were already set as VMT share.

First, the vehicle sale percentages defined in the VT scenario were incorporated into the VISION model to estimate shares of VMT by vehicle type (e.g., passenger cars, light-duty trucks, etc.) and fuels (ICE, BEV, PHEV, and shares of biofuel and renewable diesel replacements for conventional diesel). For this analysis, the EV and PHEV percentages of new vehicle sales were increased to reflect the target adoption scenarios, and the remaining fuels were decreased to keep sales totals at 100%. While VISION has predetermined vehicle adoption curves, the ICF team made some adjustments to incorporate the latest market trends and industry data. For instance, while the VT.1 scenario sets 50% of all light-duty new vehicle sales to be EV by 2030, the market for light-duty passenger EVs (sedans, etc.) is more developed than the one for light-duty passenger trucks (as of July 2021, four models were announced to enter the market in late 2021 and early 2022, with several more in late 2022 or early 2023[13]). Thus, adoption of light-duty passenger EVs was assumed to begin in 2023, while light-duty passenger truck adoption was delayed until 2025.

Furthermore, EV targets were split between BEV and PHEV to reflect current market trends and projections. In the VT.1 scenario, for example, 70% of new light-duty vehicle sales were assumed to be BEV and 30% were assumed to be PHEV. For medium-duty vehicles, 75% of new vehicle sales were supposed to be BEV and 25% PHEV. (PHEV is not a technology currently available for heavy-duty vehicles, therefore was not applied to vehicle Class 7-8). Depending on the EV sale target years for each vehicle class in each scenario, the PHEV fraction is reduced linearly to 0%, while the BEV fraction is increased. For example, for light-duty vehicles whose 100% EV sales target year is 2040, the PHEV fraction of new vehicle sales is decreased from 30% in 2030 to 0% in 2040. The analysis for the VT.2 scenario followed the same combined VISION model and sketch modeling approach as described for the VT.1 scenario. The ICF team made similar adjustments for the vehicle adoption curves of light-duty trucks, which was also delayed until 2025. Like in VT.1, EV targets were split between BEV and PHEV for light-duty vehicles, with 70% of new vehicle sales assumed to be BEV and 30% assumed to be PHEV (a phase out of PHEV after 2030 was also applied for VT.2). However, medium-duty vehicles assumed BEV sales only.

The VISION model outputs of VMT shares for all vehicle classes and fuel types calculated using the percentages of new EV sales by 2030 and 2050 assumed in the VT.1 and VT.2 scenarios are reported in Table 12.

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to compile these fleet makeup estimates into a single summary tab, and these results were used as the EV and PHEV fleet penetration projections.

[13] InsideEVs, "Electric Trucks - Every Upcoming Pickup Truck in 2021-2022", https://insideevs.com/car-lists/electric-trucks/

**Table 12. VMT shares for all vehicle classes and fuel types calculated using the percentages of new EV sales by 2030 and 2050 assumed in the VT.1 and VT.2 scenarios.**

| VT.1 | | | | | | VT.2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Light Duty Passenger Vehicles** | | | | | | **Light Duty Passenger Vehicles** | | | | |
| Technology | 2020 | 2030 | 2040 | 2050 | | Technology | 2020 | 2030 | 2040 | 2050 |
| EV A | 0% | 0% | 0% | 0% | | EV A | 0% | 0% | 0% | 0% |
| EV B | 0% | 0% | 0% | 0% | | EV B | 0% | 0% | 0% | 0% |
| EV C | 0% | 18% | 66% | 93% | | EV C | 0% | 25% | 73% | 96% |
| E-85 FFV | 4% | 2% | 1% | 0% | | E-85 FFV | 4% | 2% | 0% | 0% |
| Diesel | 1% | 0% | 0% | 0% | | Diesel | 1% | 0% | 0% | 0% |
| CNG | 0% | 0% | 0% | 0% | | CNG | 0% | 0% | 0% | 0% |
| SI HEV on Gasoline | 4% | 4% | 2% | 1% | | SI HEV on Gasoline | 4% | 2% | 0% | 0% |
| SI HEV on E85/H2 | 0% | 0% | 0% | 0% | | SI HEV on E85/H2 | 0% | 0% | 0% | 0% |
| Diesel HEV | 0% | 0% | 0% | 0% | | Diesel HEV | 0% | 0% | 0% | 0% |
| SI PHEV A (2) | 0% | 8% | 9% | 3% | | SI PHEV A (2) | 0% | 10% | 13% | 4% |
| SI PHEV B (3) | 0% | 0% | 0% | 0% | | SI PHEV B (3) | 0% | 0% | 0% | 0% |
| Diesel PHEV | 0% | 0% | 0% | 0% | | Diesel PHEV | 0% | 0% | 0% | 0% |
| Fuel Cell | 0% | 0% | 0% | 0% | | Fuel Cell | 0% | 0% | 0% | 0% |
| Conventional | 90% | 67% | 21% | 3% | | Conventional | 90% | 60% | 13% | 1% |
| **Light Duty Passenger Trucks** | | | | | | **Light Duty Passenger Trucks** | | | | |
| Technology | 2020 | 2030 | 2040 | 2050 | | Technology | 2020 | 2030 | 2040 | 2050 |
| EV A | 0% | 0% | 0% | 0% | | EV A | 0% | 0% | 0% | 0% |
| EV B | 0% | 0% | 0% | 0% | | EV B | 0% | 0% | 0% | 0% |
| EV C | 0% | 6% | 51% | 90% | | EV C | 0% | 19% | 70% | 95% |
| E-85 FFV | 14% | 12% | 6% | 1% | | E-85 FFV | 14% | 9% | 2% | 0% |
| Diesel | 2% | 4% | 3% | 1% | | Diesel | 2% | 2% | 1% | 0% |
| CNG | 0% | 0% | 0% | 0% | | CNG | 0% | 0% | 0% | 0% |
| SI HEV on Gasoline | 1% | 3% | 2% | 1% | | SI HEV on Gasoline | 1% | 2% | 0% | 0% |
| SI HEV on E85/H2 | 0% | 0% | 0% | 0% | | SI HEV on E85/H2 | 0% | 0% | 0% | 0% |
| Diesel HEV | 0% | 0% | 0% | 0% | | Diesel HEV | 0% | 0% | 0% | 0% |
| SI PHEV A (2) | 0% | 2% | 4% | 1% | | SI PHEV A (2) | 0% | 8% | 12% | 3% |
| SI PHEV B (3) | 0% | 1% | 1% | 0% | | SI PHEV B (3) | 0% | 0% | 0% | 0% |
| Diesel PHEV | 0% | 0% | 0% | 0% | | Diesel PHEV | 0% | 0% | 0% | 0% |
| Fuel Cell | 0% | 0% | 0% | 0% | | Fuel Cell | 0% | 0% | 0% | 0% |
| Conventional | 82% | 72% | 34% | 6% | | Conventional | 82% | 60% | 15% | 1% |

| **Mid Truck (3-6)** | | | | | | **Mid Truck (3-6)** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Technology | 2020 | 2030 | 2040 | 2050 | | Technology | 2020 | 2030 | 2040 | 2050 |
| Conventional Gasoline | 24% | 22% | 15% | 6% | | Conventional Gasoline | 25% | 16% | 3% | 0% |
| Conventional Diesel | 69% | 61% | 42% | 20% | | Conventional Diesel | 71% | 63% | 33% | 10% |
| Natural Gas | 0% | 0% | 0% | 0% | | Natural Gas | 0% | 0% | 0% | 0% |
| Ethanol - E85 FFV | 5% | 7% | 10% | 7% | | Ethanol - E85 FFV | 5% | 7% | 9% | 4% |
| Electricity | 0% | 6% | 30% | 65% | | Electricity | 0% | 14% | 54% | 85% |
| Diesel PHEV | 2% | 4% | 3% | 1% | | Diesel PHEV | 0% | 0% | 0% | 0% |
| Gasoline PHEV | 0% | 0% | 0% | 0% | | Gasoline PHEV | 0% | 0% | 0% | 0% |
| Fuel Cell | 0% | 0% | 0% | 0% | | Fuel Cell | 0% | 0% | 0% | 0% |
| **Heavy Duty Truck (7-8) (Vocational, Day Cab, and Sleeper)** | | | | | | **Heavy Duty Truck (7-8) (Vocational, Day Cab, and Sleeper)** | | | | |
| Technology | 2020 | 2030 | 2040 | 2050 | | Technology | 2020 | 2030 | 2040 | 2050 |
| Diesel | 98% | 96% | 81% | 50% | | Diesel | 98% | 93% | 63% | 23% |
| Gasoline | 0% | 0% | 0% | 0% | | Gasoline | 0% | 0% | 0% | 0% |
| LPG | 0% | 0% | 0% | 0% | | LPG | 0% | 0% | 0% | 0% |
| NG | 1% | 1% | 2% | 2% | | NG | 1% | 1% | 3% | 1% |
| EV | 0% | 3% | 17% | 47% | | EV | 0% | 5% | 34% | 76% |
| PHEV D | 0% | 0% | 0% | 0% | | PHEV D | 0% | 0% | 0% | 0% |
| PHEV G | 0% | 0% | 0% | 0% | | PHEV G | 0% | 0% | 0% | 0% |
| FC | 0% | 0% | 0% | 0% | | FC | 0% | 0% | 0% | 0% |

Next, the VMT percentage shares obtained from the VISION fleet turnover model were imported into the Excel-based sketch model to obtain GHG emission reductions (in MTCO2e) using the vehicle and fuel type-specific fuel economies (in gCO2e/mile) shown in Table 7 and 8.

In addition to these values, the ICF team calculated emissions rates for light duty passenger PHEVs as the weighted average of ICE and EV emissions rates, assuming that 55% of VMT are driven in BEV mode according to the Department of Energy Alternative Fuel Data Center Electricity Sources and Emissions Tool.[14]

## Analysis of Effects of Shifts to Biodiesel and Renewable Diesel

In the case of medium- and heavy-duty vehicles operating on diesel, it was assumed that a portion of the 'residual' diesel fuel after electrification is replaced over time by biofuels and renewable diesel consistent with what might be achieved with a low-carbon fuel standard policy and supported by carbon pricing. While the differences in tailpipe emission reductions of biofuels and renewable diesel are small compared to fossil diesel,[15]

[14] Alternative Fuels Data Center: Emissions from Hybrid and Plug-In Electric Vehicles. Available at https://afdc.energy.gov/vehicles/electric_emissions.html

[15] Emission Factors for Greenhouse Gas Inventories (epa.gov), and Renewable Diesel Testing in UPS Fleet Vehicles | Transportation and Mobility Research | NREL

reductions in upstream emissions were incorporated for these alternative fuels to be consistent with the modeled decrease in the carbon intensity of electric power generation for the electricity fuel. Average lifecycle emissions factors (g $CO_2e$ per mile) for diesel, biodiesel (B20), and renewable diesel were estimated individually for light-duty commercial trucks, medium-duty trucks, and heavy-duty trucks using standard fuel energy density assumptions and pathway carbon intensity assumptions released by the California Air Resources Board (CARB).[16] The $CO_2e$ savings per mile between lifecycle carbon emissions factors of conventional diesel and renewable or biodiesel was then used as an emissions "credit" to account for reduced upstream emissions associated with these fuels. The emissions factors used and the resulting credits are shown in Table 13.

**Table 13. Lifecycle Emissions Factors and Resulting Credit to Account for Upstream Emissions Reductions**

| Vehicle Category | Fuel | Lifecycle Emission Factor (g $CO_2e$/mile) | Difference between conventional diesel and alternative fuel (g $CO_2e$/mile) |
|---|---|---|---|
| Light Duty Commercial Trucks | Diesel | 844.2 | - |
| | Biodiesel (B20) | 714.8 | -129.4 |
| | Renewable Diesel | 298.9 | -545.3 |
| Medium Duty Trucks and Buses | Diesel | 1300.3 | - |
| | Biodiesel (B20) | 1114.8 | -185.5 |
| | Renewable Diesel | 477.6 | -822.8 |
| Heavy Duty Trucks | Diesel | 1933.9 | - |
| | Biodiesel (B20) | 1657.9 | -276.0 |
| | Renewable Diesel | 710.2 | -1223.6 |

Then, a fuel economy weighted average was obtained for alternative diesel vehicles (assuming 50% biofuel and 50% renewable diesel). This weighted average incorporated assumptions of the number of diesel vehicles using alternative fuels. For VT.1, 10% penetration in 2030 and 20% penetration in 2050 were assumed. For VT.2, 20% penetration in 2030 and 30% penetration in 2050 were assumed. Lastly, a new weighted average ICE emissions rate was obtained using the alternative diesel emissions rate, the baseline ICE emissions rate, and the percent of ICE vehicles assumed to be 'residual' diesel as estimated from the VISION model. The resulting ICE emissions rate was multiplied by VMT to obtain total annual emissions.

[16] California Air Resources Board, "Average carbon intensities from LCFS certified pathways", 2019. https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities

# Mode Shift and Travel Behavior (MSTB) Strategies Analysis

This section discusses the calculations and assumptions used to simulate the impacts of the mode shift and travel behavior (MSTB) scenarios.

## Analysis of Land Use Strategies

The analysis of land use strategies included three components:

1) Developing a revised 2030 land use allocation to reflect the land use strategies, running the regional travel model to estimate VMT, and comparing the results in relation to the baseline 2030 VMT to assess the impacts of the land use change;
2) Developing a baseline 2050 land use allocation, since none had been developed to date, and running the regional travel model to estimate baseline VMT for 2050 for purposes of calculating the benefits of the land use strategies;[17] and
3) Developing a revised 2050 land use allocation to reflect the land use strategies, running the regional travel model to estimate VMT, and comparing the results in relation to the baseline 2050 VMT to assess the impacts of the land use change.

These steps are described below.

### 2030 Land Use Strategy Assumptions and Method

**Guiding Principles**

A balanced land use zone.dbf modeling input file was prepared for year the 2030 following the approach used in the MWCOG Long Range Plan Task Force Initiative 8[18][19]; with assumptions updated for the year 2030. The guiding principles of this land use balancing exercise are:

- Optimize jobs/housing balance regionwide by addressing the region's east-west divide, shifting employment growth from the western subregion to the eastern subregion.
- Increase jobs and housing around underutilized rail stations and Activity Centers with high-capacity transit.
- Build more housing in the region to match employment (about 77,000 more households).

Additional information about and constraints on the land use optimization process include:

- The Round 9.1a Cooperative Forecast in 2025 remains unchanged.
- Only the increment of growth between 2025 and 2030 outside of Activity Centers in the western subregion ("growth increment") is shifted.
- Eastern/western subregions are defined in 2006 Regional Mobility and Accessibility Study[20].

[17] Note that the estimated 2050 baseline VMT from this land use analysis was used for the purpose of having a point of comparison with the 2050 forecast with the land use strategies, in order to calculate the percent change in VMT that was applied in the scenario analysis. The 2050 baseline VMT estimates by vehicle type shown in Table 3 above were used as the baseline for calculating GHG emissions.

[18] Fehr & Peers DC. "MWCOG Long-Range Plan Task Force – Regional Land Use Optimization (Initiative 8) Approach." Memorandum. Metropolitan Washington Council of Governments, National Capital Region Transportation Planning Board, September 8, 2017.

[19] Fehr & Peers DC. "Initiative 8: Regional Land Use Optimization – TAZ Allocation." Memorandum. Metropolitan Washington Council of Governments, National Capital Region Transportation Planning Board, September 27, 2017.

[20] COG, Regional Mobility and Accessibility Study, 2006. https://www.mwcog.org/documents/2006/11/17/regional-mobility-and-accessibility-study-afa-enhanced-mobility/

- Household growth is not reallocated from the eastern to the western subregion.
- 77,000 households are added in addition to forecast growth.
- A maximum household growth of 40,000 additional households (both anticipated and reallocated) between 2025 and 2030 is assumed to be accommodated in the western region portion of the District of Columbia.

**Approach**

Year 2030 land use was allocated in the following steps:

1. Determine the 2030 job/household ratio, including 77,000 additional households, for the TPB Planning Region, the eastern subregion, and the western subregion.
2. Identify the "growth increment" eligible to be allocated. This increment includes (1) job growth between the 2025 and 2030 Round 9.1a Cooperative Forecasts outside of Activity Centers; (2) housing growth between the 2025 and 2030 Round 9.1a Cooperative Forecasts outside of Activity Centers in the western subregion only; and (3) the 77,000 additional households to be reallocated from outside the region.
3. Identify the eastern/western subregion allocation of growth that will achieve jobs/housing balance between the eastern and western subregions and shift growth to underutilized rail stations and Activity Centers with high-capacity transit in the eastern subregion.
4. Allocate job and household growth within the eastern and western subregions to individual jurisdictions in an iterative process with the goal of each jurisdiction approaching the regional job/household ratio.
5. Allocate the growth increment within each jurisdiction to individual TAZs,[21] prioritizing Activity Centers with High Capacity Transit, TAZs with High Capacity Transit (but not Activity Centers), and Activity Centers (but not High Capacity Transit) TAZs.

These steps are described in more detail below.

**1. East/West Subregional Balance The subregions are shown in Figure 1.**

Table 14 summarizes the jobs and housing included in the 2030 Round 9.1a Cooperative Forecasts, with and without the additional 77,000 households. To reach a 1.54 jobs-households ratio in both subregions, growth will shift to increase the ratio in the eastern subregion and decrease it in the western subregion. The subregions are shown in Figure 1.

**Table 14. Regional Job and Household Summary**

| Region | Jobs | Households | Ratio |
|---|---|---|---|
| Western Subregion (2030) | 2,330,330 | 1,401,657 | 1.66 |
| Eastern Subregion (2030) | 1,458,870 | 981,922 | 1.49 |
| TPB Planning Region (2030) | 3,789,200 | 2,383,579 | 1.59 |
| TPB Planning Region Plus 77,000 Households | 3,789,200 | 2,460,579 | 1.54 |

*Source: MWCOG – Round 9.1a 2030 zone.dbf; Eastern3722TAZs.shp; TPBTAZ3722_TPBPlan.shp*

[21] TAZ refers to Transportation Analysis Zone, which is a predefined area used in regional transportation demand modeling

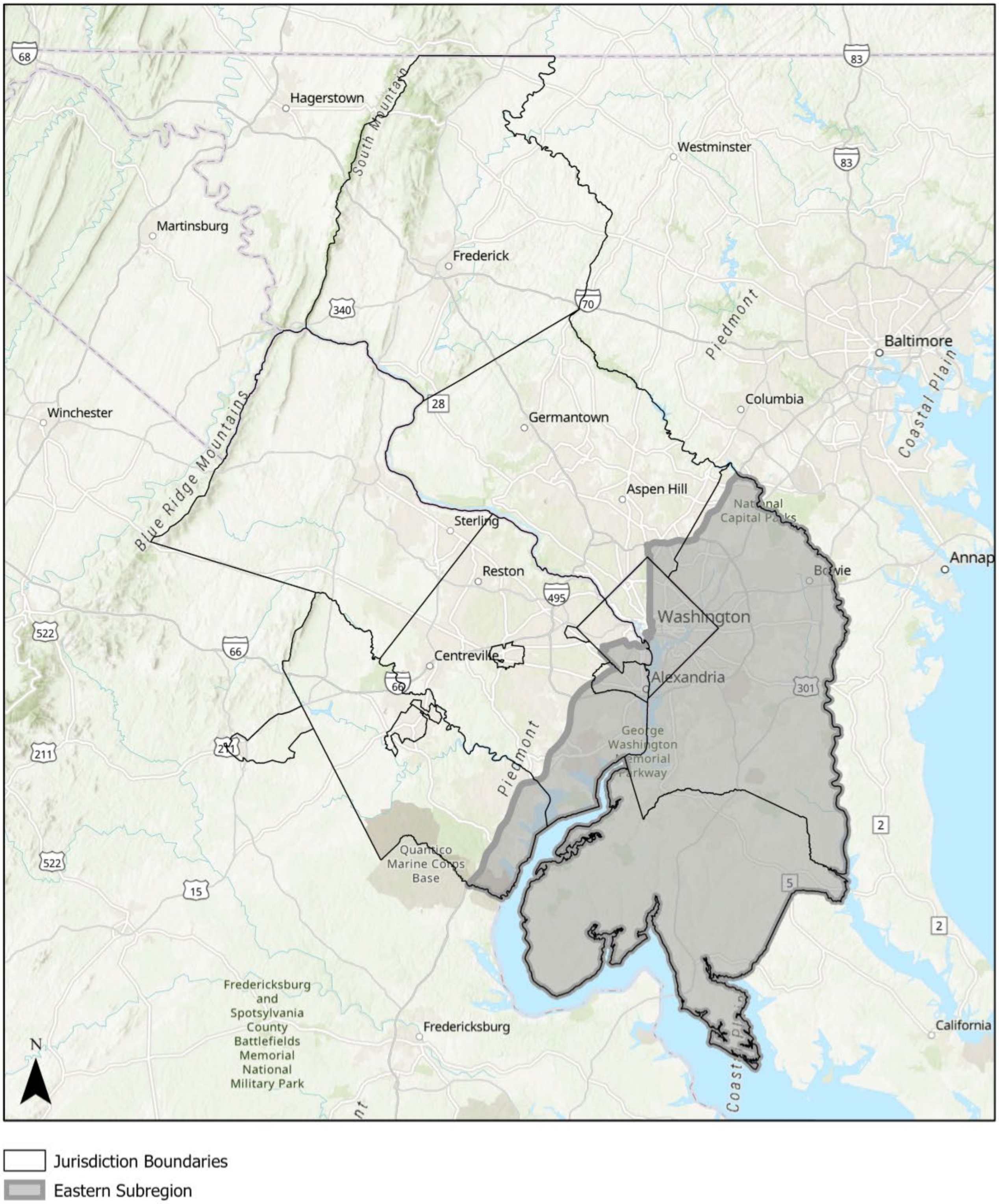


**Figure 1. TPB CCMS East/West Subregions**

**2. Identifying the "Growth Increment"**

The "growth increment" of job and household growth between 2025 and 2030 eligible to be reallocated across subregions within the TPB Planning Region comprises (1) job and housing growth outside of Activity Centers in the western subregion and (2) the 77,000 additional households (Table 15). Figure 2 illustrates that this increment is a small share of overall regional jobs and households in the year 2030.

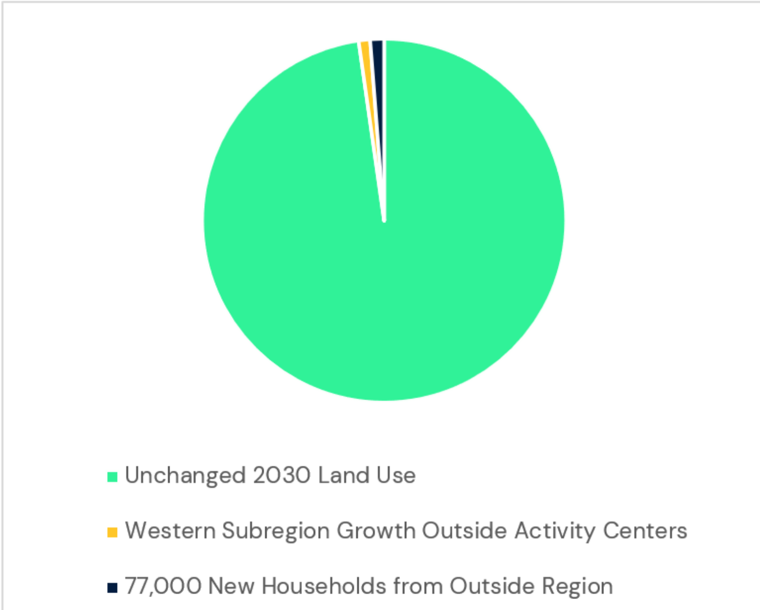


**Figure 2. "Growth Increment" in Context of Total 2030 Round 9.1a Cooperative Forecasts Land Use (Jobs Plus Households)**

**Table 15. 2025-2030 Growth Increment Eligible for Reallocation**

| | Jobs | Households |
|---|---|---|
| Western Subregion Outside Activity Centers | 41,494 | 21,931 |
| Households from Outside of Region | — | 77,000 |
| **Total Eligible Growth Increment** | **41,494** | **98,931** |

*Source: MWCOG – Round9.1a 2025 zone.dbf; Round9.1a 2030 zone.dbf; Eastern3722TAZs.shp; TPBTAZ3722_TPBPlan.shp; COG_TAZ_by_Activity_Center.shp*

**3. Identifying the Eastern/Western Subregion Allocation**

Table 16 illustrates the allocation of the jobs and households from the growth increment that achieves jobs/housing balance between the eastern and western subregions and shifts growth to underutilized rail stations and Activity Centers with high-capacity transit in the eastern subregion.

**Table 16. Subregional Job/House Allocation**

| | Jobs | Households | Ratio |
|---|---|---|---|
| *Growth Increment* | | | |
| Total Eligible Growth Increment | 41,494 | 98,931 | — |
| Growth Allocated to Eastern Subregion | 41,494 | 0 | — |
| Growth Allocated to Western Subregion | 0 | 98,931 | — |
| *Resulting Allocation* | | | |
| Adjusted Eastern Subregion (2030) | 1,500,364 | 981,922 | 1.53 |
| Adjusted Western Subregion (2030) | 2,288,836 | 1,478,657 | 1.55 |
| TPB Planning Region Total | 3,789,200 | 2,460,579 | 1.54 |

*Source: MWCOG – Round9.1a 2025 zone.dbf; Round9.1a 2030 zone.dbf; Eastern3722TAZs.shp; TPBTAZ3722_TPBPlan.shp; COG_TAZ_by_Activity_Center.shp*

**4. Jurisdiction-Level Allocation**

The growth increment land use available for reallocation is too small for all jurisdictions to reach the regional job/housing ratio of 1.54; jobs and households were allocated to individual jurisdictions within each subregion in proportion to the delta between the current jurisdiction's job/household ratio and the regional ratio of 1.54. Even this allocation would result in a large amount of household growth in the western portion of the District of Columbia, so growth there was capped at 38,344 households (in addition to all household growth between 2025 and 2030 based on Round 9.1a Cooperative Forecasts) and the remaining households were allocated to other jurisdictions to further close their job/household ratio deltas.

Only Loudoun and Prince William Counties' job/household ratio diverged from 1.54. In the west, these jurisdictions must lose household and job growth outside activity centers but are able to gain back only households in this region. Jobs can be gained back in the east, but these are allocated based on percentage need compared to the rest of the region, and this is inapplicable to Loudoun County. For Loudoun and Prince William County, this loss in jobs results in the job/household ratios decreasing.

**Table 17. Jurisdiction-Level Job and Household Summary**

| Jurisdiction | 2030 | | | Modified 2030 Land Use | | |
|---|---|---|---|---|---|---|
| | Households | Jobs | Ratio | Households | Jobs | Ratio |
| City of Alexandria | 84,118 | 127,266 | 1.51 | 84,118 | 127,266 | 1.51 |
| Arlington County | 123,857 | 231,251 | 1.87 | 138,528 | 231,993 | 1.67 |
| Charles County | 72,911 | 52,685 | 0.72 | 72,911 | 61,746 | 0.85 |
| District of Columbia | 362,524 | 937,854 | 2.59 | 400,252 | 936,347 | 2.34 |
| Fairfax County | 463,462 | 787,246 | 1.70 | 495,609 | 787,584 | 1.59 |
| City of Fairfax | 12,060 | 23,131 | 1.92 | 13,901 | 23,131 | 1.66 |
| City of Falls Church | 7,405 | 17,600 | 2.38 | 9,907 | 17,600 | 1.78 |
| Fauquier County Urb. Area | 8,931 | 18,681 | 2.09 | 11,844 | 20,961 | 1.77 |
| Frederick County | 115,066 | 128,627 | 1.12 | 109,991 | 124,009 | 1.13 |
| Loudoun County | 157,982 | 243,375 | 1.54 | 155,104 | 225,147 | 1.45 |
| City of Manassas | 15,430 | 30,089 | 1.95 | 17,985 | 30,089 | 1.67 |
| City of Manassas Park | 5,036 | 4,908 | 0.97 | 5,036 | 4,908 | 0.97 |
| Montgomery County | 422,320 | 604,516 | 1.43 | 416,895 | 602,874 | 1.45 |
| Prince George's County | 355,494 | 379,379 | 1.07 | 355,482 | 404,012 | 1.14 |
| Prince William County | 176,983 | 202,592 | 1.14 | 173,016 | 191,533 | 1.11 |
| Eastern Subregion | 981,922 | 1,458,870 | 1.49 | 981,922 | 1,500,364 | 1.53 |
| Western Subregion | 1,401,657 | 2,330,330 | 1.66 | 1,478,657 | 2,288,836 | 1.55 |
| TPB Planning Region Total | 2,460,579 | 3,789,200 | 1.54 | 2,460,579 | 3,789,200 | 1.54 |

*Source: Round9.1a 2030 zone.dbf; Eastern3722TAZs.shp; TPBTAZ3722_TPBPlan.shp*

**5. TAZ-Level Allocation**

**First Allocation:** Households and jobs from the "growth increment" were allocated to TAZs that are both activity center and high capacity transit TAZs ("activity center + high capacity transit TAZs"). TAZ growth was allocated based on the proportion of the TAZ households plus jobs to the jurisdiction households plus jobs for the 2030 unadjusted Round 9.1a totals (segmented by eastern and western subregion when the jurisdiction has TAZs in both subregions). Household growth was not allocated to TAZs with zero households in the 2030 unadjusted Round 9.1a totals.

Final household and job totals were calculated separately in the east and west. The east received only job growth, and the west received only household growth from the reallocation process. In the east, allocated job growth was added to the 2030 Round 9.1a totals. TAZs in the east that received zero growth retained the housing and job totals from the 2030 Round 9.1a. In the west, allocated household growth was added to the 2030 Round 9.1a totals. TAZs in the west that received zero growth differed based on whether the TAZ is an activity center:

- Activity center TAZs retained the housing and job totals from the 2030 Round 9.1a Cooperative Forecasts

- Non-activity center TAZs retained the housing and job totals from the 2025 Round 9.1a Cooperative Forecasts

**Thresholds:** TAZ growth was capped in two ways:

- **TAZ Density:** TAZ density is defined as the sum of TAZ jobs and households divided by the TAZ acreage. TAZ density resulting from growth assigned from the growth increment is capped for each jurisdiction (segmented by east and west when the jurisdiction has TAZs in both regions). The threshold is 828 households plus jobs per acre, selected to equal the maximum TAZ density for the 2050 baseline land use described in the "2050 Base Land Use Assumptions Memo" (September 9, 2021).
- **TAZ Growth:** TAZ growth is capped based on the percent growth between the unadjusted Round 9.1a households plus jobs and the new, adjusted 2030 TAZ households plus jobs. TAZ growth is capped for each jurisdiction (segmented by east and west when the jurisdiction has TAZs in both regions). The cap is 50 percent growth for all jurisdictions.

**Second Allocation:** During the first allocation, if TAZs in any jurisdictions exceeded either threshold, the "overflow" allocated jobs or households were removed from the TAZ and reallocated, this time to TAZs that are high capacity transit TAZs but not activity center TAZs. This second allocation followed a similar methodology; it allocated growth based on the proportion of TAZ households plus jobs to jurisdiction households plus jobs for the 2030 unadjusted Round 9.1a totals. Household growth was not allocated to TAZs with zero households in the 2030 unadjusted Round 9.1a totals.

**Third Allocation:** During the second allocation, household growth in the west and job growth in the east exceeded the growth threshold in certain TAZs. When TAZ growth caused a TAZ to exceed either threshold, the "overflow" jobs were removed and reallocated, this time to TAZs that are activity center TAZs but not high capacity transit TAZs. This third allocation followed a similar methodology; it allocated growth based on the proportion of TAZ households plus jobs to jurisdiction households plus jobs for 2030 unadjusted Round 9.1a totals; household growth was not allocated to TAZs with zero households in the 2030 unadjusted Round 9.1a totals. After the third allocation, no TAZs in the east that received jobs exceeded the TAZ density or growth thresholds. In the west, there was an exception.

**Exception:**

- **Fauquier County:** Fauquier County Urbanized Area does not have any high capacity transit or activity center TAZs. As a result, growth was allocated to all Fauquier County Urbanized Area TAZs as a proportion of unadjusted 2030 TAZ households plus jobs to unadjusted 2030 jurisdiction households plus jobs.

**Updated Land Use Inputs:** This exercise revised the 2030 Round 9.1a total households and total employment for each TAZ. In order to run the MWCOG model, all land use inputs must be updated to reflect these changes, including household population, group quarters population, total household population, and individual employment sectors (industrial, retail, office, and other sectors).

- **Household Population:** Household population was calculated based on the ratio between the number of households and household population for each TAZ in the unadjusted 2030 Round 9.1a file. If the TAZ had zero households in unadjusted 2030 Round 9.1a forecasts, then the ratio of households to household population from the unadjusted 2025 Round 9.1a forecasts was used.
- **Group Quarters Population:** The group quarters population for the revised land use inputs is the same as the 2030 Round 9.1a unadjusted totals.

- **Total Population:** Total population is the sum of the adjusted household population and unadjusted 2030 Round 9.1a group quarters population.
- **Employment by Sector**: Employment by sector was calculated based on the ratio between each sector and total employment for each TAZ in the unadjusted 2030 Round 9.1a totals. If a TAZ had zero employment in the adjusted 2030 calculation, then all employment types were set to zero.

## 2050 Land Use Strategy Assumptions and Method

In order to estimate the VMT reductions in 2050 from the land use strategies, the analysis team developed both a baseline and adjusted land use pattern for 2050, described below.

### Baseline 2050 Land Use Assumption

Because Round 9.1a of MWCOG's Cooperative Land Use Forecasting program does not include forecasts beyond year 2045, the consultant team created a base year 2050 zone.dbf file to reflect the incremental land use change between year 2045 and 2050 before the implementation of strategies intended to mitigate climate change.

The difference between 2045 and 2040 for each Transportation Analysis Zone (TAZ) and land use attribute[22] was calculated and then added to the corresponding 2045 value to estimate a value for 2050.[23] In cases where the decrease in a value between 2040 and 2045 would result in a negative value when extended to 2050, a zero value, rather than the negative value, was used. Category totals were then adjusted as necessary such that TOTPOP = GQPOP + HHPOP and TOTEMP = INDEMP + RETEMP + OFFEMP + OTHEMP. Hypothetical calculations for households are presented in Table 1.

**Table 18. Hypothetical TAZ-Level Household Extrapolation Calculation**

| TAZ | 2040 Value | 2045 Value | 2040-2045 Change | 2050 Value |
|---|---|---|---|---|
| X | 100 | 130 | 30 | 160 |
| Y | 100 | 80 | -20 | 60 |
| Z | 100 | 25 | -75 | 0 |

Note: The extrapolation did not have any cases where the 2045 number was so much lower than the 2040 figure as to result in a 2050 value of zero for households or total employment. However, there were two TAZs where the extrapolated retail employment would have been negative and one TAZ where extrapolated office employment would have been negative; in total these amount to only 15 retail jobs and 84 office jobs.

Table 19 summarizes the values of households and total employment for the TPB Planning Region resulting from this analysis.

[22] The calculation was performed for the following land use attribute variables in the zone.dbf file: HH (households), HHPOP (household population), GQPOP (group quarters population), TOTPOP (total population), TOTEMP (total employment), INDEMP (industrial employment), RETEMP (retail employment), OFFEMP (office employment), OTHEMP (other employment).

[23] The team also considered calculating and applying percent changes in each land use category, but this resulted in undefined percentages when the 2040 value was zero and unreasonably large percent changes when the 2040 value was small compared to the 2045 value (e.g., a TAZ with 10 households in 2040 growing to 1,000 households in 2045 would result in an unreasonable 100,000 households in 2050).

**Table 19. TPB Planning Region Land Use Summary from Analysis to 2050**

| Year | Households (HH) | Employment (TOTEMP) |
|---|---|---|
| 2040 | 2,578,072 | 4,134,640 |
| 2045 | 2,673,287 | 4,293,512 |
| 2050 | 2,768,502 | 4,454,912 |
| ***Raw Changes*** | | |
| 2040 to 2045 | 95,215 | 158,872 |
| 2045 to 2050 | 95,215 | 161,400 |
| ***Percent Changes*** | | |
| 2040 to 2045 | 3.7% | 3.8% |
| 2045 to 2050 | 3.6% | 3.8% |

**Guiding Principles**

A balanced land use zone.dbf file was prepared for year 2050 following the same approach described above for 2030 but applied for year 2050. The guiding principles of this land use balancing exercise are:

- Optimize jobs/housing balance regionwide by addressing the region's east-west divide, shifting employment growth from the western subregion to the eastern subregion.
- Increase jobs and housing around underutilized rail stations and Activity Centers with high-capacity transit.
- Build more housing in the region to match employment (about 126,000 more households).

Additional information about and constraints on the land use optimization process include:

- The Round 9.1a Cooperative Forecast in 2025 remains unchanged.
- The year 2050 baseline land use is described above.
- Only the increment of growth between 2025 and unmodified 2050 outside of Activity Centers in the western subregion ("growth increment") is shifted.
- Household growth is not reallocated from the eastern to the western subregion.
- 126,000 households are added in addition to forecast growth.
- A maximum household growth of 40,000 households (in addition to the household growth outside activity centers) between 2025 and 2050 is assumed to be able to be accommodated in the western region portion of the District of Columbia.

**Approach**

Year 2050 land use was then allocated in the following steps (similar to the 2030 approach):

1. Determine the 2050 job/household ratio, including 126,000 additional households, for the TPB Planning Region, the eastern subregion, and the western subregion.
2. Identify the "growth increment" eligible to be allocated. This increment includes (1) job growth between the 2025 and 2050 Base outside of Activity Centers; (2) housing growth between the 2025 and 2050 Base outside of Activity Centers in the western subregion only; and (3) the 126,000 additional households to be reallocated from outside the region.

3. Identify the eastern/western subregion allocation of growth that will achieve jobs/housing balance between the eastern and western subregions and shift growth to underutilized rail stations and Activity Centers with high-capacity transit in the eastern subregion.
4. Allocate job and household growth within the eastern and western subregions to individual jurisdictions in an iterative process with the goal of each jurisdiction approaching the regional job/household ratio.
5. Allocate the growth increment within each jurisdiction to individual TAZs, prioritizing Activity Centers with High Capacity Transit, TAZs with High Capacity Transit (but not Activity Centers), and Activity Centers (but not High Capacity Transit) TAZs.

These steps are described in more detail below.

**1. East/West Subregional Balance**

Table 20 summarizes the jobs and housing included in the 2050 Base, with and without the additional 126,000 households. To reach a 1.54 jobs-households ratio in both subregions, growth will shift to increase the ratio in the eastern subregion and decrease it in the western subregion. The subregions are shown in Figure 1 above.

**Table 20. Regional Job and Household Summary**

| | Jobs | Households | Ratio |
|---|---|---|---|
| Western Subregion (2050) | 2,730,049 | 1,596,672 | 1.71 |
| Eastern Subregion (2050) | 1,723,658 | 1,168,853 | 1.47 |
| TPB Planning Region (2050) | 4,453,707 | 2,765,525 | 1.61 |
| TPB Planning Region Plus 126,000 Households | 4,453,707 | 2,891,525 | 1.54 |

*Source: Fehr & Peers – modified 2050 Base zone.dbf; MWCOG – Eastern3722TAZs.shp; TPBTAZ3722_TPBPlan.shp*

**2. Identifying the "Growth Increment"**

The "growth increment" of job and household growth between 2025 and 2050 eligible to be reallocated across subregions within the TPB Planning Region comprises (1) job and housing growth outside of Activity Centers in the western subregion and (2) the 126,000 additional households (Table 21). Figure 3 illustrates that this increment is a small share of overall regional jobs and households in the year 2050.

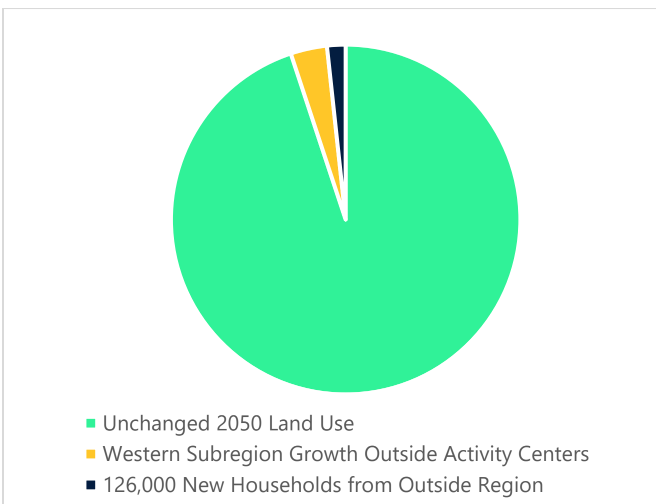


**Figure 3. "Growth Increment" in Context of Total 2050 Base Land Use (Jobs Plus Households).**

**Table 21. Job and Household "Growth Increment"**

| | 2025-2050 Growth Increment Eligible for Reallocation | |
|---|---|---|
| | Jobs | Households |
| Western Subregion Outside Activity Centers | 159,409 | 88,252 |
| Households from Outside of Region | — | 126,000 |
| Total Eligible Growth Increment | 159,409 | 214,252 |

*Source: Fehr & Peers – modified 2050 Base zone.dbf; MWCOG – Round9.1a 2025 zone.dbf; Eastern3722TAZs.shp; TPBTAZ3722_TPBPlan.shp; COG_TAZ_by_Activity_Center.shp*

**3. Identifying the Eastern/Western Subregion Allocation**

Table 22 illustrates the allocation of the jobs and households from the growth increment that achieves jobs/housing balance between the eastern and western subregions and shifts growth to underutilized rail stations and Activity Centers with high-capacity transit in the eastern subregion.

**Table 22. Subregional Job/Household Allocation**

| | Jobs | Households | Ratio |
|---|---|---|---|
| Growth Increment | | | |
| Total Eligible Growth Increment | 159,409 | 214,252 | — |
| Growth Allocated to Eastern Subregion | 109,589 | 21,370 | — |
| Growth Allocated to Western Subregion | 49,820 | 192,882 | — |
| Resulting Allocation | | | |
| Adjusted Eastern Subregion (2050) | 1,833,247 | 1,190,223 | 1.54 |
| Adjusted Western Subregion (2050) | 2,620,460 | 1,701,302 | 1.54 |
| TPB Planning Region Total | 4,453,707 | 2,891,525 | 1.54 |

*Source: Fehr & Peers – modified 2050 Base zone.dbf; MWCOG – Round9.1a 2025 zone.dbf; Eastern3722TAZs.shp; TPBTAZ3722_TPBPlan.shp; COG_TAZ_by_Activity_Center.shp*

**4. Jurisdiction-Level Allocation**

The growth increment land use available for reallocation is too small for all jurisdictions to reach the regional job/housing ratio of 1.54; jobs and households were allocated to individual jurisdictions within each subregion in proportion to the delta between the current jurisdiction's job/household ratio and the regional ratio of 1.54. Even this allocation would result in a large amount of household growth in the western portion of the District of Columbia, so growth there was capped at 40,000 additional households (in addition to growth in the 2050 Base, both within and outside activity centers) and the remaining households were allocated to other jurisdictions to further close their job/household ratio deltas. At the subregional level, jurisdictions in the west should receive a total of 192,882 households after the removal of household and job growth outside activity centers. However, because of the limit placed on the number of households the District of Columbia can receive, there is more household growth available than is needed for all other jurisdictions with initial jobs/household ratios above 1.54 in the west to achieve a ratio of 1.54. After the household allocation needed to achieve 1.54 in all jurisdictions (excluding District of Columbia), 22,715 surplus households are available for the west, and these remaining households are then allocated based on the proportion of subregional households in each jurisdiction (excluding District of Columbia) in the unadjusted 2050 Base. These additional households result in Arlington County, Fairfax County, City of Fairfax, City of Falls Church, Loudoun County and City of Manassas having their job/household ratio fall slightly below 1.54.

Prince William County also deviates from the 1.54 jobs/household ratio. The majority of Prince William County's jobs and households are outside activity centers in the western subregion. During the reallocation process, this job and household growth is removed from the county to be reallocated throughout the region. More job growth is removed than household growth, and not enough job growth is allocated to the western subregion for Prince William County to regain them, resulting in a lower jobs/household ratio than the 2050 Base.

**Table 23. Jurisdiction-Level Job and Household Summary**

| Jurisdiction | 2050 Base | | | Modified 2050 Land Use | | |
|---|---|---|---|---|---|---|
| | Households | Jobs | Ratio | Households | Jobs | Ratio |
| City of Alexandria | 121,266 | 167,455 | 1.38 | 121,316 | 175,313 | 1.45 |
| Arlington County | 148,087 | 268,951 | 1.82 | 178,503 | 271,043 | 1.52 |
| Charles County | 100,900 | 64,849 | 0.64 | 100,900 | 83,354 | 0.83 |
| District of Columbia | 427,511 | 1,078,974 | 2.52 | 488,881 | 1,072,238 | 2.19 |
| Fairfax County | 547,272 | 921,998 | 1.68 | 607,190 | 917,194 | 1.51 |
| City of Fairfax | 13,940 | 23,530 | 1.69 | 15,490 | 23,530 | 1.52 |
| City of Falls Church | 8,505 | 18,900 | 2.22 | 12,402 | 18,900 | 1.52 |
| Fauquier County | 11,193 | 23,271 | 2.08 | 13,781 | 20,961 | 1.52 |
| Frederick County | 135,795 | 149,977 | 1.10 | 119,650 | 156,859 | 1.31 |
| Loudoun County | 170,390 | 304,540 | 1.79 | 175,914 | 266,927 | 1.52 |
| City of Manassas | 16,664 | 33,004 | 1.98 | 21,684 | 33,004 | 1.52 |
| City of Manassas Park | 5,036 | 5,304 | 1.05 | 5,112 | 6,375 | 1.25 |
| Montgomery County | 472,916 | 706,068 | 1.49 | 459,665 | 683,988 | 1.49 |
| Prince George's County | 383,551 | 414,932 | 1.08 | 383,694 | 482,030 | 1.26 |
| Prince William County | 202,499 | 271,954 | 1.34 | 187,342 | 241,991 | 1.29 |
| **Eastern Subregion** | **1,168,853** | **1,723,658** | **1.47** | **1,190,223** | **1,833,247** | **1.54** |
| **Western Subregion** | **1,596,672** | **2,730,049** | **1.71** | **1,701,302** | **2,620,460** | **1.54** |
| **TPB Planning Region Total** | **2,765,525** | **4,453,707** | **1.61** | **2,891,525** | **4,453,707** | **1.54** |

*Source: Fehr & Peers – modified 2050 Base zone.dbf; MWCOG – Eastern3722TAZs.shp; TPBTAZ3722_TPBPlan.shp; COG_TAZ_by_Activity_Center.shp*

### 5. TAZ-Level Allocation

**First Allocation:** Households and jobs from the "growth increment" were allocated to TAZs that are both activity center and high capacity transit TAZs ("activity center + high capacity transit TAZs"). TAZ growth was allocated based on the proportion of the TAZ households plus jobs to the jurisdiction households plus jobs for the 2050 unadjusted Base (segmented by eastern and western subregion when the jurisdiction has TAZs in both subregions). Household growth was not allocated to TAZs with zero households in the 2050 unadjusted Base, and TAZs with zero households were not considered when calculating the jurisdiction's households plus jobs for the purpose of household allocation.

Final household and job totals were calculated separately in the east and west. In the east, allocated job and household growth was added to the 2050 Base totals. TAZs in the east that received zero growth retained the housing and job totals from the 2050 Base. In the west, allocated job and household growth was added to the 2050 Base totals for activity centers, and to the 2025 Round 9.1a totals for non-activity centers. TAZs in the west that received zero growth differed based on whether the TAZ is an activity center:

- Activity center TAZs retained the housing and job totals from the 2050 Base
- Non-activity center TAZs retained the housing and job totals from the 2025 Round 9.1a Cooperative Forecasts

**Thresholds:** TAZ growth was capped in two ways:

- **TAZ Density:** TAZ density is defined as the sum of TAZ jobs and households divided by the TAZ acreage. TAZ density resulting from growth assigned from the growth increment is capped for each jurisdiction (segmented by east and west when the jurisdiction has TAZs in both regions). The threshold is 828 households plus jobs per acre, selected to equal the maximum TAZ density for the 2050 baseline land use described in the "2050 Base Land Use Assumptions Memo" (September 9, 2021).
- **TAZ Growth:** TAZ growth is capped based on the percent growth between the unadjusted 2050 Base households plus jobs and the new, adjusted 2050 TAZ households plus jobs. TAZ growth is capped for each jurisdiction (segmented by east and west when the jurisdiction has TAZs in both regions). The cap is 50 percent growth for all jurisdictions.

**Second Allocation:** During the first allocation, if TAZs in any jurisdictions exceeded either threshold, the "overflow" allocated jobs or households were removed from the TAZ and reallocated, this time to TAZs that are high capacity transit TAZs but not activity center TAZs. These overflow jobs and households are removed in the same proportion that they are allocated, to ensure that the ratio of jobs/households allocation remains the same, until the TAZ's growth cap is reached.

The second allocation followed a similar methodology; it allocated growth based on the proportion of TAZ households plus jobs to jurisdiction households plus jobs for the 2050 unadjusted Base. Household growth was not allocated to TAZs with zero households in the 2050 unadjusted Base and TAZs with zero households were excluded from the jurisdiction's households plus jobs for the purpose of household allocation.

**Third Allocation:** During the second allocation, household and job growth exceeded the growth threshold in certain TAZs. When TAZ growth caused a TAZ to exceed either threshold, the "overflow" jobs were removed and reallocated, this time to TAZs that are activity center TAZs but not high capacity transit TAZs. This third allocation followed a similar methodology; it allocated growth based on the proportion of TAZ households plus jobs to jurisdiction households plus jobs for 2050 unadjusted Base; household growth was not allocated to TAZs with zero households in the 2050 unadjusted Base and TAZs with zero households were excluded from the jurisdiction's households plus jobs for the purpose of household allocation. After the third allocation, no TAZs in the east that received jobs exceeded the TAZ density or growth thresholds. In the west, there was an exception.

**Exception:**

- **Fauquier County:** Fauquier County Urbanized Area does not have any high capacity transit or activity center TAZs. As a result, growth was allocated to all TAZs' 2025 Round 9.1a households and jobs in proportion to the ratio of unadjusted 2025 TAZ households plus jobs to unadjusted 2025 jurisdiction households plus jobs.

**Updated Land Use Inputs:** This exercise revised the 2050 Base total households and total employment for each TAZ. In order to run the MWCOG model, all land use inputs must be updated to reflect these changes, including household population, group quarters population, total household population, and individual employment sectors (industrial, retail, office, and other sectors).

- **Household Population:** Household population was calculated based on the ratio between the number of households and household population for each TAZ in the unadjusted 2050 Base. If the TAZ had zero households in unadjusted 2050 Base, then the regional ratio of households to household population in the unadjusted 2025 Round 9.1a was used.
- **Group Quarters Population:** The group quarters population for the revised land use inputs is the same as the 2050 unadjusted Base.
- **Total Population:** Total population is the sum of the adjusted household population and unadjusted 2050 Base group quarters population.
- **Employment by Sector**: Employment by sector was calculated based on the ratio between each sector and total employment for each TAZ in the unadjusted 2050 Base. If a TAZ had zero employment in the adjusted 2050 calculation, then all employment types were set to zero.

## Analysis of Transit Enhancements and Pricing Strategies (Road Pricing, Cordon Pricing, Parking Pricing, Transit Fare Reductions)

The analysis team used a sketch planning tool, Trip Reduction Impacts of Mobility Management Strategies (TRIMMS),[24] to evaluate several of the strategies outlined in the MS scenarios. These strategies included road pricing, cordon pricing, parking pricing, and transit fare reductions. TRIMMS can handle interactions among multiple policy measures and levels of strategies, and it has been utilized in prior analysis for COG's Multisector Work Group (MSWG) and has been applied extensively in metropolitan areas around the country for analysis of transportation GHG reduction strategies. To model the strategies more precisely by applying them to only applicable trips, raw regional model outputs were aggregated by origin/destination and trip purpose "markets," as described in the following section, before estimating trip reduction impacts with TRIMMS. The TRIMMS analysis ultimately provided VMT estimates for each of the modeled strategies, which were used to calculate GHG emissions.

### Market Aggregation

The analysis team developed mode shift and travel behavior scenarios that encompass several policy strategies. Many of these strategies apply only to specific transportation markets. A transportation market encompasses both spatial and trip purpose facets. For example, one market could be home-based work (HBW) trips ending within the Washington D.C. downtown core. Another market could be a shopping trip ending in a non-DC core activity center such as Tysons Corner. Each transportation market has its own mode share, average trip length, and population of affected travelers. These three items are necessary for TRIMMS to estimate the associated passenger vehicle trip changes.

Each MS scenario policy strategy and its corresponding applicable markets are identified in Table 24. Some policies are also directional (cordon pricing would only apply to trips ending in the DC Core Activity Centers, for example). This directional distinction is considered in the analysis but is omitted from this table.

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[24] Sisinnio, Concas. TRIMMS. Center for Urban Transportation Research, University of South Florida. Accessed August 23, 2021. http://trimms.com/.

**Table 24. MSTB Policies and Applicable Transportation Markets**

| **MS.1** | | | | | | |
|---|---|---|---|---|---|---|
| Spatial Aggregation | Trip Type | Transit fare reductions | Workplace parking pricing | Transit enhance-ments | VMT Charges/Fees | Cordon Pricing |
| DC Core Activity Centers | HBW | ✓ | ✓ | ✓ | | |
| Non-DC Core Activity Centers | HBW | ✓ | ✓ | ✓ | | |
| Non-Activity Centers | HBW | ✓ | | ✓ | | |
| DC Core Activity Centers | non-HBW | ✓ | | ✓ | | |
| Non-DC Core Activity Centers | non-HBW | ✓ | | ✓ | | |
| Non-Activity Centers | non-HBW | ✓ | | ✓ | | |
| **MS.2** | | | | | | |
| Spatial Aggregation | Trip Type | Transit fare reductions | Workplace parking pricing | Transit enhance-ments | VMT Charges/Fees | Cordon Pricing |
| DC Core Activity Centers | HBW | ✓ | ✓ | ✓ | ✓ | ✓ |
| Non-DC Core Activity Centers | HBW | ✓ | ✓ | ✓ | ✓ | |
| Non-Activity Centers | HBW | ✓ | | ✓ | ✓ | |
| DC Core Activity Centers | non-HBW | ✓ | | ✓ | ✓ | ✓ |
| Non-DC Core Activity Centers | non-HBW | ✓ | | ✓ | ✓ | |
| Non-Activity Centers | non-HBW | ✓ | | ✓ | ✓ | |
| **MS.3** | | | | | | |
| Spatial Aggregation | Trip Type | Transit fare reductions | Workplace parking pricing | Transit enhance-ments | VMT Charges/Fees | Cordon Pricing |
| DC Core Activity Centers | HBW | ✓ | ✓ | ✓ | ✓ | ✓ |
| Non-DC Core Activity Centers | HBW | ✓ | ✓ | ✓ | ✓ | |
| Non-Activity Centers | HBW | ✓ | ✓ | ✓ | ✓ | |
| DC Core Activity Centers | non-HBW | ✓ | | ✓ | ✓ | ✓ |
| Non-DC Core Activity Centers | non-HBW | ✓ | | ✓ | ✓ | |
| Non-Activity Centers | non-HBW | ✓ | | ✓ | ✓ | |

The Travel Demand Model reports vehicle trips and VMT by jurisdiction, however these jurisdictions do not align spatially with the aggregations required by the MSTB scenario definitions. Therefore, the project team aggregated mode share, employment, trips, and average trip length using raw TAZ-level outputs from the regional model. This process was performed using R.[25]

[25] R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

### Aggregation from TAZ-level Outputs

The project team first defined the spatial aggregations based on activity centers defined by TPB[26] and the TAZs they contain. These spatial aggregations are displayed in Figure 4 through Figure 6.

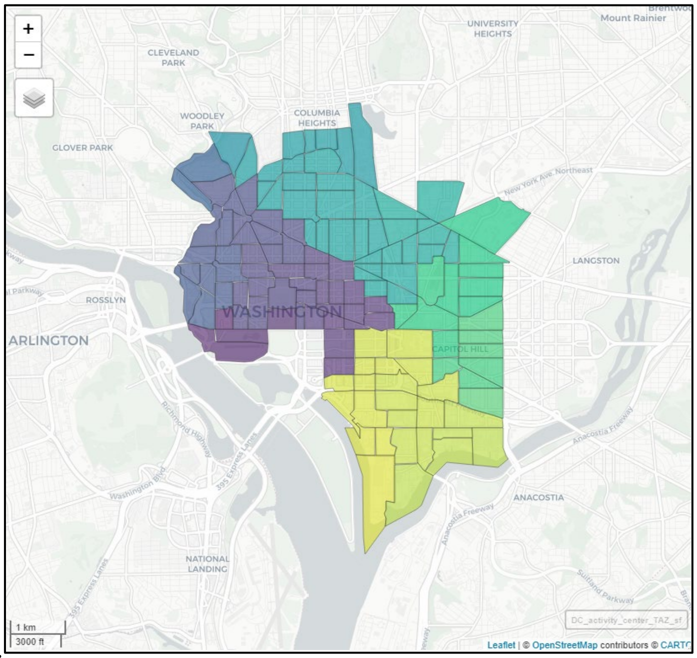


**Figure 4. DC Core Activity Centers TAZs**

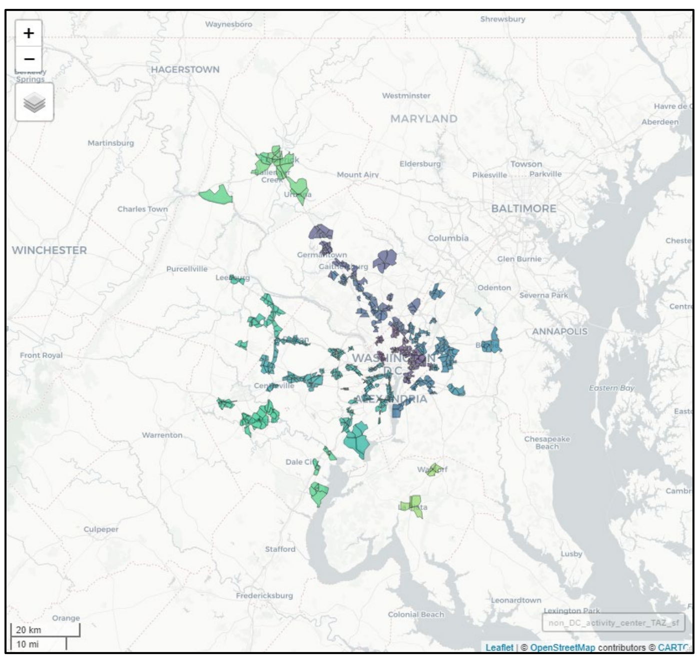


**Figure 5. Non-DC Core Activity Center TAZs**

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[26] https://rtdc-mwcog.opendata.arcgis.com/datasets/mwcog::tpb-taz-by-activity-center/about

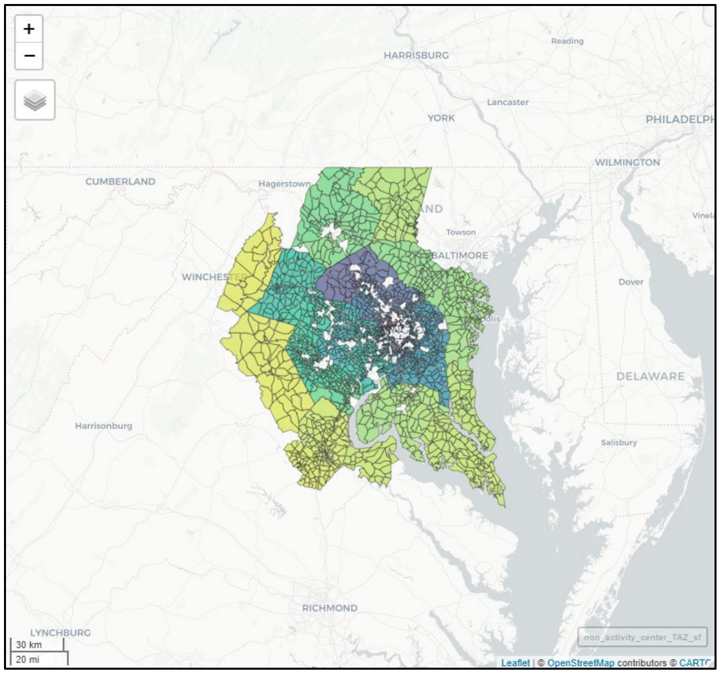


**Figure 6. Non-Activity Center TAZs**

After TAZ groupings were determined, several new statistics were calculated.

- **Total Employment** was summed for each spatial aggregation from TAZ-level employee counts (TOTEMP) for the model year in question. This information is stored in the zone.dbf file. This is used as an input for TRIMMS.
- **Motorized trips** were aggregated for each spatial aggregation from TAZ-level outputs of step 3 (mode choice) of the regional model runs.[27] Trip aggregations were subdivided by trip purpose grouping (HBW and non-HBW) and by attraction and non-attraction direction grouping. A trip attraction is defined as the non-home end of a home-based trip or the destination end of a non-home-based trip. A trip production is defined as the home end of a home-based trip or the origin of a non-home-based trip. The attraction grouping contains trips that originate outside of the spatial aggregation and end within it. The non-attraction grouping contains internal and production trips, or those trips that originate inside of the spatial aggregation and end within it or outside of it. Motorized trips refer to trips made by all motorized passenger vehicles, including transit. "DR ALONE" drive alone, "SR2" shared-ride with occupancy 2, and "SR3+" shared-ride with occupancy 3+ modes were kept separate, and all remaining motorized trips that were not DR ALONE, SR2, or SR3 were classified into a catch-all "public transit" category. To avoid double counting trips, vehicle trips going from non-DC Core Activity Center TAZs to or from DC Core Activity Center TAZs were counted only in the DC Core Activity Center attraction aggregations. Trips produced by Non-Activity Center TAZs ending in the DC Core Activity Center TAZs and non-DC Core Activity Center TAZs were not counted as trips produced by Non-Activity Center TAZs, also to avoid double counting. To validate the counting logic, the resulting total number of vehicle trips after aggregation was confirmed as the same as the standard motorized trip total reported by the default regional model summary scripts.

[27] Example filenames i4_ALL_NL_MC_M1_2030_Baseline.csv through i4_ALL_NL_MC_M14_2030_Baseline.csv

- **Private Passenger Vehicle VMT (VMT from Cars and Light-Duty Trucks)** by market was aggregated by first assuming an average occupancy for each private passenger vehicle type. DR Alone was assigned an occupancy of 1, SR2 was assigned an occupancy of 2, and SR3+ was assigned an occupancy of 3.5. Person trips for each TAZ production/attraction combination and for each mode from the previous step were divided by their corresponding vehicle occupancy to obtain vehicle trips for private passenger vehicles for each TAZ production/attraction combination. To calculate VMT, these vehicle trips for each production/attraction combination were then multiplied by the corresponding regional model step 4 (Trip Assignment) AM network distance[28] corresponding to that same TAZ production/attraction combination. Once VMT was calculated for each production/attraction combination, it was aggregated just as the above, by spatial aggregation, trip purpose grouping, and direction grouping.
- **Average VMT per person trip** by market was calculated by dividing the private passenger vehicle VMT by total person trips.
- **Mode share** was calculated for each spatial aggregation and trip purpose grouping. The calculation used the sum of attraction, production, and internal trips for each mode for that spatial aggregation and trip purpose grouping. It also took non-motorized trips into account, as TRIMMS requires a bike and walking mode share as inputs. The regional model handles non-motorized modes differently than motorized modes, in that it calculates trip ends for non-motorized trips produced/attracted by each TAZ in step 1 (Trip Generation), but it does not carry these forward into step 2 (Trip Distribution). To calculate an estimate of non-motorized trips for each production/attraction TAZ combination, the trip ends of non-motorized modes from the step 1 outputs[29] were divided by 2 for each TAZ and then summed by spatial aggregation. (As a result, there are no internal trips for non-motorized modes). Total production, attraction, and internal trips for each spatial aggregation and trip purpose grouping were then summed, using the motorized trip counts calculated above. The resulting mode share for each market is that mode's percent of trips across all modes and directions. An example mode share calculation table is shown in Table 25. Total Person Trips is the sum of Attraction Trips, Production Trips, and Internal Trips, and Mode Share is the distribution of Total Person Trips by mode.

**Table 25. DC Core Activity Center TAZ Mode Share Calculation Table**

| Mode | Total Person Trips | Attraction Trips | Production Trips | Internal Trips | Mode Share |
|---|---|---|---|---|---|
| Drive Alone | 462,508 | 370,868 | 58,496 | 33,143 | 22% |
| Public transit | 708,007 | 589,297 | 46,029 | 72,682 | 34% |
| SR2 | 192,915 | 145,913 | 24,871 | 22,131 | 9% |
| SR3+ | 159,435 | 120,255 | 20,946 | 18,234 | 8% |
| Non-Motorized | 581,817 | 434,589 | 147,229 | NA | 28% |

- **Link VMT** by mode was calculated using the spatial outputs[30] from step 4 (Trip Assignment) outputs from the regional model and summing VMT for each link by mode. VMT for each link was calculated by

[28] Example filename: i4_AM_VTT_SOV_2030_Baseline.csv
[29] Example filenames: i4_Trip_Gen_Attractions_Comp.dbf and i4_Trip_Gen_Productions_Comp.dbf
[30] Example filename: i4_Assign_Output_Link_2030_Baseline.shp

multiplying the VOL (volume) and DISTANCE fields. Aggregated VMT was also split out by roadway functional classification, which was later used in the TSMO scenario calculations.

The outputs of these aggregations performed in R are stored in the Employment Summary, Link VMT Summary, Link VMT FTYPE Summary, Modeshare Summary, and Private Vehicle VMT tabs in the calculation spreadsheet.

## Application of the TRIMMS Model

This section discusses how the TRIMMS tool was applied to model the impacts of various combinations and levels of policy measures. TRIMMS was run once for each market, for each modelled year. It was also run separately for the Attraction direction of trips to model destination-side only policies, such as workplace parking and DC Core Cordon Fees. Altogether, between 16 and 18 runs were performed for each scenario. The following describes how the tool was configured and calibrated to simulate policy measures.

- **Select Urban Area** – TRIMMS has several built-in parameters for Metropolitan Statistical Areas[31] (MSAs) around the country. These parameters include population density, employment type makeup, average wages, average household incomes, average one-way trip lengths, and average roadway speeds. To model the Washington, D.C. region as closely as possible, the Washington-Baltimore, DC-MD-VA-WV default parameters were selected.
- **Select Analysis Type** – TRIMMS offers the ability to model both region-wide and worksite-specific policy impacts. The "Area-wide" option was selected to simulate impacts for the region.
- **Commuters Affected** – For each market, the total employment (as described on page 31) was used.
- **Mode Share** – For each market, the mode share calculated (as described on page 32) was used, replacing the default values. Vanpool mode share was assumed 0% in all cases, as the regional model does not model vanpooling, but these are reflected in higher occupancy modes. Additionally, Cycling and Walking mode share were calculated by distributing the non-motorized mode share (NMT) equally between the two. For example, if non-motorized mode share was 8%, cycling made share was assigned 4% and walking mode share was assigned 4%. These figures ultimately do not make a difference in the reported GHG emissions since these are zero emissions modes.
- **Transit Fare Reduction** – To calculate transit fare reductions, a separate method was used for HBW trip markets and non-HBW trip markets.
    - For non-HBW trip markets, 2019 NTD data for unlinked trips and revenue was gathered for Washington Metropolitan Area Transit Authority (WMATA), Virginia Railway Express (VRE), and Maryland Transit Administration (MTA) (MARC commuter rail and commuter bus only). An average cost per unlinked trip of $2.30 was then calculated and used as the current trip cost for non-HBW all trips.
    - For HBW markets, 2019 ridership[32] was obtained for WMATA, VRE, and MARC. A single monthly average fare cost, weighted by ridership, across all three agencies was created from combining VRE published fares,[33] the average monthly cost based on various WMATA O-D pairs, and the

[31] Metropolitan Statistical Area are defined by the United States Office of Management and Budget (OMB), as reported by the US Census Bureau here: https://www.census.gov/programs-surveys/metro-micro/about.html
[32] WMATA: https://www.wmata.com/about/news/2019-Metrorail-ridership.cfm
VRE: https://www.vre.org/safety/safety-initiatives/passengers/
MARC: https://www.commuterpage.com/ways-to-get-around/commuter-rail-marc-vre/
[33] VRE, Service Fare Chart, https://www.vre.org/service/fares/fare-chart/

average monthly pass cost of all origin-destination combinations on MARC where DC was the destination. This monthly weighted average fare cost was next discounted by a 75%-assumed transit pass subsidy level, and then averaged with the full non-discounted transit trip price weighted by the percent of riders in each spatial market that are assumed to receive the transit subsidy, as reported by the 2019 State of the Commute Survey,[34] (The Survey reported that 66% of inner core employees receive transit subsidies, 34% of middle ring employees receive transit subsidies, and 12% of outer ring employees receive transit subsidies. These were mapped to DC Core Activity Centers, non-DC Core Activity Centers, and non-Activity Centers, respectively.) This resulted in a current average transit trip cost of $0.33 for DC Core Activity Centers, $0.63 for non-DC Core Activity Centers, and $0.85 for non-Activity Centers HBW trips. While these figures seem very low compared to the actual cost of transit fares, they reflect the average cost per trip paid by all riders after accounting for the employer subsidies.

New trip costs were then obtained by discounting the non-HBW and HBW current trip costs by the discount level specified by the scenario. For example, a $2.30 current trip cost discounted by 10% resulted in a new trip cost of $2.07.

- **Transit Travel Time Enhancements** – The 2019 State of the Commute Survey[35] reported an average commute time across all modes. The transit mode commute times were averaged, weighted by the number of respondents, resulting in a weighted average transit commute time of 53.6 minutes. This was used as the starting travel time for transit times. Scenario-specific transit travel time improvements were then applied to this value to obtain the new travel time. For example, a 15% reduction in travel time to the 53.6 average travel time resulted in a new travel time of 45.56 minutes.
- **Workplace Parking** – Workplace Parking costs were applied only to HBW trips and the regions specified in the scenario. Workplace parking was applied in TRIMMS using the parking cost fields, and it was applied equally for both Auto-Drive Alone and Auto-Rideshare modes. An average parking price of $14.00 per day for DC Core Activity Centers, $12.00 per day for non-DC Core Activity Centers, and $6.00 per day for non-Activity Centers were assumed for those employees that pay for parking. Depending on the market, these parking prices were weighted based on assumptions about the % of employees that pay for parking at their workplace based on the 2019 State of the Commute Survey.[36] Following the results of inner, middle, and outer ring employees, it was assumed that 23% of employees have free parking in DC Core Activity Centers, 80% have free parking in non-DC Core Activity Centers, and 100% have free parking in non-Activity Centers. The weighting of the parking price by the percent of employees that currently pay for parking resulted in current average parking prices of $10.78 for DC Core Activity Centers, $2.40 for non-DC Core Activity Centers, and $0.00 for non-Activity Centers. When applied to TRIMMS, the new average parking price was simply the full parking price ($6.00, $12.00, or $14.00), as the scenarios specified that 100% of certain markets would be required to pay for parking at their worksites in given years.

[34] COG, "2019 State of the Commute Survey Report", https://www.mwcog.org/documents/2020/06/17/state-of-the-commute-survey-report--carsharing-state-of-the-commute-travel-surveys/
[35] COG, "2019 State of the Commute Survey Report", https://www.mwcog.org/documents/2020/06/17/state-of-the-commute-survey-report--carsharing-state-of-the-commute-travel-surveys/
[36] COG, "2019 State of the Commute Survey Report", https://www.mwcog.org/documents/2020/06/17/state-of-the-commute-survey-report--carsharing-state-of-the-commute-travel-surveys/

- **VMT Fee** – VMT fees were applied in TRIMMS using the trip cost fields, as there is no per-VMT cost field input in TRIMMS. Current trip costs were calculated using the 2021 AAA[37] average gasoline cost of $0.1072 per mile and multiplying by the average VMT per person trip for that market, calculated in the regional model aggregation section above. This was done to avoid the starting trip cost being free. Value of travel time and maintenance/capital costs of the vehicle were not included in this calculation, as it was assumed that drivers do not often consider these costs distributed on a per mile basis when making a trip. The new trip cost was calculated by multiplying the scenario-specified per-VMT fee by the average VMT per person trip for that market, added to the current trip cost due to gasoline from the current trip cost field.
- **DC Core Cordon Fee** – The DC Cordon fee was applied only to trips in the Attraction direction market for DC Core Activity Center TAZs, as shown in Figure 4. The scenario-specified cordon fee was first divided in half to distribute the cost across both directions (to and from Activity Centers), as TRIMMS handles trips as one-way legs. Then, this half of the cordon fee was simply added on top of the new trip cost calculated in the VMT Fee section.
- **Elasticities** – Modifications to default cost and trip elasticities and cross-elasticities in TRIMMS were made based on the results obtained from the first iteration of the model runs to calibrate the results to past studies in the region and national studies. The default elasticities in the tool are based on more moderate transit price changes and are recognized to have limitations for analyzing very large reductions in transit price, particularly analysis of shifting to free transit. These modifications are listed here:
    - For MS.1 and MS.2, a value of -.245 was used for the direct transit elasticity, as reported by the DC Circulator Memo "Potential Impact of Modifications to Circulator Fares on Ridership, Revenue, & Costs Appendix B", based on studies from WMATA, to reflect the best available regional transit price elasticities.[38]
    - For MS.3, the TRIMMS tool provides unrealistic results when applying fare free transit and does not conform to studies from the field. The research team explored literature on fare free transit from around the country, including recent efforts by several cities in the U.S. (Richmond, Kansas City, Alexandria, and other localities) that have moved to fare free regional transit recently, but limited data are currently available and may not be reflecting of long-term trends due to the COVID-19 pandemic. A review of national research found that while many studies address transit ridership increases (and may derive a transit price elasticity) few directly address mode shifts and reductions in driving, and much of the ridership increase may be due to newly generated trips or shifts from bicycling or walking. A recent Northern Virginia Transportation Commission study on free and reduced fare transit (September 2021)[39], summarized: "Transit systems that have done so have seen ridership increase between 20% and 85%. U.S. examples have not shown strong evidence on mode shift from automobiles to transit, but this is highly dependent

[37] AAA, Your Driving Costs, 2021, https://newsroom.aaa.com/wp-content/uploads/2021/08/2021-YDC-Brochure-Live.pdf

[38] District Department of Transportation, "Memo, Potential Impact of Modification to Circulator Fares on Ridership, Revenues, & Costs", FY2014 DC Circulator TDP Update, http://dccirculator.com/wp-content/uploads/2015/08/Appendix_B_Fare_Elasticity_Memo.pdf - Table 1

[39] Northern Virginia Transportation Commission, "Zero-Fare and Reduced-Fare Options for Northern Virginia Transit Providers", September 2, 2021, https://novatransit.org/uploads/studiesarchive/Zero-Fare%20and%20Reduced-Fare%20White%20Paper%20Final%202021-08-30.pdf

on local factors." Building on this literature, the direct transit elasticity was adjusted from the default values to -.060 such that the resulting total trips was of the same order of magnitude of expectations for transit ridership. Additionally, cross-elasticities of 0.010 were applied for Transit/Auto and Transit/Rideshare to reflect shifts from driving higher than from the reduced price transit scenarios under MS.1 and MS.2 but within a range of literature expectations.

- Direct elasticities for Auto and Rideshare (used in the calculation of changes in driving costs through VMT fees and cordon pricing) were set to -.241, the value recommended by TRIMMS 4.0 user manual[40] to reflect long-run changes in auto trip cost. By default, a short-run change elasticity is used for these modes to reflect short-term price adjustments, but the VMT-fees and cordon pricing are assumed to be long-lasting and have long-term effects on travel behavior.

## Assessment of Telework and Bike/Ped/Micromobility Strategies

Additional calculations were performed outside of the TRIMMS tool to account for policies that TRIMMS is not designed to simulate. The process for these is described in this section.

### Telework

Telework effects were applied only to HBW trips. According to the 2019 State of the Commute Survey,[41] approximately 9.7% of employees already telecommuted from home. To reflect the change in work trips accounting for the existing telecommute uptake, the following equation was used:

$$\%\ Reduction\ in\ HBW\ trips = 1 - \frac{1 - telework\ uptake}{1 - existing\ telework\ uptake}$$

where telework uptake was set to 9.7% and the existing telework uptake was defined by each specific scenario. After multiplying the resulting reduced HBW trips in the given market by the average trip length to obtain VMT, the VMT was adjusted twice.

First, the VMT reduced by telework was discounted by 17.4%, to reflect a small increase in non-work trips for teleworkers (which may reflect additional mid-day trips or trips that would have normally be part of a trip-chain for a work trip, such as dropping off a student at school); the adjustment reflects the difference of non-work related VMT between telecommuters and non-telecommuters from the literature, as reported by Zhu & Mason, 2018.[42]

Next, the total VMT across all work trips was increased slightly to reflect anticipated shifts back to driving, reflecting significant decreases in congestion and travel times anticipated during peak periods with such high levels of telework, combined with other MSTB strategies. Building on a review of literature, estimates of reductions in travel time from high levels of telework during 2020 with the COVID-19 pandemic, and estimates of the long-term elasticity of VMT with respect to traffic speeds, the resulting total VMT for HBW trips in passenger cars and light-duty trucks following application of all MSTB strategies including telework was increased by 5% (to reflect the response to anticipated speed changes at 25% telework), and for MS. 3 the resulting VMT was

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[40] Center for Urban Transportation Research, TRIMMS. http://trimms.com/download/ - Table 4
[41] COG, "2019 State of the Commute Survey Report", https://www.mwcog.org/documents/2020/06/17/state-of-the-commute-survey-report--carsharing-state-of-the-commute-travel-surveys/.
[42] Zhu, P., and S. G. Mason. "The Impact of Telecommuting on Personal Vehicle Usage and Environmental Sustainability." International Journal of Environmental Science and Technology 11, no. 8 (November 2014): 2185–2200. https://doi.org/10.1007/s13762-014-0556-5 .

increased for all HBW trips by 10% (to reflect the effects of anticipated speeds changes and excess roadway capacity with 40% telework). These percentage figures on shifts back to driving were developed based on an estimate of a 0.64 long-term elasticity of VMT with respect to traffic speed identified from the literature (reflecting that a 10% increase in speed may increase VMT by 6.4%) and that about three-quarters is associated with the speed change itself, rather than changes in land use, from studies by Robert Cervero.[43] The result is that the figures show a small "take-back" of the substantial VMT reduction estimated from the telework and associated MSTB strategies.

### Bike/Ped/Micromobility

The effects of additional bicycle, pedestrian, and micromobility enhancements were estimated building on an analysis of micromobility usage in Arlington County, VA as a means to explore potential broader application of micromobility and related enhancements across the COG region. A 2019 report[44] assessing the performance of Shared Mobility Device systems in Arlington County, VA found that the system resulted in an average of 584 micromobility trips per day, or about 213,000 when annualized. This represents approximately 0.341% the number of vehicle trips in Arlington County, VA. This share of vehicle trips (0.341%), multiplied by a 30% vehicle trip replacement rate of micromobility trips, [45] was assumed to be the ratio of vehicle trips replaced by micromobility in 2030, or about 0.102% of vehicle trips. Because Zou et al. 2020[46] found that the average trip length of e-scooters is 0.96 miles, the number of trips replaced by micromobility was multiplied by the average trip length of e-scooters – used as a proxy for all micromobility trips - to estimate a resulting number of additional VMT that would be replaced by micromobility in 2030.

This analysis applies the Arlington micromobility uptake, that is, 0.102% of all vehicle trips, across the entire region as an additional replacement of vehicle trips associated with enhancements in the future, on top of increases in bike/pedestrian activity that were already incorporated into the analysis as part of the land use analysis. This figure was increased to 0.212% of vehicle trips for 2050. Using the trips multiplied by average micromobility trip length reflects the fact that micromobility trips tend to replace shorter vehicle trips.

These figures reflect a small incremental reduction in VMT, but it should be noted that this analysis was conducted after already accounting for the effects of other MSTB strategies within the scenarios (such as land use changes, transit enhancements, transit fare reductions, etc.) that already result in an increase in bicycle/pedestrian activity.

## Excel Layering

The various analysis techniques were layered in a structured approach using excel. This approach is summarized in Figure 7 and is described in detail below.

[43] As cited by Victoria Transport Policy Institute, "Generated Traffic and Induced Travel: Implications for Transport Planning", November 19, 2021, https://www.vtpi.org/gentraf.pdf.

[44] DeMeester, Lois R., Lama Bou Mjahed, Tasha Arreza, and Natalie Covill. "Arlington County Shared Mobility Devices (SMD) Pilot Evaluation Report," September 2019. https://1105am3mju9f3st1xn20q6ek-wpengine.netdna-ssl.com/wp-content/uploads/2019/11/ARL_SMD_Evaluation-Final-Report-1112-vff-2.pdf .

[45] McQueen, Michael, Gabriella Abou-Zeid, John MacArthur, and Kelly Clifton. "Transportation Transformation: Is Micromobility Making a Macro Impact on Sustainability?" Journal of Planning Literature, November 15, 2020, 088541222097269. https://doi.org/10.1177/0885412220972696 .

[46] Zou, Zhenpeng, Hannah Younes, Sevgi Erdoğan, and Jiahui Wu. "Exploratory Analysis of Real-Time E-Scooter Trip Data in Washington, D.C." Transportation Research Record: Journal of the Transportation Research Board 2674, no. 8 (August 2020): 285–99. https://doi.org/10.1177/0361198120919760.

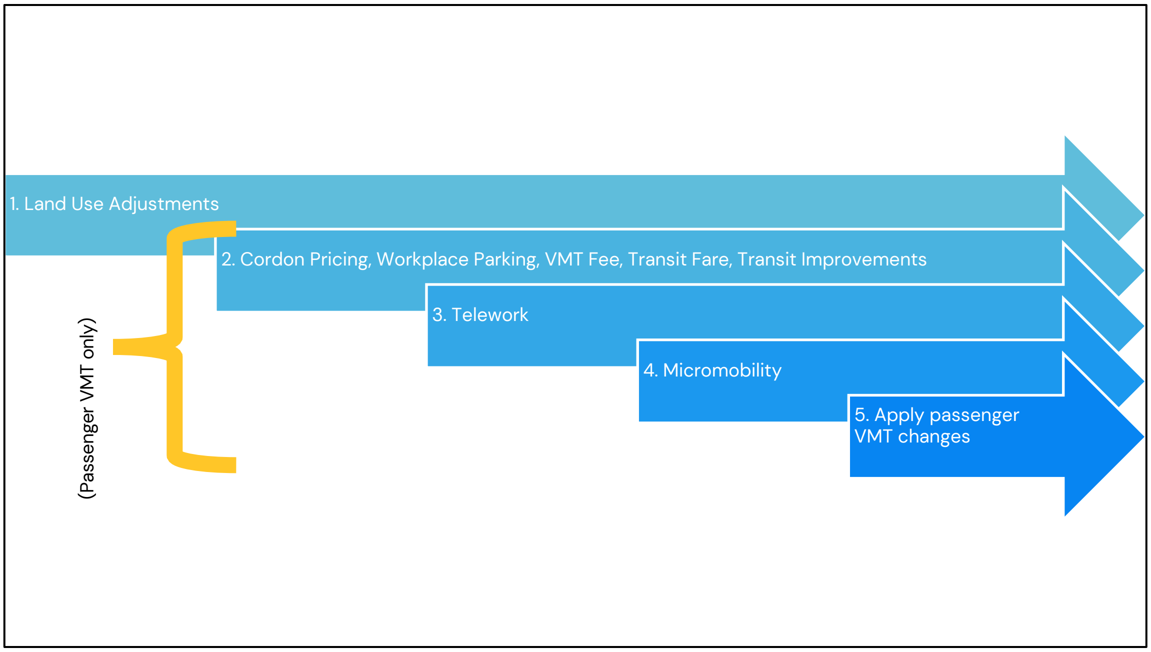


**Figure 7. Layering Approach**

1. **Land Use Adjustments** – The regionwide total link VMT, or the VMT by vehicle type distributed across the regional roadway network generated by the regional model and as calculated on page 32, was obtained for the four model runs: one using a baseline land use specification and one using revised land use specification for both 2030 and 2050. (The revised land use specification contains the modifications described in the Land Use section.) The total link VMT was aggregated by MOVES class, and percent link VMT change by class was calculated. (Airport vehicle VMT was not considered). The results of this process are summarized in Table 26. Total link VMT percent changes to Light Duty Comm. Trucks, Heavy Duty Trucks, and Combination Trucks were applied to the baseline VMT, displayed in Table 2, and saved until the emissions calculation step (step 6) after the mode shift and travel behavior policies were simulated. Passenger Cars and Passenger Trucks VMT from the baseline VMT was recalculated from the total link VMT percent changes, to be adjusted again after the mode shift and travel behavior policy simulation.

**Table 26. Baseline and Revised Land Use Regional Model Link VMT**

| Baseline Model VMT | MOVES Class | 2030 | 2050 |
|---|---|---|---|
| APX | NA | 1,882,835.58 | 2,565,608.49 |
| CV | Light Duty Comm. Trucks | 16,143,515.80 | 18,782,621.80 |
| HV2 | Pass. Cars, Pass. Trucks | 33,785,504.57 | 38,303,841.62 |
| HV3 | Pass. Cars, Pass. Trucks | 15,845,349.69 | 19,157,079.71 |
| SOV | Pass. Cars, Pass. Trucks | 125,805,501.46 | 139,167,052.90 |
| TRK | Heavy Duty Trucks, Combination Trucks | 13,498,653.06 | 15,665,755.19 |
| Total: | | 206,961,360.17 | 233,641,959.72 |
| **Revised Model VMT** | **MOVES Class** | **2030** | **2050** |
| APX | NA | 1,882,832.42 | 2,562,533.42 |
| CV | Light Duty Comm. Trucks | 16,291,151.39 | 18,487,415.33 |
| HV2 | Pass. Cars, Pass. Trucks | 32,923,214.24 | 36,675,141.13 |
| HV3 | Pass. Cars, Pass. Trucks | 15,573,365.06 | 18,365,532.30 |
| SOV | Pass. Cars, Pass. Trucks | 122,940,444.43 | 133,519,923.75 |
| TRK | Heavy Duty Trucks, Combination Trucks | 13,532,008.75 | 15,600,354.70 |
| Total: | | 203,143,016.31 | 225,210,900.63 |
| **% Change, Baseline to Revised** | **MOVES Class** | **2030** | **2050** |
| CV | Light Duty Comm. Trucks | 1% | -2% |
| HV2, HV3, SOV | Pass. Cars, Pass. Trucks | -2.3% | -4.1% |
| TRK | Heavy Duty Trucks, Combination Trucks | 0% | 0% |

2. **Cordon Pricing, Workplace Parking, VMT Fee, Transit Fare, Transit Improvements** – These mode shift and travel behavior policies were simulated using TRIMMS, with the tool setup described in the TRIMMS section beginning on page 33. Baseline trips and modeshare provided to TRIMMS were calculated using the process described in the Market Aggregation section beginning on page 28. When TRIMMS estimates the impact of travel demand management and mode shift policies, it does not preserve the initial number of trips, and assumes some induced or avoided trips. As a result, the results were interpreted differently for HBW and non-HBW markets.

   For HBW market trips, a percent change in vehicle trips was calculated using the following formula, as it was assumed that the total number of trips would not change:

$$Trip\ Adjustment = 1 - \frac{(new\ drive\ alone\ mode\ share + new\ rideshare\ mode\ share) * baseline\ oneway\ trips}{baseline\ drive\ alone\ trips + baseline\ rideshare\ trips}$$

   For non-HBW market trips, a percent change in vehicle trips was calculated using the following formula, as it was assumed that the total number of trips could change:

$$Trip\ Adjustment = \frac{\Delta\ drive\ alone\ trips + \Delta\ rideshare\ trips}{baseline\ drive\ alone\ trips + baseline\ rideshare\ trips}$$

   To calculate the impact on vehicle travel, the starting person trips for the private passenger vehicle mode, as calculated on page 31, was discounted by the Trip Adjustment factor calculated in this step.

The resulting reduced number of private passenger trips then multiplied by the average VMT/trip calculated for that market, calculated on page 32, and summed to determine the new resulting VMT due to reductions in trips. This process was repeated for each market for each year, based on that market and year's TRIMMS results.

3. **Telework** – The telework adjustment process, as described on page 36, was applied to the HBW markets only. VMT and trips were then summed across all markets.
4. **Micromobility** – The micromobility adjustment process, as described on page 37, was applied to the summed VMT and Trips resulting from the previous step.
5. **Apply Passenger VMT changes** – The percent change in VMT due to the mode shift and travel behavior policies above was again applied to the revised VMT calculated in step 1 after accounting for the land use adjustments. In effect, this stacked both the land use and mode shift and travel behavior changes on passenger vehicles only.
6. **Adjust Transit VMT due to increased transit ridership** – Due to the need for increased transit service to support higher transit ridership and decreased transit travel times, an increase in transit bus VMT of 5% in 2030 and 10% in 2050 for MS. 1 and MS. 2 were assumed. For MS.3, a 7.5% increase of transit bus VMT in 2030 and a 15% increase of transit bus VMT in 2050 were assumed.
7. **Calculate resulting emissions** – The final VMT results were multiplied by the appropriate baseline emissions rates for ICE and EV vehicles, assuming the same vehicle technology penetrations assumed in the baseline scenario. The resulting emissions were summed to produce the total emissions projected for 2030 and 2050.

## Transportation System Management and Operations (TSMO)

This section discusses the calculations and assumptions used to simulate the impacts of the transportation system management and operations (TSMO) scenario.

### Fuel Economy Modification Factors

The analysis team applied two fuel economy modification factors to vehicle fuel economies. The net impact of these modification factors is consistent with analyses of operational strategies conducted using the region's travel model for the Long-Range Plan Task Force Study.[47]

- **Corridor Operational Improvement Strategies** – Based on a simulation study from San Francisco,[48] it was assumed that a suite of corridor operational improvement strategies, including ramp metering, incident management, active signal control, and active transportation demand management strategies would lead to an emissions benefit of approximately 1.647% on affected segments  The San Francisco study results incorporated both fuel economy improvements of decreased congestion and the increased VMT effects of improved traffic flow. While VMT was not explicitly adjusted upward, the benefits are intended to account for the net impact with a small increase in VMT.
- **Eco-driving** – It was assumed that eco-driving would lead to an emissions benefit of approximately 2%. This value was chosen because it was the most conservative benefit based on ICF's earlier literature review[49].

### Application

1. Link VMT was aggregated by roadway functional classification, as shown in Table 27.

**Table 27. Daily Link VMT (millions) by Function Classification and Vehicle Class**

| Baseline Model VMT | MOVES Class | Functional Class | 2030 | 2050 |
|---|---|---|---|---|
| CV | Light Duty Comm. Trucks | Major Art, Minor Art | 7.5 | 8.3 |
| CV | Light Duty Comm. Trucks | Freeways, Expressways, Ramps | 6.1 | 7.6 |
| CV | Light Duty Comm. Trucks | Centroids, Collectors | 2.5 | 2.9 |
| HV2 | Pass. Cars, Pass. Trucks | Major Art, Minor Art | 14.4 | 15.9 |
| HV2 | Pass. Cars, Pass. Trucks | Freeways, Expressways, Ramps | 14.7 | 17.0 |
| HV2 | Pass. Cars, Pass. Trucks | Centroids, Collectors | 4.7 | 5.4 |
| HV3 | Pass. Cars, Pass. Trucks | Major Art, Minor Art | 6.2 | 7.0 |
| HV3 | Pass. Cars, Pass. Trucks | Freeways, Expressways, Ramps | 7.5 | 9.5 |
| HV3 | Pass. Cars, Pass. Trucks | Centroids, Collectors | 2.1 | 2.6 |
| SOV | Pass. Cars, Pass. Trucks | Major Art, Minor Art | 55.0 | 59.0 |
| SOV | Pass. Cars, Pass. Trucks | Freeways, Expressways, Ramps | 54.0 | 61.0 |
| SOV | Pass. Cars, Pass. Trucks | Centroids, Collectors | 16.8 | 19.2 |

[47] COG, Long Range Plan Task Force website, https://www.mwcog.org/committees/lrptf/
[48] FHWA, "Travel and Emissions Impacts of Highway Operations Strategies," Final Report, dated March 2014, prepared by Cambridge Systematics.
[49] National Capital Region Transportation Planning Board, "TPB Climate Change Mitigation Study of 2021: A Review of Climate Action Plans and Literature on Transportation Greenhouse Gas Emissions Reduction Strategies and their Effectiveness," dated July 8, 2021, prepared by ICF. https://www.mwcog.org/documents/2021/07/15/tpb-climate-change-mitigation-study-of-2021-climate-change-greenhouse-gas-scenario-planning/

| | | | | |
|---|---|---|---|---|
| TRK | Heavy Duty Trucks, Combination Trucks | Major Art, Minor Art | 5.5 | 6.2 |
| TRK | Heavy Duty Trucks, Combination Trucks | Freeways, Expressways, Ramps | 6.4 | 7.6 |
| TRK | Heavy Duty Trucks, Combination Trucks | Centroids, Collectors | 1.6 | 1.8 |
| **Total:** | | | **205.1** | **231.1** |

2. The total emissions modification factors were then assigned to functional classifications and vehicle class. A 1.65% modification factor for Corridor Operational Improvement Strategies applied to all vehicle classes across Major Art, Minor Art, Freeways, Expressways, and Ramps. A 2% modification factor for Ecodriving applied only in 2050 (not 2030) to all functional classes and vehicles to simulate efficiency improvements from CAVs. The total emissions modification factor for each functional classification and vehicle class was calculated by multiplying the applicable modification factors together in the following manner:

$$Total\ emissions\ modification\ factor_{functional\ class,vehicle\ class} = (1 - emissions\ modification\ factor_A) \times (1 - emissions\ modification\ factor_B)$$

where subscript A represents Corridor Operational Improvement Strategies and subscript B represents Ecodriving.

3. Improved emissions factors were calculated for all vehicle classes across 2030 and 2050 and for each roadway functional type using the total emissions modification factors. We assumed that efficiency improvements would only apply to ICE vehicles, because EVs have regenerative breaking capabilities that would minimize the change in efficiency due to the operational improvements.
4. A total emissions figure was calculated for all vehicle classes, propulsion types, and ICE adjusted emissions rates, weighted by the percent VMT of that vehicle class on a specific functional class group. For example:

$$ICE\ Passenger\ Car\ Emissions = \sum \%VMT\ on\ functional\ class_i * VMT\ by\ paseenger\ car\ ICE\ propulsion\ type * Adjusted\ passenger\ car\ emissions\ rate\ per\ mile\ for\ function\ class_i$$

For EVs, the baseline fleet penetration and emissions rates were used.

## Combination Scenarios

This section discusses how the previously defined scenarios were layered to create the combination scenario results:

1. **Calculate share of VMT by propulsion type (ICE, BEV, PHEV) based on results of the VT scenarios** – the share of VMT by ICE, BEV, and PHEV resulting from the VT scenarios was applied.

2. **Calculate VMT by vehicle type based on results of the MS scenarios** – Because the total VMT was modified in the MS scenarios, this total VMT was used.

3. **(COMBO.4 Only) – Account for further reduction in VMT due to increased shared rides** – As specified for the COMBO.4 scenario, an increase in sharing economy shared rides for passenger vehicle trips was modelled. To accomplish this, 60% of single occupancy vehicle (SOV) trips was assumed to be converted to shared trips with an average occupancy of 2.5 passengers. The share of SOV VMT in 2050 was adjusted using the following equation:

$$New\ SOV\ VMT = \frac{(Original\ SOV\ VMT * \%SOV\ VMT\ to\ be\ replaced)}{(New\ occupancy\ factor + SOV\ VMT * (1 - \%SOV\ VMT\ to\ be\ converted))}$$

   This new SOV VMT is added to non-SOV VMT to obtain a total passenger VMT. This results in an estimated reduction in total passenger VMT of 25%, which is in line with an estimated 30% reduction of passenger VMT proposed by McKinsey.[50]

4. **Apply adjusted emissions factors for diesel vehicles to take credit for use of biodiesel/renewable diesel** – The VT scenarios adjusted the emissions factors of buses, mid-duty trucks, and heavy-duty trucks to account for the increased use of biodiesel and renewable diesel. These adjusted emissions factors are then applied to the diesel vehicles.

5. **Apply TSMO benefits to reduce emissions factors for ICE vehicles**– The VMT at this stage is distributed by roadway functional class, as described in the TSMO calculation method, and the estimated improvement in GHG emissions rate was applied to ICE vehicles.

6. **Calculate total GHG emissions** – Emissions are calculated for all vehicle classes, propulsion types, and ICE adjusted emissions rates, weighted by the percent VMT of that vehicle class on a specific functional class group. Emissions from electricity used for EVs are then calculated by multiplying the estimated VMT by EVs by the associated energy economy for each vehicle type and multiplied by the electricity grid emissions factor for the appropriate grid assumptions.

[50] McKinsey & Company, "How shared mobility will change the automotive industry", April 18, 2017, https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/how-shared-mobility-will-change-the-automotive-industry

# Appendix A: COG Transmitted Data

This appendix contains baseline VMT and GHG inventory data transmittals from TPB Staff.

National Capital Region
**Transportation Planning Board**

**MEMORANDUM**

TO: Maia Davis, DEP Staff

FROM: Ho Jun (Daniel) Son, Jinchul (JC) Park, DTP Staff

SUBJECT: Greenhouse Gas Emissions Inventories for the 2018 GHG Inventory Update Project (Draft)

DATE: October 31, 2019

CC: Kanti Srikanth, Mark Moran, Dusan Vuksan, Erin Morrow, Jane Posey, DTP Staff
Steve Walz, Jeff King, DEP Staff

GHG_2018_Inventory_Update_Transmittal_Revised_10312019.docx



This memorandum supersedes the October 3, 2019 transmittal of greenhouse gas (GHG) inventories for the 2018 GHG Inventory Update project. It contains slight corrections to the VMT figures in Appendix B (0.01% difference at the regional level), while the rest of the memorandum is identical.

This memorandum documents assumptions, input data, and on-road mobile emissions inventories for greenhouse gases (GHG) for 2005, 2012, 2015, and 2018, estimated for the 2018 GHG Inventory Update Project, led by the Department of Environmental Programs (DEP) staff. GHG emissions for the above analysis years were estimated based on year-specific input data and assumptions. All the analyses made use of the MOVES2014b Mobile Emissions Model and the COG/TPB Version 2.3.75 Travel Demand Model.[1]

BACKGROUND

In support of an update of regional GHG inventories conducted to measure progress made toward reaching the goals outlined in the National Capital Region Climate Change Report,[2] DEP staff have requested on-road GHG emissions estimates summarized by state, jurisdiction, and vehicle type for the analysis year 2018. Department of Transportation Planning (DTP) staff suggested that, in addition to the requested 2018 estimates, on-road GHG emissions estimates for milestone years (i.e., 2005, 2012, and 2015), previously estimated at different points in time with different tools, should also be re-estimated to ensure that consistent tools were being used for each analysis year. In response, DTP staff have prepared the requested data for those four analysis years based on the Ver. 2.3.75 Travel Demand Model, the MOVES2014b Mobile Emissions Model, and Round 9.1 Cooperative Forecasts.

DATA TRANSMITTAL

The GHG emissions and annual vehicle miles of travel (VMT) are provided for the TPB Planning Area (excluding the Fauquier County urbanized area), which includes the following jurisdictions:

- City of Alexandria, Arlington County, Fairfax County (including City of Fairfax and City of Falls Church), Loudoun County, Prince William County (including City of Manassas and City of

[1] Ray Ngo et al., "User's Guide for the COG/TPB Travel Demand Forecasting Model, Version 2.3.75: Volume 1 of 2: Main Report and Appendix A (Flowcharts)" (Washington, D.C.: Metropolitan Washington Council of Governments, National Capital Region Transportation Planning Board, December 5, 2018), https://www.mwcog.org/transportation/data-and-tools/modeling/model-documentation/.

[2] Climate Change Steering Committee for the Metropolitan Washington Council of Governments Board of Directors, "National Capital Region Climate Change Report," Final Report (Washington, D.C.: Metropolitan Washington Council of Governments, November 12, 2008).

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Manassas Park), Charles County, District of Columbia, Frederick County, Montgomery County, and Prince George's County

MOVES2014b, the most recent MOVES model version, was used for this analysis. Consistent with the MOVES model reporting, the estimates are provided in short tons[3] in this memorandum. However, since greenhouse gases are frequently reported in metric tons, Appendix A contains the data for each analysis year in both short tons and metric tons. Annual VMT estimates by jurisdiction, contained in Appendix B, are summarized by the MOVES model. It is important to note that the jurisdiction-level VMT input to the model is based on the travel demand model estimates of travel occurring on the roadways in each jurisdiction, regardless of where the trips originate or terminate.

ASSUMPTIONS AND CAVEATS

Emissions estimates are based on many travel and non-travel related inputs to the MOVES model. Key modeling assumptions applied to each analysis year include:

- MOVES2014b Emissions Model
- Version 2.3.75 Travel Demand Model

Key inputs include:

- Round 9.1 Cooperative Forecasts (or latest available for each analysis year)
- Transportation networks consistent with the constrained element of Visualize 2045 Long-Range Transportation Plan adopted in October 2018 by the Transportation Planning Board
- Vehicle population data developed based on the available vehicle registration datasets
- Updated meteorological data inputs

DEP staff have conducted similar GHG inventory development exercises in the past. As such, DTP staff view this effort as an update of past GHG inventories.

It should be kept in mind that regional travel demand model VMT and MOVES model GHG estimates have not been validated for each jurisdiction, and that although the data are being provided for different geographies, the analysis conducted with the data provided in this memorandum should be undertaken at the regional level. Additional data validation, processing, and analysis may be needed to further refine estimates, especially at the jurisdiction-level.

DTP staff caution against comparing the GHG inventories developed as a part of this effort against previously developed GHG inventories. The modeling tools and assumptions have evolved, and input assumptions have been updated, therefore making any such comparisons inconsistent and not useful for trendline development.

In addition, in the near term, the regional travel demand model may fail to fully represent certain short-term changes in the transportation system, e.g., regional and national economic conditions, maintenance-related closures (e.g., WMATA SafeTrack), fluctuations in the price of gasoline, and demographic trends. Therefore, drawing trend-related inferences for three-year forecast intervals is not recommended, especially for smaller geographic areas.

DTP staff look forward to discussing this analysis and answering any questions that DEP staff may have.

[3] One "short ton" equals 2,000 pounds. By contrast, one "long ton" or "metric ton" equals 1,000 kg (ca. 2,240 pounds).

## DATA ANALYSIS

GHG emissions are mainly influenced by VMT. In general, despite the demographic growth and the associated VMT growth, GHG emissions between 2005 and 2018 remain relatively flat due to the increasing fuel efficiency of the vehicle fleet and the implementation of federal policies in recent years, both of which offset the impact of VMT growth. GHG emissions in short tons by jurisdiction and vehicle type are shown in Tables 1 and 2, respectively, while more detailed summaries that include data in metric tons are included in Appendix A. Annual VMT by jurisdiction is shown in Appendix B.

Table 1. GHG Emissions by Jurisdiction for the 2018 GHG Inventory Update Project (in short tons/year)

| Jurisdiction | 2005 | 2012 | 2015 | 2018 |
|---|---|---|---|---|
| City of Alexandria | 416,446 | 436,618 | 437,566 | 415,308 |
| Arlington County | 748,360 | 802,509 | 764,642 | 731,017 |
| Charles County | 670,318 | 658,205 | 649,295 | 624,760 |
| District of Columbia | 1,838,376 | 2,108,704 | 2,068,881 | 1,975,517 |
| Fairfax County | 5,024,392 | 5,381,532 | 5,435,846 | 5,226,943 |
| Frederick County | 1,860,917 | 1,940,430 | 1,864,579 | 1,820,695 |
| Loudoun County | 1,483,816 | 1,584,617 | 1,639,909 | 1,671,369 |
| Montgomery County | 4,323,081 | 4,437,611 | 4,354,732 | 4,164,867 |
| Prince George's County | 4,683,398 | 4,840,764 | 4,776,125 | 4,613,582 |
| Prince William County | 1,827,891 | 2,006,517 | 2,060,492 | 2,034,174 |
| Total | 22,876,995 | 24,197,506 | 24,052,067 | 23,278,232 |

Table 2. GHG Emissions by Vehicle Type for the GHG Inventory Update Project (in short tons/year)

| Vehicle Type | 2005 | 2012 | 2015 | 2018 |
|---|---|---|---|---|
| Combination Long-haul Truck | 1,362,712 | 1,485,423 | 1,430,205 | 1,323,376 |
| Combination Short-haul Truck | 839,715 | 864,537 | 826,619 | 771,713 |
| Intercity Bus | 121,085 | 167,576 | 172,742 | 185,346 |
| Light Commercial Truck | 2,398,509 | 2,694,376 | 2,697,092 | 2,694,073 |
| Motor Home | 12,133 | 13,595 | 15,684 | 17,308 |
| Motorcycle | 49,730 | 50,254 | 51,269 | 51,493 |
| Passenger Car | 9,153,938 | 9,220,942 | 9,015,694 | 8,301,256 |
| Passenger Truck | 7,380,901 | 8,178,800 | 8,210,743 | 8,177,586 |
| Refuse Truck | 88,128 | 81,049 | 87,046 | 92,902 |
| School Bus | 109,078 | 72,690 | 66,228 | 46,031 |
| Single Unit Long-haul Truck | 105,097 | 102,373 | 112,237 | 123,780 |
| Single Unit Short-haul Truck | 1,039,117 | 1,016,054 | 1,113,050 | 1,225,979 |
| Transit Bus | 216,852 | 249,837 | 253,457 | 267,390 |
| Total | 22,876,995 | 24,197,506 | 24,052,067 | 23,278,232 |

As one of the goals of this effort was to update select milestone years from past GHG inventory estimates, DTP staff used this opportunity to attempt to quantify the impacts of using updated tools and inputs on GHG inventories. Depending on the analysis year, it is estimated that the updated tools and inputs could account for regional differences in emissions of up to 6% relative to the prior estimates that were based on the MOVES2010a model, a different travel demand model, and/or different demographic data assumptions.

With recent proposed rollbacks to light-duty vehicle fuel economy standards (e.g. SAFE Rule[4]), DTP staff will continue to monitor developments in modeling methodology for GHG estimations.

[4] U.S. Environmental Protection Agency, "The Safer Affordable Fuel Efficient (SAFE) Vehicles Proposed Rule for Model Years 2021-2026," Policies and Guidance, U.S. EPA, July 19, 2018, https://www.epa.gov/regulations-emissions-vehicles-and-engines/safer-affordable-fuel-efficient-safe-vehicles-proposed.

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**APPENDIX A**

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Table A1a. 2005 Greenhouse Gas Annual Emissions by State (in short tons/year and metric tons/year)
MOVES2014b; 8.3 Cooperative Forecasts; MWCOG/TPB Travel Demand Model Version 2.3.75

| | | | | (short tons) | | (metric tons) |
|---|---|---|---|---|---|---|
| State | Atm. CO2 | Methane (CH4) | Nitrous Oxide (N2O) | CO2 Equiv.* | CO2 Equiv. % | CO2 Equiv.* |
| District of Columbia | 1,805,151 | 98 | 103 | 1,838,376 | 8.04% | 1,667,749 |
| Maryland | 11,349,064 | 603 | 583 | 11,537,713 | 50.43% | 10,466,850 |
| Virginia | 9,332,787 | 502 | 523 | 9,500,905 | 41.53% | 8,619,087 |
| Total | 22,487,002 | 1,203 | 1,209 | 22,876,995 | 100% | 20,753,686 |

*CO2 Equiv. = Atmospheric CO2 + 25 X Methane + 298 X Nitrous Oxide (Table 3-2, from Using MOVES for Estimating State and Local Inventories of Onroad Greenhouse Gas Emissions and Energy Consumption, June 2016 EPA)

Table A1b. 2005 Greenhouse Gas Emissions by Jurisdiction (in short tons/year and metric tons/year)
MOVES2014b; 8.3 Cooperative Forecasts; MWCOG/TPB Travel Demand Model Version 2.3.75

| | | | | (short tons) | | (metric tons) |
|---|---|---|---|---|---|---|
| Jurisdiction | Atm. CO2 | Methane (CH4) | Nitrous Oxide (N2O) | CO2 Equiv.* | CO2 Equiv. % | CO2 Equiv.* |
| City of Alexandria | 405,220 | 30 | 35 | 416,446 | 1.82% | 377,794 |
| Arlington County | 734,353 | 36 | 44 | 748,360 | 3.27% | 678,902 |
| Charles County | 656,086 | 42 | 44 | 670,318 | 2.93% | 608,103 |
| District of Columbia | 1,805,151 | 98 | 103 | 1,838,376 | 8.04% | 1,667,749 |
| Fairfax County | 4,939,992 | 261 | 262 | 5,024,392 | 21.96% | 4,558,058 |
| Frederick County | 1,834,661 | 80 | 81 | 1,860,917 | 8.13% | 1,688,198 |
| Loudoun County | 1,461,242 | 70 | 70 | 1,483,816 | 6.49% | 1,346,097 |
| Montgomery County | 4,249,811 | 238 | 226 | 4,323,081 | 18.90% | 3,921,837 |
| Prince George's County | 4,608,506 | 242 | 231 | 4,683,398 | 20.47% | 4,248,712 |
| Prince William County | 1,791,979 | 105 | 112 | 1,827,891 | 7.99% | 1,658,236 |
| Total | 22,487,002 | 1,203 | 1,209 | 22,876,995 | 100.00% | 20,753,686 |

*CO2 Equiv. = Atmospheric CO2 + 25 X Methane + 298 X Nitrous Oxide (Table 3-2, from Using MOVES for Estimating State and Local Inventories of Onroad Greenhouse Gas Emissions and Energy Consumption, June 2016 EPA)

Table A1c. 2005 GHG Emissions By Vehicle Type (in short tons/year and metric tons/year)
MOVES2014b; 8.3 Cooperative Forecasts; MWCOG/TPB Travel Demand Model Version 2.3.75

| | | | | (short tons) | (metric tons) |
|---|---|---|---|---|---|
| sourceTypeName | Atm. CO2 | Methane (CH4) | Nitrous Oxide (N2O) | CO2 Equiv.* | CO2 Equiv.* |
| Combination Long-haul Truck | 1,362,195 | 2 | 2 | 1,362,712 | 1,236,233 |
| Combination Short-haul Truck | 839,367 | 1 | 1 | 839,715 | 761,777 |
| Intercity Bus | 121,034 | 0 | 0 | 121,085 | 109,847 |
| Light Commercial Truck | 2,344,244 | 151 | 170 | 2,398,509 | 2,175,894 |
| Motor Home | 12,032 | 1 | 0 | 12,133 | 11,007 |
| Motorcycle | 49,404 | 5 | 1 | 49,730 | 45,114 |
| Passenger Car | 8,987,139 | 392 | 527 | 9,153,938 | 8,304,323 |
| Passenger Truck | 7,225,526 | 396 | 489 | 7,380,901 | 6,695,849 |
| Refuse Truck | 88,020 | 0 | 0 | 88,128 | 79,948 |
| School Bus | 108,281 | 9 | 2 | 109,078 | 98,954 |
| Single Unit Long-haul Truck | 104,761 | 2 | 1 | 105,097 | 95,342 |
| Single Unit Short-haul Truck | 1,034,551 | 23 | 13 | 1,039,117 | 942,672 |
| Transit Bus | 210,448 | 221 | 3 | 216,852 | 196,725 |
| Grand Total | 22,487,002 | 1,203 | 1,209 | 22,876,995 | 20,753,686 |

*CO2 Equiv. = Atmospheric CO2 + 25 X Methane + 298 X Nitrous Oxide (Table 3-2, from Using MOVES for Estimating State and Local Inventories of Onroad Greenhouse Gas Emissions and Energy Consumption, June 2016 EPA)

Table A2a. 2012 Greenhouse Gas Annual Emissions by State (in short tons/year and metric tons/year)
MOVES2014b; 9.1 Cooperative Forecasts; MWCOG/TPB Travel Demand Model Version 2.3.75

| | | | | (short tons) | | (metric tons) |
|---|---|---|---|---|---|---|
| State | Atm. CO2 | Methane (CH4) | Nitrous Oxide (N2O) | CO2 Equiv.* | CO2 Equiv. % | CO2 Equiv.* |
| District of Columbia | 2,086,902 | 90 | 66 | 2,108,704 | 8.71% | 1,912,986 |
| Maryland | 11,759,912 | 535 | 349 | 11,877,010 | 49.08% | 10,774,655 |
| Virginia | 10,102,314 | 423 | 332 | 10,211,792 | 42.20% | 9,263,993 |
| Total | 23,949,128 | 1,048 | 747 | 24,197,506 | 100% | 21,951,635 |

*CO2 Equiv. = Atmospheric CO2 + 25 X Methane + 298 X Nitrous Oxide (Table 3-2, from Using MOVES for Estimating State and Local Inventories of Onroad Greenhouse Gas Emissions and Energy Consumption, June 2016 EPA)

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Table A2b. 2012 Greenhouse Gas Emissions by Jurisdiction (in short tons/year and metric tons/year)
MOVES2014b; 9.1 Cooperative Forecasts; MWCOG/TPB Travel Demand Model Version 2.3.75

| | | | | (short tons) | | (metric tons) |
|---|---|---|---|---|---|---|
| State | Atm. CO2 | Methane (CH4) | Nitrous Oxide (N2O) | CO2 Equiv.* | CO2 Equiv. % | CO2 Equiv.* |
| City of Alexandria | 430,586 | 20 | 19 | 436,618 | 1.80% | 396,094 |
| Arlington County | 794,162 | 28 | 26 | 802,509 | 3.32% | 728,025 |
| Charles County | 649,165 | 33 | 28 | 658,205 | 2.72% | 597,115 |
| District of Columbia | 2,086,902 | 90 | 66 | 2,108,704 | 8.71% | 1,912,986 |
| Fairfax County | 5,326,783 | 218 | 166 | 5,381,532 | 22.24% | 4,882,049 |
| Frederick County | 1,924,191 | 83 | 48 | 1,940,430 | 8.02% | 1,760,331 |
| Loudoun County | 1,568,280 | 65 | 49 | 1,584,617 | 6.55% | 1,437,542 |
| Montgomery County | 4,392,887 | 207 | 133 | 4,437,611 | 18.34% | 4,025,738 |
| Prince George's County | 4,793,668 | 212 | 140 | 4,840,764 | 20.01% | 4,391,472 |
| Prince William County | 1,982,503 | 92 | 73 | 2,006,517 | 8.29% | 1,820,283 |
| Total | 23,949,128 | 1,048 | 747 | 24,197,506 | 100.00% | 21,951,635 |

*CO2 Equiv. = Atmospheric CO2 + 25 X Methane + 298 X Nitrous Oxide (Table 3-2, from Using MOVES for Estimating State and Local Inventories of Onroad Greenhouse Gas Emissions and Energy Consumption, June 2016 EPA)

Table A2c. 2012 GHG Emissions By Vehicle Type (in short tons/year and metric tons/year)
MOVES2014b; 9.1 Cooperative Forecasts; MWCOG/TPB Travel Demand Model Version 2.3.75

| | | | | (short tons) | (metric tons) |
|---|---|---|---|---|---|
| sourceTypeName | Atm. CO2 | Methane (CH4) | Nitrous Oxide (N2O) | CO2 Equiv.* | CO2 Equiv.* |
| Combination Long-haul Truck | 1,483,493 | 57 | 2 | 1,485,423 | 1,347,555 |
| Combination Short-haul Truck | 863,843 | 15 | 1 | 864,537 | 784,296 |
| Intercity Bus | 167,429 | 3 | 0 | 167,576 | 152,022 |
| Light Commercial Truck | 2,657,731 | 122 | 113 | 2,694,376 | 2,444,299 |
| Motor Home | 13,504 | 1 | 0 | 13,595 | 12,334 |
| Motorcycle | 49,886 | 5 | 1 | 50,254 | 45,590 |
| Passenger Car | 9,123,428 | 247 | 307 | 9,220,942 | 8,365,108 |
| Passenger Truck | 8,079,584 | 307 | 307 | 8,178,800 | 7,419,692 |
| Refuse Truck | 80,952 | 2 | 0 | 81,049 | 73,526 |
| School Bus | 72,350 | 5 | 1 | 72,690 | 65,943 |
| Single Unit Long-haul Truck | 102,126 | 4 | 1 | 102,373 | 92,872 |
| Single Unit Short-haul Truck | 1,012,409 | 32 | 10 | 1,016,054 | 921,750 |
| Transit Bus | 242,392 | 249 | 4 | 249,837 | 226,649 |
| Grand Total | 23,949,128 | 1,048 | 747 | 24,197,506 | 21,951,635 |

*CO2 Equiv. = Atmospheric CO2 + 25 X Methane + 298 X Nitrous Oxide (Table 3-2, from Using MOVES for Estimating State and Local Inventories of Onroad Greenhouse Gas Emissions and Energy Consumption, June 2016 EPA)

Table A3a. 2015 Greenhouse Gas Annual Emissions by State (in short tons/year and metric tons/year)
MOVES2014b; 9.1 Cooperative Forecasts; MWCOG/TPB Travel Demand Model Version 2.3.75

| | | | | (short tons) | | (metric tons) |
|---|---|---|---|---|---|---|
| State | Atm. CO2 | Methane (CH4) | Nitrous Oxide (N2O) | CO2 Equiv.* | CO2 Equiv. % | CO2 Equiv.* |
| District of Columbia | 2,050,621 | 85 | 54 | 2,068,881 | 8.60% | 1,876,859 |
| Maryland | 11,544,955 | 492 | 294 | 11,644,731 | 48.41% | 10,563,935 |
| Virginia | 10,242,145 | 427 | 288 | 10,338,455 | 42.98% | 9,378,900 |
| Total | 23,837,721 | 1,004 | 636 | 24,052,067 | 100% | 21,819,694 |

*CO2 Equiv. = Atmospheric CO2 + 25 X Methane + 298 X Nitrous Oxide (Table 3-2, from Using MOVES for Estimating State and Local Inventories of Onroad Greenhouse Gas Emissions and Energy Consumption, June 2016 EPA)

Table A3b. 2015 Greenhouse Gas Emissions by Jurisdiction (in short tons/year and metric tons/year)
MOVES2014b; 9.1 Cooperative Forecasts; MWCOG/TPB Travel Demand Model Version 2.3.75

| | | | | (short tons) | | (metric tons) |
|---|---|---|---|---|---|---|
| State | Atm. CO2 | Methane (CH4) | Nitrous Oxide (N2O) | CO2 Equiv.* | CO2 Equiv. % | CO2 Equiv.* |
| City of Alexandria | 431,716 | 21 | 18 | 437,566 | 1.82% | 396,954 |
| Arlington County | 757,425 | 27 | 22 | 764,642 | 3.18% | 693,673 |
| Charles County | 641,393 | 33 | 24 | 649,295 | 2.70% | 589,031 |
| District of Columbia | 2,050,621 | 85 | 54 | 2,068,881 | 8.60% | 1,876,859 |
| Fairfax County | 5,387,267 | 229 | 144 | 5,435,846 | 22.60% | 4,931,323 |
| Frederick County | 1,850,374 | 78 | 41 | 1,864,579 | 7.75% | 1,691,520 |
| Loudoun County | 1,625,876 | 65 | 42 | 1,639,909 | 6.82% | 1,487,702 |
| Montgomery County | 4,316,202 | 176 | 115 | 4,354,732 | 18.11% | 3,950,551 |
| Prince George's County | 4,736,986 | 206 | 114 | 4,776,125 | 19.86% | 4,332,833 |
| Prince William County | 2,039,862 | 85 | 62 | 2,060,492 | 8.57% | 1,869,249 |
| Total | 23,837,721 | 1,004 | 636 | 24,052,067 | 100.00% | 21,819,694 |

*CO2 Equiv. = Atmospheric CO2 + 25 X Methane + 298 X Nitrous Oxide (Table 3-2, from Using MOVES for Estimating State and Local Inventories of Onroad Greenhouse Gas Emissions and Energy Consumption, June 2016 EPA)

Table A3c. 2015 GHG Emissions By Vehicle Type (in short tons/year and metric tons/year)
MOVES2014b; 9.1 Cooperative Forecasts; MWCOG/TPB Travel Demand Model Version 2.3.75

| | | | | (short tons) | (metric tons) |
|---|---|---|---|---|---|
| State | Atm. CO2 | Methane (CH4) | Nitrous Oxide (N2O) | CO2 Equiv.* | CO2 Equiv. % |
| Combination Long-haul Truck | 1,428,433 | 51 | 2 | 1,430,205 | 1,297,462 |
| Combination Short-haul Truck | 825,834 | 19 | 1 | 826,619 | 749,897 |
| Intercity Bus | 172,561 | 4 | 0 | 172,742 | 156,709 |
| Light Commercial Truck | 2,665,207 | 115 | 97 | 2,697,092 | 2,446,764 |
| Motor Home | 15,596 | 1 | 0 | 15,684 | 14,229 |
| Motorcycle | 50,896 | 5 | 1 | 51,269 | 46,511 |
| Passenger Car | 8,934,300 | 231 | 254 | 9,015,694 | 8,178,910 |
| Passenger Truck | 8,124,310 | 291 | 266 | 8,210,743 | 7,448,669 |
| Refuse Truck | 86,936 | 2 | 0 | 87,046 | 78,967 |
| School Bus | 65,993 | 4 | 0 | 66,228 | 60,081 |
| Single Unit Long-haul Truck | 111,975 | 5 | 0 | 112,237 | 101,820 |
| Single Unit Short-haul Truck | 1,109,484 | 39 | 9 | 1,113,050 | 1,009,744 |
| Transit Bus | 246,196 | 237 | 5 | 253,457 | 229,932 |
| Grand Total | 23,837,721 | 1,004 | 636 | 24,052,067 | 21,819,694 |

*CO2 Equiv. = Atmospheric CO2 + 25 X Methane + 298 X Nitrous Oxide (Table 3-2, from Using MOVES for Estimating State and Local Inventories of Onroad Greenhouse Gas Emissions and Energy Consumption, June 2016 EPA)

Table A4a. 2018 Greenhouse Gas Annual Emissions by State (in short tons/year and metric tons/year)
MOVES2014b; 9.1 Cooperative Forecasts; MWCOG/TPB Travel Demand Model Version 2.3.75

| | | | | (short tons) | | (metric tons) |
|---|---|---|---|---|---|---|
| State | Atm. CO2 | Methane (CH4) | Nitrous Oxide (N2O) | CO2 Equiv.* | CO2 Equiv. % | CO2 Equiv.* |
| District of Columbia | 1,960,423 | 71 | 45 | 1,975,517 | 8.49% | 1,792,161 |
| Maryland | 11,139,560 | 457 | 245 | 11,223,904 | 48.22% | 10,182,166 |
| Virginia | 9,996,477 | 377 | 245 | 10,078,811 | 43.30% | 9,143,355 |
| Total | 23,096,460 | 905 | 535 | 23,278,232 | 100% | 21,117,682 |

*CO2 Equiv. = Atmospheric CO2 + 25 X Methane + 298 X Nitrous Oxide (Table 3-2, from Using MOVES for Estimating State and Local Inventories of Onroad Greenhouse Gas Emissions and Energy Consumption, June 2016 EPA)

Table A4b. 2018 Greenhouse Gas Emissions by Jurisdiction (in short tons/year and metric tons/year)
MOVES2014b; 9.1 Cooperative Forecasts; MWCOG/TPB Travel Demand Model Version 2.3.75

| | | | | (short tons) | | (metric tons) |
|---|---|---|---|---|---|---|
| State | Atm. CO2 | Methane (CH4) | Nitrous Oxide (N2O) | CO2 Equiv.* | CO2 Equiv. % | CO2 Equiv.* |
| City of Alexandria | 410,608 | 18 | 14 | 415,308 | 1.78% | 376,762 |
| Arlington County | 725,014 | 23 | 18 | 731,017 | 3.14% | 663,169 |
| Charles County | 617,845 | 31 | 21 | 624,760 | 2.68% | 566,773 |
| District of Columbia | 1,960,423 | 71 | 45 | 1,975,517 | 8.49% | 1,792,161 |
| Fairfax County | 5,185,967 | 197 | 121 | 5,226,943 | 22.45% | 4,741,809 |
| Frederick County | 1,808,032 | 80 | 36 | 1,820,695 | 7.82% | 1,651,709 |
| Loudoun County | 1,658,614 | 61 | 38 | 1,671,369 | 7.18% | 1,516,242 |
| Montgomery County | 4,132,232 | 162 | 96 | 4,164,867 | 17.89% | 3,778,308 |
| Prince George's County | 4,581,450 | 184 | 93 | 4,613,582 | 19.82% | 4,185,376 |
| Prince William County | 2,016,275 | 79 | 53 | 2,034,174 | 8.74% | 1,845,374 |
| Total | 23,096,460 | 905 | 535 | 23,278,232 | 100.00% | 21,117,682 |

*CO2 Equiv. = Atmospheric CO2 + 25 X Methane + 298 X Nitrous Oxide (Table 3-2, from Using MOVES for Estimating State and Local Inventories of Onroad Greenhouse Gas Emissions and Energy Consumption, June 2016 EPA)

Table A4c. 2018 GHG Emissions By Vehicle Type (in short tons/year and metric tons/year)
MOVES2014b; 9.1 Cooperative Forecasts; MWCOG/TPB Travel Demand Model Version 2.3.75

| | | | | (short tons) | (metric tons) |
|---|---|---|---|---|---|
| State | Atm. CO2 | Methane (CH4) | Nitrous Oxide (N2O) | CO2 Equiv.* | CO2 Equiv. % |
| Combination Long-haul Truck | 1,321,353 | 62 | 2 | 1,323,376 | 1,200,548 |
| Combination Short-haul Truck | 770,843 | 22 | 1 | 771,713 | 700,087 |
| Intercity Bus | 185,126 | 5 | 0 | 185,346 | 168,143 |
| Light Commercial Truck | 2,666,601 | 100 | 84 | 2,694,073 | 2,444,025 |
| Motor Home | 17,223 | 1 | 0 | 17,308 | 15,701 |
| Motorcycle | 51,130 | 5 | 1 | 51,493 | 46,714 |
| Passenger Car | 8,236,080 | 194 | 203 | 8,301,256 | 7,530,781 |
| Passenger Truck | 8,103,041 | 248 | 230 | 8,177,586 | 7,418,590 |
| Refuse Truck | 92,774 | 3 | 0 | 92,902 | 84,279 |
| School Bus | 45,788 | 4 | 1 | 46,031 | 41,758 |
| Single Unit Long-haul Truck | 123,486 | 7 | 0 | 123,780 | 112,291 |
| Single Unit Short-haul Truck | 1,222,288 | 49 | 8 | 1,225,979 | 1,112,190 |
| Transit Bus | 260,728 | 206 | 5 | 267,390 | 242,573 |
| Grand Total | 23,096,460 | 905 | 535 | 23,278,232 | 21,117,682 |

*CO2 Equiv. = Atmospheric CO2 + 25 X Methane + 298 X Nitrous Oxide (Table 3-2, from Using MOVES for Estimating State and Local Inventories of Onroad Greenhouse Gas Emissions and Energy Consumption, June 2016 EPA)

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**APPENDIX B**

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Table B1. Model Estimates of Annual VMT by Jurisdiction for the 2018 GHG Inventory Update Project (in miles)*

| Jurisdiction | 2005 | 2012 | 2015 | 2018 |
|---|---|---|---|---|
| City of Alexandria | 709,887,400 | 744,529,228 | 763,515,169 | 778,871,862 |
| Arlington County | 1,485,146,675 | 1,530,633,432 | 1,503,528,592 | 1,538,650,619 |
| Charles County | 1,158,975,249 | 1,152,558,466 | 1,180,327,456 | 1,223,278,357 |
| District of Columbia | 3,512,490,964 | 3,633,821,850 | 3,643,818,984 | 3,723,548,184 |
| Fairfax County | 9,463,359,389 | 9,739,947,383 | 10,233,965,326 | 10,485,758,912 |
| Frederick County | 3,168,786,201 | 3,359,178,513 | 3,374,206,350 | 3,507,685,133 |
| Loudoun County | 2,514,198,650 | 2,644,184,323 | 2,882,617,582 | 3,130,691,282 |
| Montgomery County | 7,927,547,532 | 8,087,337,413 | 8,230,167,147 | 8,465,908,965 |
| Prince George's County | 8,479,640,323 | 8,753,729,614 | 8,946,605,335 | 9,180,988,355 |
| Prince William County | 3,122,734,469 | 3,438,483,566 | 3,702,220,157 | 3,890,576,953 |
| Total | 41,542,766,853 | 43,084,403,788 | 44,460,972,098 | 45,925,958,621 |

* MOVES2014B Model Summary

National Capital Region
**Transportation Planning Board**

**MEMORANDUM**

| | |
|---|---|
| TO: | Maia Davis, DEP Staff |
| FROM: | Ho Jun (Daniel) Son, Jinchul (JC) Park, DTP Staff |
| SUBJECT: | Greenhouse Gas Emissions Inventories for the 2030 Climate Action Plan (Draft) |
| DATE: | November 1, 2019 |
| CC: | Kanti Srikanth, Mark Moran, Dusan Vuksan, Erin Morrow, Jane Posey, DTP Staff<br>Steve Walz, Jeff King, DEP Staff |

GHG_2030_Climate_Action_Plan_Transmittal_11012019.docx



This memorandum documents assumptions, input data, and on-road mobile emissions inventories for greenhouse gases (GHG) estimated for the COG's 2030 Regional Climate and Energy Action Plan, led by the Department of Environmental Programs (DEP) staff. GHG emissions for 2030 were estimated based on year-specific input data and assumptions. All the analyses made use of the MOVES2014b Mobile Emissions Model and the COG/TPB Version 2.3.75 Travel Demand Model.[1]

BACKGROUND

In support of the activities related to the COG's 2030 Regional Climate and Energy Action Plan conducted to measure progress made toward reaching the goals outlined in the National Capital Region Climate Change Report,[2] DEP staff have requested on-road GHG emissions estimates summarized by state, jurisdiction, and vehicle type for the analysis year 2030. In response, DTP staff have prepared the requested data based on the Ver. 2.3.75 Travel Demand Model, the MOVES2014b Mobile Emissions Model, and Round 9.1 Cooperative Forecasts.

DATA TRANSMITTAL

The GHG emissions and annual vehicle miles of travel (VMT) for 2030 are provided for the TPB Planning Area (excluding the Fauquier County urbanized area), which includes the following jurisdictions:

- City of Alexandria, Arlington County, Fairfax County (including City of Fairfax and City of Falls Church), Loudoun County, Prince William County (including City of Manassas and City of Manassas Park), Charles County, District of Columbia, Frederick County, Montgomery County, and Prince George's County

Other analysis years (2005, 2012, 2015, and 2018) from recent GHG planning activities are also included in some of the tables for quality assurance purposes. MOVES2014b, the most recent MOVES model version, was used for this analysis. Consistent with the MOVES model reporting, the estimates are provided in short tons[3] in this memorandum. However, since greenhouse gases are frequently reported in metric tons, Appendix A contains the 2030 data in both short tons and metric

[1] Ray Ngo et al., "User's Guide for the COG/TPB Travel Demand Forecasting Model, Version 2.3.75: Volume 1 of 2: Main Report and Appendix A (Flowcharts)" (Washington, D.C.: Metropolitan Washington Council of Governments, National Capital Region Transportation Planning Board, December 5, 2018), https://www.mwcog.org/transportation/data-and-tools/modeling/model-documentation/.

[2] Climate Change Steering Committee for the Metropolitan Washington Council of Governments Board of Directors, "National Capital Region Climate Change Report," Final Report (Washington, D.C.: Metropolitan Washington Council of Governments, November 12, 2008).

[3] One "short ton" equals 2,000 pounds. One "long ton" or "metric ton" equals 1,000 kg (ca. 2,240 pounds).

tons. Annual VMT estimates by jurisdiction, contained in Appendix B, are summarized for each analysis year by the MOVES model. It is important to note that the jurisdiction-level VMT input to the model is based on the travel demand model estimates of travel occurring on the roadways in each jurisdiction, regardless of where the trips originate or terminate.

ASSUMPTIONS AND CAVEATS

Emissions estimates are based on many travel and non-travel related inputs to the MOVES model. As noted earlier, this analysis makes use of the following two models:

- MOVES2014b Emissions Model
- Version 2.3.75 Travel Demand Model

Key inputs include:

- Round 9.1 Cooperative Forecasts
- Transportation networks consistent with the constrained element of Visualize 2045 Long-Range Transportation Plan adopted in October 2018 by the Transportation Planning Board
- Vehicle population data developed based on the most recent 2016 vehicle registration data
- Updated meteorological data inputs

It should be kept in mind that regional travel demand model VMT and MOVES model GHG estimates have not been validated for each jurisdiction. Thus, although the modeled estimates are being provided, in some cases, at the jurisdictional level, further analyses conducted with the modeled estimates provided in this memorandum should be undertaken at the regional level. Additional data validation, processing, and analysis may be needed to further refine estimates, especially at the jurisdiction level.

DTP staff caution against comparing the GHG inventories developed as a part of this effort against GHG inventories developed using different assumptions. The modeling tools and assumptions have evolved, and input assumptions have been updated, therefore making any such comparisons inconsistent and not useful for trendline development.

DTP staff look forward to discussing this analysis and answering any questions that DEP staff may have.

DATA ANALYSIS

All else equal, GHG emissions are mainly influenced by VMT. However, despite the demographic growth and the associated VMT growth, GHG emissions between 2018 and 2030 are predicted to decline due to the increasing fuel efficiency of the vehicle fleet and the implementation of federal policies in recent years, both of which offset the impact of VMT growth. GHG emissions in short tons by jurisdiction and vehicle type are shown in Tables 1 and 2, respectively, while more detailed summaries that include data in metric tons are included in Appendix A. Annual VMT by jurisdiction is shown in Appendix B. Recent GHG and VMT estimates associated with the 2018 GHG Inventory development are included in Tables 1 and 2, and in Appendix B, for quality assurance purposes.

Table 1. GHG Emissions by Jurisdiction for the 2018 GHG Inventory Update Project and 2030 Climate Action Plan (in short tons/year)

| Jurisdiction | 2005 | 2012 | 2015 | 2018 | 2030 |
|---|---|---|---|---|---|
| City of Alexandria | 416,446 | 436,618 | 437,566 | 415,308 | 330,940 |
| Arlington County | 748,360 | 802,509 | 764,642 | 731,017 | 554,416 |
| Charles County | 670,318 | 658,205 | 649,295 | 624,760 | 569,730 |
| District of Columbia | 1,838,376 | 2,108,704 | 2,068,881 | 1,975,517 | 1,486,069 |
| Fairfax County | 5,024,392 | 5,381,532 | 5,435,846 | 5,226,943 | 4,336,432 |
| Frederick County | 1,860,917 | 1,940,430 | 1,864,579 | 1,820,695 | 1,604,682 |
| Loudoun County | 1,483,816 | 1,584,617 | 1,639,909 | 1,671,369 | 1,484,409 |
| Montgomery County | 4,323,081 | 4,437,611 | 4,354,732 | 4,164,867 | 3,406,851 |
| Prince George's County | 4,683,398 | 4,840,764 | 4,776,125 | 4,613,582 | 3,767,866 |
| Prince William County | 1,827,891 | 2,006,517 | 2,060,492 | 2,034,174 | 1,781,411 |
| **Total** | 22,876,995 | 24,197,506 | 24,052,067 | 23,278,232 | 19,322,806 |

Table 2. GHG Emissions by Vehicle Type for the GHG Inventory Update Project and 2030 Climate Action Plan (in short tons/year)

| Vehicle Type | 2005 | 2012 | 2015 | 2018 | 2030 |
|---|---|---|---|---|---|
| Combination Long-haul Truck | 1,362,712 | 1,485,423 | 1,430,205 | 1,323,376 | 1,432,827 |
| Combination Short-haul Truck | 839,715 | 864,537 | 826,619 | 771,713 | 842,949 |
| Intercity Bus | 121,085 | 167,576 | 172,742 | 185,346 | 178,211 |
| Light Commercial Truck | 2,398,509 | 2,694,376 | 2,697,092 | 2,694,073 | 2,151,441 |
| Motor Home | 12,133 | 13,595 | 15,684 | 17,308 | 19,244 |
| Motorcycle | 49,730 | 50,254 | 51,269 | 51,493 | 57,169 |
| Passenger Car | 9,153,938 | 9,220,942 | 9,015,694 | 8,301,256 | 6,368,541 |
| Passenger Truck | 7,380,901 | 8,178,800 | 8,210,743 | 8,177,586 | 6,400,066 |
| Refuse Truck | 88,128 | 81,049 | 87,046 | 92,902 | 101,906 |
| School Bus | 109,078 | 72,690 | 66,228 | 46,031 | 44,819 |
| Single Unit Long-haul Truck | 105,097 | 102,373 | 112,237 | 123,780 | 134,288 |
| Single Unit Short-haul Truck | 1,039,117 | 1,016,054 | 1,113,050 | 1,225,979 | 1,333,711 |
| Transit Bus | 216,852 | 249,837 | 253,457 | 267,390 | 257,634 |
| Total | 22,876,995 | 24,197,506 | 24,052,067 | 23,278,232 | 19,322,806 |

With recent proposed rollbacks to light-duty vehicle fuel economy standards (e.g. SAFE Rule[4]), DTP staff will continue to monitor developments in modeling methodology for GHG estimations.

[4] U.S. Environmental Protection Agency, "The Safer Affordable Fuel Efficient (SAFE) Vehicles Proposed Rule for Model Years 2021-2026," Policies and Guidance, U.S. EPA, July 19, 2018, https://www.epa.gov/regulations-emissions-vehicles-and-engines/safer-affordable-fuel-efficient-safe-vehicles-proposed.

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**APPENDIX A**

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Table 1a. 2030 Greenhouse Gas Annual Emissions by State (in short tons/year and metric tons/year)
MOVES2014b; 9.1 Cooperative Forecasts; MWCOG/TPB Travel Demand Model Version 2.3.75

| | | | | (short tons) | | (metric tons) |
|---|---|---|---|---|---|---|
| State | Atm. CO2 | Methane (CH4) | Nitrous Oxide (N2O) | CO2 Equiv.* | CO2 Equiv. % | CO2 Equiv.* |
| District of Columbia | 1,475,298 | 56 | 32 | 1,486,069 | 7.69% | 1,348,140 |
| Maryland | 9,289,960 | 357 | 169 | 9,349,130 | 48.38% | 8,481,398 |
| Virginia | 8,424,071 | 318 | 187 | 8,487,608 | 43.93% | 7,699,837 |
| Total | 19,189,329 | 730 | 387 | 19,322,806 | 100% | 17,529,375 |

*CO2 Equiv. = Atmospheric CO2 + 25 X Methane + 298 X Nitrous Oxide (Table 3-2, from Using MOVES for Estimating State and Local Inventories of Onroad Greenhouse Gas Emissions and Energy Consumption, June 2016 EPA)

Table 1b. 2030 Greenhouse Gas Emissions by Jurisdiction (in short tons/year and metric tons/year)
MOVES2014b; 9.1 Cooperative Forecasts; MWCOG/TPB Travel Demand Model Version 2.3.75

| | | | | (short tons) | | (metric tons) |
|---|---|---|---|---|---|---|
| State | Atm. CO2 | Methane (CH4) | Nitrous Oxide (N2O) | CO2 Equiv.* | CO2 Equiv. % | CO2 Equiv.* |
| City of Alexandria | 327,530 | 14 | 10 | 330,940 | 1.71% | 300,224 |
| Arlington County | 550,244 | 16 | 13 | 554,416 | 2.87% | 502,959 |
| Charles County | 565,035 | 24 | 14 | 569,730 | 2.95% | 516,851 |
| District of Columbia | 1,475,298 | 56 | 32 | 1,486,069 | 7.69% | 1,348,140 |
| Fairfax County | 4,305,219 | 162 | 91 | 4,336,432 | 22.44% | 3,933,950 |
| Frederick County | 1,595,283 | 74 | 25 | 1,604,682 | 8.30% | 1,455,745 |
| Loudoun County | 1,473,749 | 55 | 31 | 1,484,409 | 7.68% | 1,346,634 |
| Montgomery County | 3,383,044 | 121 | 70 | 3,406,851 | 17.63% | 3,090,647 |
| Prince George's County | 3,746,597 | 138 | 60 | 3,767,866 | 19.50% | 3,418,155 |
| Prince William County | 1,767,328 | 71 | 41 | 1,781,411 | 9.22% | 1,616,071 |
| Total | 19,189,329 | 730 | 387 | 19,322,806 | 100.00% | 17,529,375 |

*CO2 Equiv. = Atmospheric CO2 + 25 X Methane + 298 X Nitrous Oxide (Table 3-2, from Using MOVES for Estimating State and Local Inventories of Onroad Greenhouse Gas Emissions and Energy Consumption, June 2016 EPA)

Table 1c. 2030 GHG Emissions by Vehicle Type (in short tons/year and metric tons/year)
MOVES2014b; 9.1 Cooperative Forecasts; MWCOG/TPB Travel Demand Model Version 2.3.75

| State | Atm. CO2 | Methane (CH4) | Nitrous Oxide (N2O) | CO2 Equiv.* (short tons) | CO2 Equiv. % (metric tons) |
|---|---|---|---|---|---|
| Combination Long-haul Truck | 1,430,156 | 85 | 2 | 1,432,827 | 1,299,841 |
| Combination Short-haul Truck | 841,888 | 28 | 1 | 842,949 | 764,711 |
| Intercity Bus | 177,951 | 7 | 0 | 178,211 | 161,671 |
| Light Commercial Truck | 2,132,897 | 72 | 56 | 2,151,441 | 1,951,757 |
| Motor Home | 19,195 | 1 | 0 | 19,244 | 17,458 |
| Motorcycle | 56,759 | 5 | 1 | 57,169 | 51,863 |
| Passenger Car | 6,319,085 | 136 | 155 | 6,368,541 | 5,777,450 |
| Passenger Truck | 6,348,642 | 157 | 160 | 6,400,066 | 5,806,050 |
| Refuse Truck | 101,760 | 4 | 0 | 101,906 | 92,448 |
| School Bus | 44,655 | 4 | 0 | 44,819 | 40,659 |
| Single Unit Long-haul Truck | 133,978 | 8 | 0 | 134,288 | 121,824 |
| Single Unit Short-haul Truck | 1,330,680 | 56 | 5 | 1,333,711 | 1,209,924 |
| Transit Bus | 251,685 | 169 | 6 | 257,634 | 233,722 |
| Grand Total | 19,189,329 | 730 | 387 | 19,322,806 | 17,529,375 |

*CO2 Equiv. = Atmospheric CO2 + 25 X Methane + 298 X Nitrous Oxide (Table 3-2, from Using MOVES for Estimating State and Local Inventories of Onroad Greenhouse Gas Emissions and Energy Consumption, June 2016 EPA)

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**APPENDIX B**

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Table B1. Annual VMT by Jurisdiction for the 2018 GHG Inventory Update Project and 2030 Climate Action Plan (in miles)

| Jurisdiction | 2005 | 2012 | 2015 | 2018 | 2030 |
|---|---|---|---|---|---|
| City of Alexandria | 709,887,400 | 744,529,228 | 763,515,169 | 778,871,862 | 850,106,464 |
| Arlington County | 1,485,146,675 | 1,530,633,432 | 1,503,528,592 | 1,538,650,619 | 1,631,898,742 |
| Charles County | 1,158,975,249 | 1,152,558,466 | 1,180,327,456 | 1,223,278,357 | 1,465,208,161 |
| District of Columbia | 3,512,490,964 | 3,633,821,850 | 3,643,818,984 | 3,723,548,184 | 3,819,077,452 |
| Fairfax County | 9,463,359,389 | 9,739,947,383 | 10,233,965,326 | 10,485,758,912 | 11,692,759,918 |
| Frederick County | 3,168,786,201 | 3,359,178,513 | 3,374,206,350 | 3,507,685,133 | 4,025,914,741 |
| Loudoun County | 2,514,198,650 | 2,644,184,323 | 2,882,617,582 | 3,130,691,282 | 3,613,331,288 |
| Montgomery County | 7,927,547,532 | 8,087,337,413 | 8,230,167,147 | 8,465,908,965 | 9,424,970,973 |
| Prince George's County | 8,479,640,323 | 8,753,729,614 | 8,946,605,335 | 9,180,988,355 | 10,007,835,008 |
| Prince William County | 3,122,734,469 | 3,438,483,566 | 3,702,220,157 | 3,890,576,953 | 4,447,436,336 |
| Total | 41,542,766,853 | 43,084,403,788 | 44,460,972,098 | 45,925,958,621 | 50,978,539,085 |

* MOVES2014B Model Summary

National Capital Region
**Transportation Planning Board**

**MEMORANDUM**

TO: Jeff King, DEP Staff
FROM: Jinchul (JC) Park, DTP Staff
SUBJECT: Regional Greenhouse Gas Emissions Inventories for the Analysis Year 2045
DATE: February 13, 2020
CC: Kanti Srikanth, Mark Moran, Dusan Vuksan, Erin Morrow, Jane Posey, DTP Staff
Steve Walz, Maia Davis, DEP Staff

GHG_2045_Regional_Estimates _Transmittal_02132020.docx



This memorandum documents assumptions, input data, and on-road mobile emissions inventories for greenhouse gas (GHG) estimated for the analysis year 2045 in support of COG's regional climate and energy action planning, led by the Department of Environmental Programs (DEP) staff. GHG emissions for 2045 were estimated based on year-specific input data and assumptions. The analysis made use of the MOVES2014b Mobile Emissions Model and the COG/TPB Version 2.3.78 Travel Demand Model, which does not differ substantially from the Version 2.3.75 that was used recently in similar activities.[1]

BACKGROUND

In support of the activities related to the COG's regional climate and energy action planning activities conducted to measure progress made toward reaching the goals outlined in the National Capital Region Climate Change Report,[2] DEP staff have requested on-road GHG emissions estimates summarized by state, jurisdiction, and vehicle type for the analysis year 2045. In response, DTP staff have prepared the requested data based on the Ver. 2.3.78 Travel Demand Model, the MOVES2014b Mobile Emissions Model, and Round 9.1a Cooperative Forecasts.

DATA TRANSMITTAL

The GHG emissions and annual vehicle miles of travel (VMT) for 2045 are provided for the TPB Planning Area (excluding the Fauquier County urbanized area), which includes the following jurisdictions:

- City of Alexandria, Arlington County, Fairfax County (including City of Fairfax and City of Falls Church), Loudoun County, Prince William County (including City of Manassas and City of Manassas Park), Charles County, District of Columbia, Frederick County, Montgomery County, and Prince George's County

Other analysis years (2005, 2012, 2015, 2018, and 2030) from recent GHG planning activities are also included in some of the tables for quality assurance purposes. MOVES2014b, the most recent MOVES model version, was used for this analysis. Consistent with the MOVES model reporting, the

[1] Ray Ngo et al., "User's Guide for the COG/TPB Travel Demand Forecasting Model, Version 2.3.75: Volume 1 of 2: Main Report and Appendix A (Flowcharts)" (Washington, D.C.: Metropolitan Washington Council of Governments, National Capital Region Transportation Planning Board, December 5, 2018), https://www.mwcog.org/transportation/data-and-tools/modeling/model-documentation/.

[2] Climate Change Steering Committee for the Metropolitan Washington Council of Governments Board of Directors, "National Capital Region Climate Change Report," Final Report (Washington, D.C.: Metropolitan Washington Council of Governments, November 12, 2008).

METROPOLITAN WASHINGTON COUNCIL OF GOVERNMENTS
777 NORTH CAPITOL STREET NE, SUITE 300, WASHINGTON, DC 20002 MWCOG.ORG/TPB (202) 962-3200

estimates are provided in short tons[3] in this memorandum. However, since greenhouse gases are frequently reported in metric tons, Appendix A contains the 2045 data in both short tons and metric tons. Annual VMT estimates by jurisdiction, contained in Appendix B, are summarized for each analysis year by the MOVES model. It is important to note that the jurisdiction-level VMT input to the model is based on the travel demand model estimates of travel occurring on the roadways in each jurisdiction, regardless of where the trips originate or terminate.

ASSUMPTIONS AND CAVEATS

Emissions estimates are based on many travel and non-travel related inputs to the MOVES model. As noted earlier, this analysis makes use of the following two models:

- MOVES2014b Emissions Model
- Version 2.3.78 Travel Demand Model

Key inputs include:

- Round 9.1a Cooperative Forecasts
- Transportation networks consistent with the constrained element of the 2020 Amendment to the Visualize 2045 Long-Range Transportation Plan, scheduled for approval by the Transportation Planning Board in March 2020
- Vehicle population data developed based on the most recent 2016 vehicle registration data
- Updated meteorological data inputs

It is worth noting that the 2045 assumptions are slightly different from recently developed assumptions used in climate action planning for analysis years 2005, 2012, 2015, 2018 and 2030, but that both sets of assumptions should result in comparable sets of GHG estimates. For example, 2030 GHG inventories were based on Round 9.1 Cooperative Forecasts and the Visualize 2045 Long Range Transportation Plan that was adopted in 2018.

It should be kept in mind that regional travel demand model VMT and MOVES model GHG estimates have not been validated for each jurisdiction. Thus, although the modeled estimates are being provided, in some cases, at the jurisdictional level, further analyses conducted with the modeled estimates provided in this memorandum should be undertaken at the regional level. Additional data validation, processing, and analysis may be needed to further refine estimates, especially at the jurisdiction level.

DTP staff caution against comparing the GHG inventories developed as a part of this effort against GHG inventories developed using different assumptions. The modeling tools and assumptions have evolved, and input assumptions have been updated, therefore making any such comparisons inconsistent and not useful for trendline development.

DTP staff look forward to discussing this analysis and answering any questions that DEP staff may have.

[3] One “short ton” equals 2,000 pounds. One “long ton” or “metric ton” equals 1,000 kg (ca. 2,240 pounds).

**DATA ANALYSIS**

All else equal, GHG emissions are mainly influenced by VMT. However, despite the demographic growth and the associated VMT growth, GHG emissions between 2018 and 2045 are predicted to decline due to the increasing fuel efficiency of the vehicle fleet and the implementation of federal policies in recent years, both of which offset the impact of VMT growth. GHG emissions in short tons by jurisdiction and vehicle type are shown in Tables 1 and 2, respectively, while more detailed summaries that include data in metric tons are included in Appendix A. Annual VMT by jurisdiction is shown in Appendix B. Recent GHG and VMT estimates associated with the 2018 GHG Inventory development are included in Tables 1 and 2, and in Appendix B, for quality assurance purposes.

Table 1. GHG Emissions by Jurisdiction for Climate Action Planning Activities (in short tons/year)

| Jurisdiction | 2005 | 2012 | 2015 | 2018 | 2030 | 2045 |
|---|---|---|---|---|---|---|
| City of Alexandria | 416,446 | 436,618 | 437,566 | 415,308 | 330,940 | 326,269 |
| Arlington County | 748,360 | 802,509 | 764,642 | 731,017 | 554,416 | 526,049 |
| Charles County | 670,318 | 658,205 | 649,295 | 624,760 | 569,730 | 619,928 |
| District of Columbia | 1,838,376 | 2,108,704 | 2,068,881 | 1,975,517 | 1,486,069 | 1,406,824 |
| Fairfax County | 5,024,392 | 5,381,532 | 5,435,846 | 5,226,943 | 4,336,432 | 4,276,448 |
| Frederick County | 1,860,917 | 1,940,430 | 1,864,579 | 1,820,695 | 1,604,682 | 1,618,600 |
| Loudoun County | 1,483,816 | 1,584,617 | 1,639,909 | 1,671,369 | 1,484,409 | 1,527,433 |
| Montgomery County | 4,323,081 | 4,437,611 | 4,354,732 | 4,164,867 | 3,406,851 | 3,275,489 |
| Prince George's County | 4,683,398 | 4,840,764 | 4,776,125 | 4,613,582 | 3,767,866 | 3,625,157 |
| Prince William County | 1,827,891 | 2,006,517 | 2,060,492 | 2,034,174 | 1,781,411 | 1,882,960 |
| Total | 22,876,995 | 24,197,506 | 24,052,067 | 23,278,232 | 19,322,806 | 19,085,158 |

Table 2. GHG Emissions by Vehicle Type for Climate Action Planning Activities (in short tons/year)

| Vehicle Type | 2005 | 2012 | 2015 | 2018 | 2030 | 2045 |
|---|---|---|---|---|---|---|
| Combination Long-haul Truck | 1,362,712 | 1,485,423 | 1,430,205 | 1,323,376 | 1,432,827 | 1,582,486 |
| Combination Short-haul Truck | 839,715 | 864,537 | 826,619 | 771,713 | 842,949 | 936,419 |
| Intercity Bus | 121,085 | 167,576 | 172,742 | 185,346 | 178,211 | 177,887 |
| Light Commercial Truck | 2,398,509 | 2,694,376 | 2,697,092 | 2,694,073 | 2,151,441 | 2,080,225 |
| Motor Home | 12,133 | 13,595 | 15,684 | 17,308 | 19,244 | 62,555 |
| Motorcycle | 49,730 | 50,254 | 51,269 | 51,493 | 57,169 | 21,198 |
| Passenger Car | 9,153,938 | 9,220,942 | 9,015,694 | 8,301,256 | 6,368,541 | 6,038,075 |
| Passenger Truck | 7,380,901 | 8,178,800 | 8,210,743 | 8,177,586 | 6,400,066 | 6,142,722 |
| Refuse Truck | 88,128 | 81,049 | 87,046 | 92,902 | 101,906 | 111,655 |
| School Bus | 109,078 | 72,690 | 66,228 | 46,031 | 44,819 | 43,840 |
| Single Unit Long-haul Truck | 105,097 | 102,373 | 112,237 | 123,780 | 134,288 | 149,411 |
| Single Unit Short-haul Truck | 1,039,117 | 1,016,054 | 1,113,050 | 1,225,979 | 1,333,711 | 1,483,345 |
| Transit Bus | 216,852 | 249,837 | 253,457 | 267,390 | 257,634 | 255,341 |
| Total | 22,876,995 | 24,197,506 | 24,052,067 | 23,278,232 | 19,322,806 | 19,085,158 |

4

With recent proposed rollbacks to light-duty vehicle fuel economy standards (e.g. SAFE Rule[4]), DTP staff will continue to monitor developments in modeling methodology for GHG estimations.

[4] U.S. Environmental Protection Agency, "The Safer Affordable Fuel Efficient (SAFE) Vehicles Proposed Rule for Model Years 2021-2026," Policies and Guidance, U.S. EPA, July 19, 2018, https://www.epa.gov/regulations-emissions-vehicles-and-engines/safer-affordable-fuel-efficient-safe-vehicles-proposed.

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**APPENDIX A**

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Table A1. 2045 Greenhouse Gas Annual Emissions by State (in short tons/year and metric tons/year)
MOVES2014b; 9.1a Cooperative Forecasts; MWCOG/TPB Travel Demand Model Version 2.3.78

| | | | | (short tons) | | (metric tons) |
|---|---|---|---|---|---|---|
| State | Atm. CO2 | Methane (CH4) | Nitrous Oxide (N2O) | CO2 Equiv.* | CO2 Equiv. % | CO2 Equiv.* |
| District of Columbia | 1,395,679 | 53 | 33 | 1,406,824 | 7.37% | 1,276,251 |
| Maryland | 9,079,081 | 343 | 173 | 9,139,174 | 47.89% | 8,290,929 |
| Virginia | 8,471,594 | 310 | 201 | 8,539,159 | 44.74% | 7,746,604 |
| Total | 18,946,354 | 705 | 407 | 19,085,158 | 100% | 17,313,784 |

*CO2 Equiv. = Atmospheric CO2 + 25 X Methane + 298 X Nitrous Oxide (Table 3-2, from Using MOVES for Estimating State and Local Inventories of On-road Greenhouse Gas Emissions and Energy Consumption, June 2016 EPA)

Table A2. 2045 Greenhouse Gas Emissions by Jurisdiction (in short tons/year and metric tons/year)
MOVES2014b; 9.1a Cooperative Forecasts; MWCOG/TPB Travel Demand Model Version 2.3.78

| | | | | (short tons) | | (metric tons) |
|---|---|---|---|---|---|---|
| Jurisdiction | Atm. CO2 | Methane (CH4) | Nitrous Oxide (N2O) | CO2 Equiv.* | CO2 Equiv. % | CO2 Equiv.* |
| City of Alexandria | 322,720 | 13 | 11 | 326,269 | 1.71% | 295,986 |
| Arlington County | 521,929 | 15 | 13 | 526,049 | 2.76% | 477,225 |
| Charles County | 614,989 | 27 | 14 | 619,928 | 3.25% | 562,390 |
| District of Columbia | 1,395,679 | 53 | 33 | 1,406,824 | 7.37% | 1,276,251 |
| Fairfax County | 4,243,803 | 154 | 97 | 4,276,448 | 22.41% | 3,879,533 |
| Frederick County | 1,609,333 | 75 | 25 | 1,618,600 | 8.48% | 1,468,371 |
| Loudoun County | 1,515,422 | 57 | 36 | 1,527,433 | 8.00% | 1,385,665 |
| Montgomery County | 3,250,849 | 113 | 73 | 3,275,489 | 17.16% | 2,971,477 |
| Prince George's County | 3,603,910 | 127 | 61 | 3,625,157 | 18.99% | 3,288,691 |
| Prince William County | 1,867,719 | 72 | 45 | 1,882,960 | 9.87% | 1,708,194 |
| Total | 18,946,354 | 705 | 407 | 19,085,158 | 100.00% | 17,313,784 |

*CO2 Equiv. = Atmospheric CO2 + 25 X Methane + 298 X Nitrous Oxide (Table 3-2, from Using MOVES for Estimating State and Local Inventories of On-road Greenhouse Gas Emissions and Energy Consumption, June 2016 EPA)

Table A3. 2045 GHG Emissions By Vehicle Type (in short tons/year and metric tons/year)
MOVES2014b; 9.1a Cooperative Forecasts; MWCOG/TPB Travel Demand Model Version 2.3.78

| Vehicle Type | Atm. CO2 | Methane (CH4) | Nitrous Oxide (N2O) | (short tons) CO2 Equiv.* | (metric tons) CO2 Equiv. % |
|---|---|---|---|---|---|
| Combination Long-haul Truck | 1,579,337 | 101 | 2 | 1,582,486 | 1,435,609 |
| Combination Short-haul Truck | 935,200 | 32 | 1 | 936,419 | 849,506 |
| Intercity Bus | 177,602 | 7 | 0 | 177,887 | 161,376 |
| Light Commercial Truck | 2,061,514 | 63 | 58 | 2,080,225 | 1,887,150 |
| Motor Home | 21,153 | 1 | 0 | 21,198 | 19,230 |
| Motorcycle | 62,088 | 6 | 1 | 62,555 | 56,749 |
| Passenger Car | 5,985,591 | 120 | 166 | 6,038,075 | 5,477,656 |
| Passenger Truck | 6,090,136 | 129 | 166 | 6,142,722 | 5,572,590 |
| Refuse Truck | 111,493 | 4 | 0 | 111,655 | 101,292 |
| School Bus | 43,637 | 5 | 0 | 43,840 | 39,771 |
| Single Unit Long-haul Truck | 149,072 | 9 | 0 | 149,411 | 135,544 |
| Single Unit Short-haul Truck | 1,480,120 | 65 | 5 | 1,483,345 | 1,345,670 |
| Transit Bus | 249,409 | 163 | 6 | 255,341 | 231,642 |
| Grand Total | 18,946,354 | 705 | 407 | 19,085,158 | 17,313,784 |

*CO2 Equiv. = Atmospheric CO2 + 25 X Methane + 298 X Nitrous Oxide (Table 3-2, from Using MOVES for Estimating State and Local Inventories of On-road Greenhouse Gas Emissions and Energy Consumption, June 2016 EPA)

A-4

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**APPENDIX B**

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Table B1. Annual VMT by Jurisdiction for Climate Action Planning Activities (in miles)

| Jurisdiction | 2005 | 2012 | 2015 | 2018 | 2030 | 2045 |
|---|---|---|---|---|---|---|
| City of Alexandria | 709,887,400 | 744,529,228 | 763,515,169 | 778,871,862 | 850,106,464 | 915,130,969 |
| Arlington County | 1,485,146,675 | 1,530,633,432 | 1,503,528,592 | 1,538,650,619 | 1,631,898,742 | 1,716,244,667 |
| Charles County | 1,158,975,249 | 1,152,558,466 | 1,180,327,456 | 1,223,278,357 | 1,465,208,161 | 1,765,055,443 |
| District of Columbia | 3,512,490,964 | 3,633,821,850 | 3,643,818,984 | 3,723,548,184 | 3,819,077,452 | 3,997,007,894 |
| Fairfax County | 9,463,359,389 | 9,739,947,383 | 10,233,965,326 | 10,485,758,912 | 11,692,759,918 | 12,564,454,131 |
| Frederick County | 3,168,786,201 | 3,359,178,513 | 3,374,206,350 | 3,507,685,133 | 4,025,914,741 | 4,456,306,475 |
| Loudoun County | 2,514,198,650 | 2,644,184,323 | 2,882,617,582 | 3,130,691,282 | 3,613,331,288 | 4,040,035,410 |
| Montgomery County | 7,927,547,532 | 8,087,337,413 | 8,230,167,147 | 8,465,908,965 | 9,424,970,973 | 9,957,884,842 |
| Prince George's County | 8,479,640,323 | 8,753,729,614 | 8,946,605,335 | 9,180,988,355 | 10,007,835,008 | 10,840,454,440 |
| Prince William County | 3,122,734,469 | 3,438,483,566 | 3,702,220,157 | 3,890,576,953 | 4,447,436,336 | 5,189,377,801 |
| Total | 41,542,766,853 | 43,084,403,788 | 44,460,972,098 | 45,925,958,621 | 50,978,539,085 | 55,441,952,072 |

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