GHG Transportation Report

Determining Compliance with the GHG Transportation Planning Standard

Submitted to TC August 16, 2022 & amended September 7, 2022

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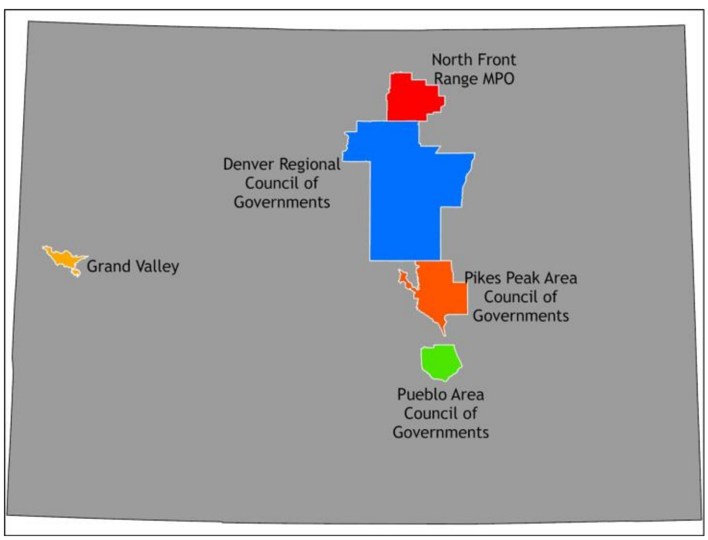
EXECUTIVE SUMMARY

The Colorado Greenhouse Gas Pollution Reduction Planning Rule was finalized by the state Transportation Commission on December 16, 2021. The Rule requires the Colorado Department of Transportation (CDOT) and the state's five metropolitan planning organizations (MPOs) to determine the total greenhouse gas emissions expected from future transportation projects and reduce emissions by set amounts. This GHG Transportation Report, which is required by the Rule[1], details CDOT's compliance with the GHG reduction levels established in the Rule.

The Rule applies to CDOT's 10-Year Plan[2] as adopted by the Transportation Commission and, more specifically to:

- "regionally significant projects" within the Plan[3]
- projects located outside the boundaries of the state's five MPO areas (see Figure 1 below)

Figure 1



[1] 2 CCR 601-22, Section 8.02.6" 8.02.6 Demonstrating Compliance. At least thirty (30) days prior to adoption or amendment of any Applicable Planning Document except amendments to MPO TIPs, CDOT for NonMPO areas, and the MPOs for their areas shall provide to the Commission a GHG Transportation Report containing the following information..."

[2] The 10-Year Plan is the Applicable Planning Document as defined in the Rule in Section 1.02.

[3] Regionally Significant Projects are projects that result in a fundamental change to the way people travel (e.g., new highway lanes). This distinction, consistent with legislative direction, creates an important differentiation between those projects that materially alter how the infrastructure will be used or its impact on a community, versus those changes that are strictly asset management. CDOT has developed a guidance memo detailing the process for evaluating projects to determine whether they are Regionally Significant.

CDOT used two different methodologies to determine compliance. For the near-term compliance years of 2025 and 2030, compliance is based on analyzing projects within the 10-Year Plan. For 2040 and 2050 — years for which CDOT has not yet identified transportation projects — a scenario-based analysis was used. This Report describes both approaches.

CDOT is able to meet the required 2025 GHG reduction level through the updated 10 Year Plan. To meet the required GHG reductions levels in 2030, 2040, and 2050, CDOT relies on a combination of GHG Mitigation Measures from a wide variety of categories, including transit, transportation demand management (TDM), operational improvements, changes to the built environment, and heavy-duty fleet electrification. Table 1 below summarizes results across all compliance years.

Table 1. GHG Reduction Results and Compliance

	2025	2030	2040	2050
Required GHG Reduction Amount (MMT)	0.12	0.36	0.30	0.17
Reductions achieved through Modeling	0.30	0.21	0.06	0.04
Reductions achieved through GHG Mitigations	n/a	0.157	0.249	0.135
Total Reductions achieved	0.30	0.367	0.309	0.175
Compliance Result	Met	Met	Met	Met

GHG EMISSIONS ANALYSIS - 2025 & 2030

CDOT's Travel Demand Model is the primary tool used to determine compliance. The capabilities and sophistication of the Travel Demand Model make it a powerful tool to evaluate the effects on travel behavior of a wide range of characteristics of regions, people and travel modes and therefore permit a realistic evaluation of transportation planning's effects on air pollutant emissions. Notably, the model:

- Depicts each person individually, including characteristics important to that individual's travel choices.
- Explicitly depicts the choice between work-from-home and work elsewhere, allowing scenarios in which changes in propensity to work from home are

affected by planning activities (programs/infrastructure) or by larger changes in society (e.g., COVID effects.)

- Estimates the trips (number, type, etc.) that people make based on the activities they need to accomplish in a day, and the effect of travel conditions on peoples' choice of how best to accomplish those tasks. This modeling approach permits the model to estimate changes in peoples' demand for travel as travel conditions change.
- Depicts the location of households and jobs at the address level rather than at the coarse "zone" level that is common in older models. This is particularly important for modeling active transportation modes such as walking and biking.

The primary output of the Travel Demand Model is total estimated Vehicle Miles Traveled for a given year. EPA's MOVES model is necessary to translate this VMT into greenhouse gas emissions. CDOT hired a consultant, Felsburg, Holt and Ullevig (FHU), to run MOVES for this compliance demonstration. FHU worked with the Colorado Department of Public Health and Environment's (CDPHE) MOVES modelers to replicate CDPHE methods for running MOVES, including input files, model parameters and settings, etc. Numerous tests were run to ensure that FHU could replicate CDPHE outcomes. A description of the process of running MOVES can be found in the Appendix.

The GHG reduction levels in the Rule must be achieved relative to a baseline amount of emissions. The Rule requires each agency to determine this baseline, which is the first step in the analysis. CDOT's process is described below.

Description of Baseline GHG Emission Values for 2025 and 2030

The baseline model run uses the 10-Year Plan as adopted by the Commission in 2019. This run assumes full build-out of all projects in the 10-Year Plan. The land use (population and job totals and locations) begin with existing development as built. Development growth for the years 2025 and 2030 is taken from county-level forecasts provided by the State Demographer's Office in the Colorado Department of Local Affairs (DOLA). Additional households and jobs (due to projected growth) are placed in buildable areas in each county (e.g., avoiding national forests, water, road rights of way, steep slopes, etc.) but are otherwise distributed randomly within each county.[4]

[4] At this stage CDOT does not have local zoning and comprehensive plans necessary to place future development in a manner more consistent with local government intentions.

The VMT resulting from this baseline run is then analyzed by MOVES in order to obtain the GHG emission values for 2025 and 2030.

CDOT calculates values for non-MPOs areas by modeling the entire state and then removing results for the MPO areas. Thus, the baseline runs for the various years called for in the Rule include specific highway and transit projects listed in CDOT and MPO plans that were adopted on or before the date of the GHG rule adoption (January 20th, 2022). Categories/quantities of funds that are included in such plans, but have not been assigned to projects, are not included in baseline scenarios. Instead they are included in compliance scenarios. In general, the statewide model is well able to depict regionally significant highway projects, and fixed-route transit services in urbanized areas. CDOT's statewide model does not explicitly depict bicycle and pedestrian facilities. The effects of funds allocated to these modes are approximated by adjusting parameters in the statewide model that depict people's response to overall service levels afforded by the bicycle/pedestrian networks (e.g., general perceptions of safety, convenience, speed, etc.)

Plan elements by mode in the 10-Year Plan baseline model run are depicted as follows:

- Highway: Includes all regionally significant projects in the 2019 Ten Year Plan, including in some cases project clarification/detail provided by CDOT region staff. In the MPO areas, the networks include all regionally significant projects included in the MPO travel models.
- Transit: includes all existing services in the MPO areas, all existing services of rural transit providers, and all existing Bustang services.
- Bicycle/pedestrian: bicycle and pedestrian service levels afforded by the current system are assumed to remain the same in all future baseline scenarios. This is reflected in the statewide travel model by leaving at their current value all model parameters that depict the extent to which various demographic groups choose to walk or bicycle. For example, the model includes parameters, developed from survey data, that show women choosing to bicycle less readily than do men: the same is true of younger and older people of all genders.

Baseline emission results are listed in the table below along with the resulting percentage reduction in GHG emissions as required by the Rule.

Table 2: Baseline GHG Emissions Levels and Reduction Percentages

	2025 (MMT)	2030 (MMT)
GHG Baseline: 2019 10 Year Plan	6.3	4.84
Required GHG Reduction Amount	0.12	0.36
% Reduction from Baseline	1.9%	7.4%

Description of Compliance GHG Emission Values for 2025 and 2030

For the past several months CDOT has been working to update its 10-Year Plan; a process that involved input from the state's 15 Transportation Planning Regions. As required by the Rule, all Regionally Significant Projects within the updated Plan were coded into the travel demand model, a process referred to here as the "compliance run."

CDOT also adjusted several assumptions within the model to reflect changed travel patterns caused by the COVID-19 pandemic and increased investments in multimodal funding.

- The percentage of Coloradans working from home increased. Prior to the COVID pandemic, US Census Bureau data used by CDOT in its modeling work estimated that 6.3% of Colorado workers worked from home on a typical day. During the COVID pandemic, the Census Bureau conducted a series of weekly "pulse" surveys, in which as many as 45% of Colorado households said that some adults in their household had shifted some or all work trips to work-from-home due to COVID, over and above pre-existing work-from-home habits. While these data do not of course provide certainty of future work-from-home behaviors, there are no indications that work-from-home behaviors will return fully to their pre-COVID levels. CDOT therefore has adjusted the statewide model to produce approximately 20% work-from-home. This represents a somewhat more conservative assumption than is being used by DRCOG and the NFRMPO.
- An increased amount of tele-health and tele-university in rural areas due to broadband expansion.
- Changes to average bicycling and walking speed and adjustments in model factors that reflect increased adoption of e-bikes and a greater perception of bicycle/pedestrian safety, comfort and convenience among some demographic groups that currently are less likely to use active modes. All these changes contribute to more trips using these modes and are assumed to occur due to

extensive, recent investments in bicycle and pedestrian infrastructure.[5]

Table 3: Model Assumption Changes

	Baseline	2025 compliance	2030 compliance
Tele-work	6%	20%	20%
Walk/bike speed	3/12 mph	5/12.7 mph	5/13 mph
Telehealth and tele-university	Low pre-COVID	Partway to 2030 assumptions *(reflecting dramatic change in post-COVID period)* 1.3% telehealth 26.7% tele-university	2% (additional) telehealth 40% tele-university

Plan elements by mode in the 10-Year Plan compliance model run are depicted as follows:

- Highway: while in the non-MPO areas, the plan contains a number of highway projects, none of them added lane miles, interchanges, etc., so in the non-MPO areas, the network is the same as the baseline scenario.
- Transit: the travel model network includes all existing urban and small town fixed-route services, and existing Bustang services. New rural transit and Bustang/Outrider expansion was evaluated in the context of mitigation action plans, separate from the travel model.
- Bicycle/pedestrian: as discussed above, bicycle/pedestrian parameters simulating lower use of these modes by some demographic groups were reduced by 50%, simulating improved acceptance of these modes in these demographic groups.

The results from this compliance run, summarized in the table below, show achievement of reduction levels in 2025 and a 150,000 ton shortfall in 2030. In order to achieve the additional GHG reductions, CDOT uses GHG Mitigation Measures as outlined in Policy Directive 1610.0, which are further explained in the next section of

[5] This includes increased and long-term funding for the Multi-modal Transportation and Mitigation Options Fund (MMOF) along with the Safer Main Streets and Revitalizing Main Streets programs.

this report.

Table 4: Compliance Run Results Compared to Required Reductions

	2025	2030
Total GHGs Reduced in Compliance Run	0.30	0.21
Table 1 Required Reduction Amount	0.12	0.36
Difference	-0.18 (compliance achieved)	0.15 (GHG Mitigation Measures needed)

MITIGATIONS NEEDED FOR COMPLIANCE

To close the 2030 reduction gap, CDOT analyzed the reduction benefits of a number of mitigation measures (as provided for in Policy Directive 1610[6]). These Measures — which are analyzed comprehensively in a GHG Mitigation Action Plan in Appendix 1 — include transit, Transportation Demand Management (TDM), operational improvements, changes to the built environment, and heavy duty fleet electrification. It is important to note that several of these investments were included in the updated 10-Year Plan, however their travel and GHG benefits could not be accurately or easily captured and quantified in the statewide travel demand model thus requiring analysis as mitigation measures. CDOT's GHG Mitigation Measures are summarized briefly below. Table 5 summarizes the GHG benefit of these GHG Mitigation Measures.

Rural Transit

While Colorado has one of the largest rural transit networks in the nation — made possible by the investments and support CDOT provides through FASTER Transit and FTA funding — current modeling practice is not able to fully capture the GHG reductions achieved by these services. Thus, CDOT applied the GHG Mitigation

[6]https://www.codot.gov/programs/environmental/greenhousegas/assets/pd-1610-0-greenhouse-gas-mitigation-measures-june2022.pdf

Measure methodology outlined in Policy Directive 1610 to rural intercity and local transit. Two transit mitigation measures were calculated.

1. Bustang Expansion: The passage of Senate Bill-180 in 2022 provided $30 million in direct funding for the expansion of Bustang service throughout the 3-year pilot program. The expansion is expected to result in an additional 51,000 new riders annually.
2. Return to Pre-Pandemic Service Levels: To date, transit ridership across much of the state has not yet returned to pre-pandemic ridership. Through strategic use of state and federal funds, CDOT aims to return the intercity, local, and demand response service levels of the state's rural transit agencies to pre-COVID levels by 2030 or earlier.

Heavy-duty Electrification

There are currently 25 zero emission transit buses that are either in operation or have been awarded to transit agencies in the non-MPO areas. CDOT has prioritized the replacement of diesel transit vehicles in rural transit agencies through the allocation of funds in the Volkswagen Diesel Emission Settlement, FTA grants, SB 228, and FASTER. The full timeline of these measures depend on whether an Advanced Clean Truck/Heavy-duty Low NOx Omnibus rule is adopted in Colorado.

Transportation Demand Management

The Strategic Transportation Demand Management (TDM) Grant Program, developed by CDOT's Office of Innovative Mobility, provides programmatic and funding support to communities and organizations as they expand and enhance existing trip-reduction interventions and develop new and innovative projects and programs that are capable of meeting Colorado's evolving transportation challenges. The Mitigation Action Plan looks at several of the most recent grant awardees in the non-MPO areas and the anticipated GHG benefits of these projects and programs.

Operational Improvements

In addition to strategies that focus on reducing single occupancy vehicle travel, CDOT has also updated its 10 Year Plan to include a number of operational improvements such as roundabouts. While roundabouts have long been recognized for their safety and mobility benefits, the increased efficiency that they provide at intersections also benefit air quality by reducing GHG emissions. In addition to over 10 roundabouts that were prioritized for funding during initial 10 Year Plan Development, CDOT has updated its Plan to add three additional roundabouts. As the statewide travel model does not distinguish between a roundabout and traditional signalized intersection, CDOT has included them in the Mitigation Action Plan to capture the additional air quality benefits that the newly added roundabout projects bring to the 10 Year Plan.

Built Environment

The need for attainable workforce housing in many communities in non-MPO areas of Colorado has led many local governments to adopt a vision that incorporates dense mixed-use development in or near downtowns, in addition to planning for Transit-Oriented Development (TOD). This is especially true in the mountain regions where the distinct topography creates development patterns similar to urban areas. For example, the presence of steep grades causes development to be concentrated in linear corridors along valleys where flat, developable land is more readily available. Dense, mixed-use land use patterns lead to higher transit, multimodal travel, and VMT reduction, which lead to GHG reductions. These changes can be tracked via rezonings and calculated using the methodologies adopted in GHG Mitigation Measures, Policy Directive 1610.

Counting these GHG reductions from built environment factors does not in any way alter Colorado's system of local control over land use. CDOT remains solely in the role of being responsive to local plans for new development, with a goal of providing investments in multi-modal hubs, Bustang service, and grants provided by the Revitalizing Main Streets program that can, in many cases, make it more feasible for communities to increase the proximity of housing to jobs, transit, and daily needs, which reduces VMT and leads to reductions in GHG emissions, in addition to improving the daily lives of Colorado's residents in a number of other ways.

Table 5. GHG Mitigation Measures Summary Table

GHG Mitigation Action Plan Project	2030 Metric Tons Reduced	2040 Metric Tons Reduced	2050 Metric Tons Reduced
Transit			
Bustang Service Expansion	9,414	4,707	4,707
Rural Transit Service Recovery	7,201	4,303	3,205

GHG Mitigation Action Plan Project	2030 Metric Tons Reduced	2040 Metric Tons Reduced	2050 Metric Tons Reduced
Heavy-duty Electrification			
Electric transit buses	2,125	N/A	N/A
Transportation Demand Management			
TDM Grant: Creation of the Glenwood Springs Transportation Management Association	1,157	N/A	N/A
TDM Grant: I-70 Coalition Public Awareness Campaign & Research Effort	120	N/A	N/A
TDM Grant: City of Aspen, Micro Transit and Bike Share Pilot Expansion	7	N/A	N/A
TDM Grant: Summit County, Trailhead Shuttle Pilot Expansion	102	N/A	N/A
Operational Improvements			
Roundabouts	336	197	82
Efficient Development of the Built Environment			
Increase residential density	78,870	93,405	45,270
Increase Job Density	N/A	55,000	26,800
Mixed-use Transit Oriented Development (higher intensity)	31,948	51,800	26,975
Mixed-use Transit Oriented Development (moderate intensity)	26,000	40,250	28,215
TOTAL GHG Emissions from GHG Mitigation Measures	**157,280**	**249,662**	**135,251**

Due to the GHG Mitigation Measures outlined above in Table 5, CDOT achieves compliance with the required 2030 reduction level. Table 6 shows total GHG emissions reductions from the combination of the compliance run and GHG Mitigation Measures.

Table 6: Summary Compliance Results for 2030

	2030 (GHGs in MMT)
GHG Baseline	4.84
Required Reduction Amount	0.36
Reduction from Compliance Run	0.21
Reduction from GHG Mitigation Measures	0.157
Total Reduction from 10 Yr Plan and GHG MItigations	0.367

FUTURE SCENARIOS 2040 AND 2050

CDOT applied a different analytical approach to demonstrating compliance in 2040 and 2050. Because CDOT does not have a specific list of projects to model beyond the scope of the 10-Year Plan, the Department used scenarios in order to determine the type and amount of investments (i.e. funding for transit, biking and walking infrastructure, and estimated amounts of such infrastructure based on unit costs) that future 10 Year Plans would need to include in order to meet the 2040 and 2050 GHG emission reduction levels.

CDOT accomplished this by running the Statewide Travel Model and MOVES (similar to the 2025 and 2030 compliance runs), and using FHWA's Energy and Emissions Reduction Policy Analysis Tool (EERPAT[7]) in order to show the types of investments that would need to be made in future 10 year plans in order to achieve the targets. EERPAT is an advanced sketch-planning tool capable of examining policies such as Smart Growth and other land use changes; transit and non-motorized modes; pricing of fuel, parking, or distance traveled; and vehicle technology improvements.

Description of Baseline GHG emission values for 2040 and 2050.
Calculation of the baseline for 2040 and 2050 is similar to the process for 2025 and 2030. However, CDOT's furthest future year model scenario is for the year 2045, as that is the horizon year used in the most current rounds of CDOT planning. Greenhouse gas results for the year 2040 are created by interpolating between the 2045 and 2030 runs. Greenhouse gas results for the year 2050 are created by extrapolating from 2045 to 2050. The practice of extrapolating or interpolating model results is standard modeling practice for cases in which model scenario years have been developed that are close to but not exactly a desired planning year.

- Highway: outside the MPO areas, the 2045 baseline includes all projects in the 2030 baseline, and no additional projects. This is consistent with the approach described above, that only projects specifically described in plans are included in the baseline scenarios. Inside the MPO areas, highway networks match those used in the MPO baseline scenarios.
- Transit: to best depict a "no action" transit growth scenario, the model

[7] For more information on EERPAT - see this presentation from FHWA: https://environment.transportation.org/wp-content/uploads/2021/05/Day-2_Session-3_1_FHWA_AQ-Peer-Exchange-FHWA-GHG-Analysis-Tools.pdf

assumes that the growth in vehicle revenue miles (VRM, the miles transit vehicles are operated in service picking up passengers) will be the same per year as the growth rate between 2010 and 2020. CDOT uses the EERPAT model to estimate VMT effects of this increase in transit service, then adjusts the results of the statewide model to be consistent with this VMT effect.

- Bike/ped: as in the 2030 baseline scenario, bicycle and pedestrian service levels afforded by the current system are assumed to remain the same in all future baseline scenarios, modeled in the same way as the 2030 baseline.

Description of Action/Compliance GHG emission values for 2040 and 2050.

The compliance runs are based on CDOT's plan as well as the DRCOG and NFRMPO plans, as updated to comply with GHG reduction requirements.[8] This includes all regionally significant projects explicitly listed and described in those plans. It also includes funding categories that are not specifically assigned to projects (e.g., Multimodal Transportation and Mitigation Options Funds). As the statewide travel model effectively depicts regionally significant projects, these are included in the model runs. Smaller CDOT projects, or funding not explicitly allocated to projects, are included in the compliance runs by estimating their VMT effect using the EERPAT model, then adjusting the outputs of the statewide model to take into account these VMT effects. This is especially true for the 2045 compliance scenario, since CDOT does not develop plans beyond the 10-year plan (out to 2030). CDOT's planning staff began with CDOT's *2045 Program Distribution* (July 2021), and estimated likely total expansion of the roadway network in the non-MPO areas.

Compliance runs also assume a significant increase in the share of people working from home. Prior to the COVID pandemic, US Census Bureau data used by CDOT in its modeling work estimated that 6.3% of Colorado workers worked from home on a typical day. During the COVID pandemic, the Census Bureau conducted a series of weekly "pulse" surveys, in which as many as 45% of Colorado households said that some adults in their household had shifted some or all work trips to work-from-home over due to COVID, over and above pre-existing work-from-home habits. While these data do not of course provide certainty of future work-from-home behaviors, there are no indications that work-from-home behaviors will return fully to their pre-COVID levels. CDOT therefore has adjusted the statewide model to produce approximately

[8] As with 2025/2030 analysis, the entire state is modeled and MPO areas removed from results.

20% work-from-home for model years 2030 and later. This represents a somewhat more conservative assumption than is being used by DRCOG and the NFRMPO.

CDOT also has made modest adjustments to the statewide travel model to take into account shifts in other "from home" activities, particularly in the non-MPO areas, where the Colorado Broadband Office is focusing its effort to improve internet broadband service in rural areas. CDOT assumes that 40% of non-MPO-area university student trips will be eliminated in favor of on-line class attendance, and that a 2% reduction in "personal business" trips will also occur, simulating additional use of tele-medicine and other at-home substitutes for travel.

Finally, CDOT adjusted model parameters in the statewide travel model to simulate the effect of significant investment in bicycle and pedestrian infrastructure as part of the updated plan. Current levels of safety, speed and convenience for these modes have resulted in younger and older residents, and in all women using these modes at lower rates than men. To simulate the greatly improved safety conditions and convenience for these modes, CDOT modified model parameters that depicted these effects: for 2030, these parameters were reduced by 50%, and for 2045 they were eliminated, simulating a condition in which all residents are equally comfortable using these modes. CDOT also slightly increased the average walking speed as part of simulating enhanced pedestrian infrastructure, and likewise slightly increased bicycling speed to simulate the increased popularity of E-bikes.

2045

- Highway: the compliance network includes all projects present in the 2030 compliance network (the CDOT 10-year plan), plus the added 2045 projects in the MPOs compliance runs. CDOT's planning staff also evaluated the 2045 Program Distribution funding allocation program and estimated the addition of 40 lane miles in the non-MPO areas.[9] The effect of this addition to the highway network was evaluated using EERPAT.
- Transit: based on expected CDOT transit funding, CDOT's planning team estimates statewide VRM growth of 2.5% annually between 2030 and 2050. CDOT used EERPAT to evaluate the VMT effect of this growth, which was then integrated into the statewide travel model's results through a post-process adjustment.

[9] CDOT also examined the amount of lane miles added over the period of the 10 Year Plan and assumed a slower growth in lane miles over the 2030-2050 period.

- Bike/ped: expected bike/ped funding through the year 2050 is large enough that CDOT modelers and planners expect it to have a "game changing" effect upon active mode safety, speed and convenience. To simulate this effect, modelers eliminated parameters that simulated lower use by women, and by younger and older residents, essentially depicting a condition in which all residents feel safe and comfortable using active modes. Likewise, speeds of active modes were increased to reflect the actual result of increased e-bike adoption as well as increased perceptions of safety and comfort. See Table 7 below.

Table 7: Model Assumption Changes for 2040 and 2050

	Baseline	2040 compliance	2050 compliance
Tele-work	6%	20%	20%
Bike speed	12 mph	13.7 mph	14.3 mph
Walk speed (perception)	3 mph	5 mph (40% more comfortable than existing)	5 mph (40% more comfortable than existing)
Telehealth and tele-university	Low in pre-COVID period	2% (beyond baseline) telehealth 40% tele-university	2% (additional) telehealth 40% tele-university

Due to the GHG Mitigation Measures outlined above in Table 5, CDOT achieves compliance with the required 2040 and 2050 reduction levels. Table 8 shows total GHG emissions reductions from the combination of the compliance run and GHG Mitigation Measures.

Table 8: Compliance Results

	2040 (GHGs in MMT)	2050 (GHGs in MMT)

GHG Baseline	3.34	2.09
Required Reduction Amount	0.30	0.17
Reduction from Compliance Run	0.06	0.04
Reduction from GHG Mitigation Measures	0.249	0.135
Total Reduction from 10 Year Plan and GHG Mitigations	0.309	0.175

TECHNICAL APPENDICES

1. Appendix 1: GHG Mitigation Action Plan
2. Appendix 2: Modeling Technical Details and Methodology

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Appendix 1 - GHG Mitigation Action Plans

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Table A1-1.1 Summary table of GHG Emissions Analysis and the Mitigation Action Plans (MAPs)

	2025	2030	2040	2050
Table 1 Reduction Target (MMT)	0.12	0.36	0.30	0.17
Reductions achieved through Modeling	0.30	0.21	0.06	0.04
Reductions achieved through GHG Mitigations	n/a	0.157	0.249	0.135
Total Reductions achieved	0.30	0.367	0.309	0.175
Compliance Result	Met	Met	Met	Met

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Department of Transportation

Table A1-2.1 Transportation Demand Management (TDM) Grant: Creation of the Glenwood Springs Transportation Management Association

<table>
<tr><th>Component</th><th>Description of information to be submitted with application.</th></tr>
<tr><td>Measure Description</td><td>Creation of the Glenwood Springs Transportation Management Association through CDOT funding, which will develop transportation demand management strategies recommended by the City's 2021 Multimodal Options for a Vibrant Economy (MOVE) study, completed alongside the Roaring Fork Transportation Authority (RFTA). By 2030, the Association will have dedicated resources to communicate travel options, work with local employers to help create TDM plans and strategies, advocate for the integration of TDM principles into local developments and land use regulations, and have fully developed incentives for participation as well as a methodology for measuring and tracking the performance of TDM programmatic strategies.</td></tr>
<tr><td>Timing</td><td>Anticipated Start Date: August 2022
Completion Date: Ongoing program, current CDOT grant period and funding due to end 03/30/2024.</td></tr>
<tr><td>GHG Reductions</td><td>2030: 1,157
<table>
<tr><th>Mitigation Project Type</th><th>Metric (per 1,000 covered employees)</th><th>Points per Metric in 2030</th><th>Total</th></tr>
<tr><td>Commute Trip Reduction Program - Voluntary</td><td>13</td><td>89</td><td>1,157</td></tr>
</table></td></tr>
<tr><td>Co-benefits</td><td><table>
<tr><th>VMT change per 1,000 covered employees</th><th>1,000 covered employees</th><th>Total</th></tr>
</table></td></tr>
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	<table><tr><td>317,500</td><td>13</td><td>4,127,500</td></tr></table> <table><tr><th>Pollutants Avoided</th><th>Estimated Kg avoided annually (2030)</th></tr><tr><td>CO</td><td>9,373</td></tr><tr><td>NOx</td><td>257</td></tr><tr><td>PM 2.5</td><td>27</td></tr><tr><td>SO2</td><td>7</td></tr><tr><td>VOCs</td><td>195</td></tr></table>
Benefits to Disproportionately Impacted Communities	CDOT will be working in the coming months to outline how benefits to Disproportionately Impacted Communities should be quantified. When that work is completed CDOT will include updated information in the annual MAP.
Measure Origin and History	CDOT's Strategic Transportation Demand Management (TDM) Grant Program was developed by the Office of Innovative Mobility to support communities and organizations as they expand and enhance existing trip-reduction initiatives and develop new and innovative projects and programs that are capable of meeting Colorado's evolving transportation challenges. The three funding opportunities within the Strategic TDM Grant Program represent a multi-pronged approach to advancing the capacities and practice of TDM statewide: 1. The Transportation Management Organization (TMO) Support Grants are designed to supplement existing TDM programming and allow established TDM leaders to expand their reach and impact;

	2. The TMO Seed Funding Grants facilitate the creation of new TMOs in currently un-represented areas of the state and add new perspectives to the TDM conversation that have the potential to increase TDM success in non-urban areas; 3. And the TDM Innovation Grants support projects that incentivize innovative ideas to help TDM reach new audiences, address current TDM gaps, and scale up existing best practices to expand their impact. Using the grant money from the TMO Seed Funding program, Glenwood Springs will design and start a transportation management association to address the unique traffic and transit concerns of the area. Glenwood Springs was identified as an area of high need for dedicated TDM programming by both the 2019 Statewide TDM Plan and the MOVE study conducted by the City of Glenwood Springs and RFTA in 2020. As a regional center of employment and a statewide recreation and tourism destination at the junction of I-70 and the CO-82 corridor through the Roaring Fork Valley, CDOT identified significant long-term potential for trip and emissions reductions benefits in the creation of a permanent framework and advocate for local and regional coordination around transportation issues and TDM specifically.
Funding/ Resources/ Partnerships	Through CDOT's TDM Grant Program, the Glenwood Springs Transportation Management Association (TMA) has received an initial $60,000 to support the development of the program. The award of Seed Funding grants is pursued by CDOT in line with a long-term statewide strategy for creating capacities and representatives across Colorado for TDM consistent with an increasingly coordinated statewide approach. In this vein, CDOT has already begun to lay the foundations for a long-term partnership with the City of Glenwood Springs and the newly-founded TMA through the creation of a practitioners network and cross-regional mentorship programs. As the Glenwood Springs TMA matures, the organization will become eligible for continuing TMO Support funding designed to advance TDM priorities and to serve as a basis for ongoing partnership in regional and statewide emissions-reductions efforts.
Other Info As Needed	N/A

Table A1-2.2 TDM Grant: I-70 Coalition Public Awareness Campaign & Research Effort

<table>
<tr><th>Component</th><th>Description of information to be submitted with application.</th></tr>
<tr><td>Measure Description</td><td>A research effort into I-70 travelers' behaviors, the effectiveness of existing travel alternatives and marketing efforts, and the identification of new opportunities in order to calibrate the messaging, medium, and approach of a redesigned trip-reduction marketing campaign. The campaign aims to drive travelers to non-single occupancy vehicle (SOV) travel modes, to encourage more efficient travel behaviors (e.g. off-peak travel and travel to higher-capacity destinations along the road network), and to promote existing resources and tools designed to convert audiences into routine users of alternative travel modes.</td></tr>
<tr><td>Timing</td><td>Start Date: October 2021.
Milestones: February 2022 (launch)
Completion Date: July 2022 (end of CDOT grant period).</td></tr>
<tr><td>GHG Reductions</td><td>2030: 120<table><tr><th>Mitigation Project Type</th><th>Metric (per program $1,000)</th><th>Points per Metric in 2030</th><th>Total</th></tr><tr><td>Trip Reduction - Marketing</td><td>60</td><td>2</td><td>120</td></tr></table></td></tr>
<tr><td>Co-benefits</td><td><table><tr><th>Annual VMT reduced per program $1,000</th><th>Program $1,000</th><th>Total</th></tr><tr><td></td><td></td><td></td></tr></table></td></tr>
</table>

<table>
<tr><td></td><td>
<table>
<tr><td>7</td><td>60</td><td>420</td></tr>
</table>
<table>
<tr><th>Pollutants Avoided</th><th>Estimated Kg avoided annually (2030)</th></tr>
<tr><td>CO</td><td>954</td></tr>
<tr><td>NOx</td><td>24</td></tr>
<tr><td>PM 2.5</td><td>3</td></tr>
<tr><td>SO2</td><td>0.6</td></tr>
<tr><td>VOCs</td><td>18</td></tr>
</table>
</td></tr>
<tr><td>Benefits to Disproportionately Impacted Communities</td><td>CDOT will be working in the coming months to outline how benefits to Disproportionately Impacted Communities should be quantified. When that work is completed CDOT will include updated information in the annual MAP.</td></tr>
<tr><td>Measure Origin and History</td><td>CDOT’s Strategic Transportation Demand Management (TDM) Grant Program was developed by the Office of Innovative Mobility to support communities and organizations as they expand and enhance existing trip-reduction initiatives and develop new and innovative projects and programs that are capable of meeting Colorado’s evolving transportation challenges.

The three funding opportunities within the Strategic TDM Grant Program represent a multi-pronged approach to advancing the capacities and practice of TDM statewide:

1. The Transportation Management Organization (TMO) Support Grants are designed to supplement existing TDM programming and allow established TDM leaders to expand their reach and impact;
2. The TMO Seed Funding Grants facilitate the creation of new TMOs in currently un-represented areas of the state and add new perspectives to the TDM conversation that have the potential to increase TDM success in non-urban areas;</td></tr>
</table>

	3. And the TDM Innovation Grants support projects that incentivize innovative ideas to help TDM reach new audiences, address current TDM gaps, and scale up existing best practices to expand their impact. Using the grant money from the TMO Support program, the I-70 Coalition sought to address the increasing share of recreational trips along the I-70 Corridor by better calibrating program and message interventions, designed to influence the behaviors of recreational travelers, through market research and by creating a structure for a long-term marketing campaign informed by their findings.
Funding/ Resources/ Partnerships	Through CDOT's TDM Grant Program, the I-70 coalition has received an initial $60,000 to support the development and advertisement of the program.
Other Info As Needed	N/A

Table A1-2.3 TDM Grant: City of Aspen, Micro Transit and Bike Share Pilot Expansion

<table>
<tr><th>Component</th><th>Description of information to be submitted with application.</th></tr>
<tr><td>Measure Description</td><td>The expansion of an existing micro transit service program, demonstrating new, on-demand service models and approaches to users requesting services. The program will also include the installation of permanent e-bike share infrastructure and the purchase of additional shared e-bikes for the existing fleet. By 2030, the program anticipates adding more than 46 e-bikes and incorporating successful micro-transit models demonstrated within the pilot into long-term transit programming within the City.</td></tr>
<tr><td>Timing</td><td>Anticipated Start Date: July 2022
Completion Date: March 2023 (end of CDOT grant period).</td></tr>
<tr><td>GHG Reductions</td><td>2030: 7
<table>
<tr><th>Mitigation Project Type</th><th>Metric (per 100 bikes)</th><th>Points per Metric in 2030</th><th>Total</th></tr>
<tr><td>Bikeshare Program</td><td>0.46</td><td>15</td><td>7</td></tr>
</table></td></tr>
<tr><td>Co-benefits</td><td>
<table>
<tr><th>Annual VMT reduced per bike</th><th>Number of bikes</th><th>Total</th></tr>
<tr><td>531</td><td>46</td><td>54,426</td></tr>
</table>
<table>
<tr><th>Pollutants Avoided</th><th>Estimated Kg avoided annually (2030)</th></tr>
<tr><td>CO</td><td>56</td></tr>
</table></td></tr>
</table>

NOx	2
PM 2.5	0.1
SO2	0.05
VOCs	1

Benefits to Disproportionately Impacted Communities	CDOT will be working in the coming months to outline how benefits to Disproportionately Impacted Communities should be quantified. When that work is completed CDOT will include updated information in the annual MAP.
Measure Origin and History	CDOT’s Strategic Transportation Demand Management (TDM) Grant Program was developed by the Office of Innovative Mobility to support communities and organizations as they expand and enhance existing trip-reduction initiatives and develop new and innovative projects and programs that are capable of meeting Colorado’s evolving transportation challenges. The three funding opportunities within the Strategic TDM Grant Program represent a multi-pronged approach to advancing the capacities and practice of TDM statewide: 1. The Transportation Management Organization (TMO) Support Grants are designed to supplement existing TDM programming and allow established TDM leaders to expand their reach and impact; 2. The TMO Seed Funding Grants facilitate the creation of new TMOs in currently un-represented areas of the state and add new perspectives to the TDM conversation that have the potential to increase TDM success in non-urban areas; 3. And the TDM Innovation Grants support projects that incentivize innovative ideas to help TDM reach new audiences, address current TDM gaps, and scale up existing best practices to expand their impact. Using the grant money from the TDM Innovation program, the City of Aspen seeks to expand and introduce

	new service models to its existing microtransit programming — and to expand its shared micromobility fleet in response to growing congestion, parking management issues, and mobility and access concerns identified in recent planning and outreach efforts.
Funding/ Resources/ Partnerships	Through CDOT's TDM Grant Program, the City of Aspen has received an initial $50,000 to support the pilot of the new, on-demand microtransit model and the expansion of its bikeshare program.
Other Info As Needed	N/A

Table A1-2.4 TDM Grant: Summit County, Trailhead Shuttle Pilot Expansion

<table>
<tr><th>Component</th><th>Description of information to be submitted with application.</th></tr>
<tr><td>Measure Description</td><td>The expansion of a pilot program initially launched for Quandry Peak and McCullough Gulch, which will operate daily shuttle service to the highly trafficked trailheads in Summit County while reducing congestion in the region and serving as a foundation for additional demand and parking management strategies.</td></tr>
<tr><td>Timing</td><td>Anticipated Start Date: May 2022
Completion Date: March 2023 (end of CDOT grant period).</td></tr>
<tr><td>GHG Reductions</td><td>2030: 102

The GHG reductions for this strategy were calculated using the user-input method for new transit service that is included as part of PD 1610. The following inputs were used:
<table>
<tr><th>Variables</th><th>2025</th></tr>
<tr><td>Planned new annual vehicle revenue miles</td><td>30,480</td></tr>
<tr><td>Anticipated new ridership</td><td>21,000</td></tr>
<tr><td>Anticipated share of new riders who previously drove</td><td>90%</td></tr>
<tr><td>Average unlinked trip length of new riders</td><td>18</td></tr>
<tr><td>Transit vehicle size</td><td>15-20’ van</td></tr>
<tr><td>Transit vehicle technology</td><td>Fleet average</td></tr>
</table></td></tr>
<tr><td>Co-benefits</td><td>VMT reduction in 2030: 421,200 miles.
VMT reduction of this strategy was also calculated using the user-input method for new transit service. As the technology currently stands, the shuttle service will reduce VOCs in 2030 by an estimated 18 kg annually. Future electrification of the shuttle will result in significantly greater co-pollutant reductions.</td></tr>
</table>

Benefits to Disproportionately Impacted Communities	CDOT will be working in the coming months to outline how benefits to Disproportionately Impacted Communities should be quantified. When that work is completed CDOT will include updated information in the annual MAP.
Measure Origin and History	Summit County, alongside local partners, launched a pilot parking reservation and shuttle program in 2021 to help address public safety issues in the area, due to significant increases in visitation to Quandary Peak and McCullough Gulch over the past several years. Illegally parked vehicles block emergency access on roadways and limit resident's ability to access or feel safe in their own neighborhoods. The parking reservation system and shuttle service alleviates these pressures while making it easier for hikers to safely and legally access trailheads.
Funding/ Resources/ Partnerships	Through CDOT's TDM Grant Program, Summit County has received an initial $50,000 to support the expansion of its trailhead shuttle program and to explore complementary demand management strategies.
Other Info As Needed	N/A

Table A1-3.1: Bustang Service Expansion

Component	Description of information to be submitted with application.
Measure Description	Implement enhanced levels of service on I-70 and I-25 that will allow Bustang to serve more people and provide increased flexibility to residents and visitors of Colorado. Over the next three years, service on the I-25 North/South corridor, Fort Collins to Denver and Colorado Springs to Denver, will increase by 100% on weekdays and 200% on weekends. Service along I-70 West, Grand Junction to Denver, will increase approximately 250%. A comprehensive media campaign will be developed to increase public awareness of Bustang and the expansion.
Timing	The expansion will occur in three phases, with the first phase scheduled to be implemented in the fall of 2022. The set of expansions will occur in late fall/early winter 2023, and the final third expansion will occur in the fall/winter of 2024.
GHG Reductions	**2030: 9,414** **2040: 4,707** **2050: 4,707**

Project (New/increased fixed-route transit service - intercity - fleet average)	**Metric (per 1,000 new VRM)**	**Points per Metric in 2030**	**Points per Metric in 2040**	**Points per Metric in 2050**	**Total 2030**	**Total 2040**	**Total 2050**
North Line Bustang Expansion	2	2	1	1	4	2	2
South Line (DUS) Bustang Expansion	12	2	1	1	24	12	12

West Line Bustang Expansion	3,929	2	1	1	7,858	3,929	3,929
Outrider Routes	764	2	1	1	1,528	764	764
Total Points					**9,414**	**4,707**	**4,707**

CDOT is taking credit for the new bus vehicle revenue miles (VRM) that occur only within the non-MPO areas, as some of the new VRM occurs within the boundaries of the state's five MPOs.

Co-benefits

Expanded Bustang service results in about 170 additional Bustang riders each weekday (Compliance versus Baseline), or about 51,000 more riders annually (2030). The connections created by the Bustang network can result in local operators seeing additional ridership while their service levels are constant. That is, the 170 additional Bustang riders above may also be making additional rides on local systems at either end of their journey.

Annual VMT reduced per 1,000 new VRM	New 1,000 VRM	Total VMT reduced/year
9,200	4,707	43,304,400

Pollutants Avoided	Estimated Kg avoided annually (2030)	Estimated Kg avoided annually (2040)	Estimated Kg avoided annually (2050)
CO	85,096	43,823	15,118

NOx	-	448	159
PM 2.5	6	248	208
SO2	54	47	21
VOCs	1,390	1,198	559

Benefits to Disproportionately Impacted Communities	CDOT will be working in the coming months to outline how benefits to Disproportionately Impacted Communities should be quantified. When that work is completed CDOT will include updated information in the annual MAP.
Measure Origin and History	CDOT launched Bustang service in the I-25 and I-70 corridors in 2015, providing much needed transit to and from the communities along these routes. In 2018, Bustang Outrider services were launched across the state, bringing rural connections to the Bustang I-70 and I-25 service. In March 2020, the COVID-19 pandemic shut down Bustang services, but were reinstated in January of 2021. System-wide ridership is currently at 75% pre-COVID levels of service, and the West Line along I-70 was at 136% of pre-pandemic ridership as of March 2022. CDOT is planning to expand Bustang for a three-year period in an attempt to attract additional travelers into a transit option on our busiest interstate corridors. This expansion, made possible by new funding from the state legislature, includes new, enhanced service on I-70 and I-25 that will allow Bustang to serve more people and provide increased flexibility for existing riders.
Funding/ Resources/ Partnerships	The passage of SB-180 gave $30 million in direct funding for the expansion of Bustang service throughout the 3-year pilot program. Further, the dedication of the State’s portion of the MMOF funds to State Transit Operations and Maintenance ensures that existing Bustang services, the operation and maintenance of the State’s mobility hubs, and the future expansions of the Bustang Family of services can continue as an integral part of Colorado’s transportation system. Additionally, within the 10-Year Plan, CDOT has committed nearly $120 million in Bustang investments with mobility hubs and bus purchases.

Other Info As Needed	Route expansion details. I-25 North (Fort Collins to Denver) - Phase 1: Increasing from 6 daily round trips on week days to 8 daily round trips on weekdays - Phase 2: 10 daily round trips on weekdays and going from 2 daily round trips on weekends to 4 daily round trips - Phase 3: 12-13 daily round trips weekdays, 6 daily round trips weekends I-25 South (Colorado Springs to Denver) - Phase 1: Increasing from 6 daily round trips on weekdays to 8 daily round trips - Phase 2: 10 daily round trips on weekdays and increasing from 2 daily round trips on weekends to 4 daily round trips - Phase 3: 12-13 daily round trips on weekdays to 6 daily round trips on weekends I-70 west (Grand Junction to Denver) - Phase 1: Increasing from 2 daily round trips Grand Junction and Denver to 4 daily round trips - Phase 2: 9-10 daily round trips between Grand Junction and Denver - Phase 3: 13-15 daily round trips between Grand Junction and Denver

Table A1-3.2: Rural Transit Service Recovery following the COVID-19 pandemic

<table>
<tr><th>Component</th><th>Description of information to be submitted with application.</th></tr>
<tr><td>Measure Description</td><td>Following the COVID-19 pandemic, traffic in many parts of the state returned to pre-pandemic levels, while transit ridership and service remained low. Through state and federal funds, CDOT aims to return the intercity, local, and demand response service levels of the state’s rural transit agency to pre-COVID levels by 2030 or earlier.</td></tr>
<tr><td>Timing</td><td>This recovery will occur effective immediately and is expected to achieve pre-COVID levels by 2030 or earlier.</td></tr>
<tr><td>GHG Reductions</td><td>Local rural transit lines
2030: 1,680
2040: 1,260
2050: 588
Intercity rural transit lines
2030: 4,666
2040: 2,333
2050: 2,333
Demand response transit service
2030: 854
2040: 710
2050: 284
<table>
<tr><th>Mitigation Project Type</th><th>Metric (per 1,000 new VRH for local, per 1,000 new VRM for intercity)</th><th>Points per Metric in 2030</th><th>Points per Metric in 2040</th><th>Points per Metric in 2050</th><th>Total 2030</th><th>Total 2040</th><th>Total 2050</th></tr>
<tr><td>New/ increased fixed-route transit</td><td>84</td><td>20</td><td>15</td><td>7</td><td>1,680</td><td>1,260</td><td>588</td></tr>
</table>
</td></tr>
</table>

	<table><tr><td>service</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr><tr><td>New/ increased fixed-route transit service - intercity</td><td>2,333</td><td>2</td><td>1</td><td>1</td><td>4,666</td><td>2,333</td><td>2,333</td></tr><tr><td>New/ increased demand-response bus service</td><td>142</td><td>6</td><td>5</td><td>2</td><td>852</td><td>710</td><td>284</td></tr></table>
Co-benefits	*Intercity*<table><tr><th>Annual VMT reduced per 1,000 new VRM</th><th>New 1,000 VRM</th><th>Total VMT reduced/year</th></tr><tr><td>9,200</td><td>2,333</td><td>21,463,600</td></tr></table>*Local*<table><tr><th>Annual VMT reduced per 1,000 new VRH</th><th>New 1,000 VRH</th><th>Total VMH reduced/year</th></tr><tr><td>89,700</td><td>84</td><td>7,534,800</td></tr></table>*Demand response*<table><tr><th>Annual VMT reduced per 1,000 new VRH</th><th>New 1,000 VRH</th><th>Total VMH reduced/year</th></tr><tr><td>28,800</td><td>142</td><td>4,089,600</td></tr></table>

New/increased fixed-route transit service - intercity

Pollutants Avoided	2030 (Estimated kg)	2040 (Estimated kg)	2050 (Estimated kg)
CO	42,177	21,721	7,493
NOx	-	222	79
PM 2.5	3	123	103
SO2	27	23	10
VOCs	689	594	277

New/increased fixed-route transit service - local

Pollutants Avoided	2030 (Estimated kg)	2040 (Estimated kg)	2050 (Estimated kg)
CO	10,664	7,625	2,630
NOx	-	78	28
PM 2.5	-	43	36
SO2	5	8	4
VOCs	178	208.53	97.26

New/increased demand response bus

<table>
<tr><td></td><td>

Pollutants Avoided	2030 (Estimated kg)	2040 (Estimated kg)	2050 (Estimated kg)
CO	2,268	4,134	1,426
NOx	15	42	15
PM 2.5	-	23	20
SO2	-	4	2
VOCs	185	113	53

</td></tr>
<tr><td>Benefits to Disproportionately Impacted Communities</td><td>CDOT will be working in the coming months to outline how benefits to Disproportionately Impacted Communities should be quantified. When that work is completed CDOT will include updated information in the annual MAP.</td></tr>
<tr><td>Measure Origin and History</td><td>The following rural transit agencies saw decreases in transit service operations due to the COVID-19 pandemic. These agencies also receive state and federal funding:
- Bent County Transit, The Lift (City of Winter Park), ECO Transit (Eagle County), Gunnison Valley RTA, Mountain Express, Northeast Colorado Association of Local Governments (NECALG), RFTA, San Miguel Authority for Regional Transportation (SMART), SRDA, Southern Colorado Community Action Agency (SoCoCAA, based in Ignacio), Steamboat Springs Transit (SST), Summit Stage, Black Hawk & Central City Tramway, Cripple Creek Transit, Durango Transit, Ride Glenwood Springs, La Junta, Envida, East Central Council of Local Governments, All Points Transit (Montrose), Prowers County, Summit Stage, Teller County, Canon City, Avon Transit, Mountain Village, Snowmass Village, Galloping Goose, Via Mobility Services, Wet Mountain Valley Rotary, Dolores County, South Central COG, and Montezuma County.</td></tr>
</table>

Funding/ Resources/ Partnerships	Rural transit agencies operations are funded primarily through FTA formula funds for rural areas (FTA 5311 and FTA 5310), and local funding sources. Rural capital projects are funded through FASTER, SB228, SB267, FTA 5304, 5310, 5311, and 5339 funds.
Other Info As Needed	N/A

Table A1-4.1: Built Environment

<table>
<tr><th>Component</th><th>Description of information to be submitted with application.</th></tr>
<tr><td>Measure Description</td><td>The parameters for this mitigation measure are set by PD 1610:
<table>
<tr><th>Mitigation Measure</th><th>Metric</th><th>2030 Points/ Metric</th><th>2040 Points/ Metric</th><th>2050 Points/ Metric</th></tr>
<tr><td>Increase Residential Density</td><td>Per acre rezoned from <10 units/acre to at least 15-25 units/acre meeting "smart growth" criteria</td><td>22</td><td>13</td><td>6</td></tr>
<tr><td>Increase Job Density</td><td>Per acre rezoned from <0.5 FAR to at least 1.0 FAR meeting "smart growth" criteria</td><td>18</td><td>11</td><td>5</td></tr>
<tr><td>Mixed-use Transit-Oriented Development (higher intensity)</td><td>Per acre of area rezoned for mixed-use TOD accommodating at least 25 residential units/acre and 150 jobs/acre, within 1/2 mile of fixed-guideway transit station</td><td>49</td><td>28</td><td>13</td></tr>
<tr><td>Mixed-use Transit-Oriented Development (moderate intensity)</td><td>Per acre of area rezoned for mixed-use TOD accommodating at least 15 residential units/acre and 100 jobs/acre, within 1/2 mile of high-frequency bus transit or fixed-guideway station</td><td>40</td><td>23</td><td>11</td></tr>
</table>
In order to be eligible, per PD 1610, a rezoning must meet a requirement for "smart growth". For the purposes of "Residential Density" rezonings, smart growth will be defined as infill growth within</td></tr>
</table>

	existing municipal boundaries. For the TOD categories, rezonings must be within ½ mile of an eligible transit station. It is important to note that these rezonings are wholly within the authority of the local government. Land use is an area where CDOT has no authority. Any rezonings that occur will be voluntary, and responsive to local policy, market, and demographic factors. Where local governments do have this vision, CDOT can be responsive, as it always has been, by providing infrastructure. CDOT's 10-Year Plan includes numerous strategic investments that are intended to complete the multimodal networks in partnership with local investments. These investments will create synergies that will not only increase the attractiveness of multimodal options, but provide the infrastructure necessary for successful high-density development in downtowns, neighborhood centers, and Transit-Oriented Developments (TODs). These investments include: • development of a network of Mobility Hubs (particularly along I-70 Bustang routes) • transit investments in Bustang, Pegasus, Outrider, and regional transit agency partners • first-last mile ped/bike connections through 10-year Plan projects • grant programs that build multimodal infrastructure (Revitalizing Main Streets, MMOF, etc) In order to track the rezonings that occur within communities where a CDOT multimodal infrastructure project has assisted with making it more feasible, each year, CDOT will review the zoning maps of the (which are public documents typically posted online) to identify any zoning changes that have occurred within the "assistance areas" (defined below). CDOT will measure the acreage of these rezonings, and calculate the corresponding GHG reductions per the 1610 PD.
Timing	The investment changes will occur through a phased approach as set forth below. It is important to note that the planning for both rezonings (by local governments) and investments (by CDOT) take several years, and that the influence of CDOTs investments on rezonings was instigated with the adoption of the 2022 10-Year Plan. CDOT will calculate points annually on that basis, with 2022 as a starting point. The timing of construction of various improvements will be approximately as follows: **Start date - 2022; Completion date - 2050** • Investments in mobility hubs along I-70 and I-25. • Implement grant programs such as RMS to connect multimodal projects to dense housing.

	• Bustang, Outrider and Pegasus Expansion Annually: • Track rezoning in municipalities to track targets identified in table below • Adjust above policies and investment strategies as needed • Continue to be responsive to local entities on connecting transportation investments to housing programs and initiatives
GHG Reductions	**2030: 136,720** **2040:231,095** **2050: 122,940** **2030 Mitigations**

Mitigation Measure	2030 Points/ Metric	Metric: acres of rezoning (goal)	2030 total points	total "assistance area" (acres) per type of rezoning for 43 largest non-MPO communities	% of "assistance area" - projection for rezonings (acres)*
High-density Residential	22	3,585	78,870	143,379 (this equals average size of RRC municipal boundary)	2.5%
High density TOD	49	650	31,850	21,740 (this equals size of ½ mile of TOD)	3.00%
Medium density TOD	40	650	26,000	21,740 (this equals size of ½ mile of TOD)	3.00%
TOTAL		4,885	136,720		

*targets for acres of rezonings were set based on a projection for a percentage of the "assistance area" that would be rezoned by local governments, where feasibility has been increased by CDOT investments. The "assistance area" is the area adjacent to a CDOT project where a new multimodal infrastructure project may make a rezoning more feasible.

- For "**High-Density Residential"**, the assistance area is defined as the **municipal boundary**. The total area of larger non-MPO municipalities (43 municipalities above 5,000 pop.) is 143,379 acres. Staff projects that 2% of land within municipal boundaries will be rezoned to "High Density Residential" by 2030, which equals 2,865 acres.

- For the two "**TOD" categories,** the assistance area is defined as ½ **mile radius around the transit station**. The total size of this area in larger non-MPO municipalities (43 total above 5,000 pop.) equals 21,740 acres. Staff projects that 3% of land within the ½ mile radius will be rezoned to each"TOD" category by 2030, equaling 650 acres each.

In PD 1610, increasing residential density and mixed-used Transit-Oriented Development (TOD) moderate and higher intensity have a lifetime of 30 years. The rezonings that occur between present day and 2030 will have GHG impacts until 2050 and beyond in some cases. The 2040 and 2050 GHG points for the rezonings that occur before 2030 are calculated below, as well as the 2050 points for the new rezonings which occur between 2030 and 2040..

	2040 Points/ Metric	2050 Points/Metric	Metric: acres of rezoning (goal)	2040 total points carried forward from 2030	2050 points carried forward from 2030	2050 points carried forward from 2040
High-density Residential	13	6	3,585	46,605	21,510	21,600
High density jobs	N/A	N/A	N/A	N/A	N/A	25,000
High density TOD	28	13	650	18,200	8,450	15,600
Medium density TOD	23	11	650	14,950	7,150	12,100
TOTAL				**79,755**	**37,110**	**74,300**

	To help achieve compliance with the 2040 and 2050 reduction levels, additional land use and built environment mitigations are needed after 2030.

2040 targets	points per acre	acres of rezoning (goal)	total points	total assistance area (acres)	% of influence area - goal for rezonings (additional acres)
High density Res	13	3,600	46,800	143,379	2.5%
High density jobs	11	5,000	55,000	143,379	3.5%
High density TOD	28	1,200	33,600	21,740	5.5%
medium density TOD	23	1,100	25,300	21,740	5%
TOTAL		**10,900**	**160,700**		

2050 targets	points per acre	acres of rezoning (goal)	total points	total assistance area (acres)	% of influence area - goal for rezonings (acres)
High-density Res	6	360	2,160	143,379	0.25%
High density jobs	5	360	1,800	143,379	0.25%
High density TOD	13	225	2,925	21,740	1%
medium density TOD	11	815	8,965	21,740	3.75%
TOTAL		**1,760**	**15,850**		

Co-benefits	High-density rezonings

Annual VMT reduced per metric	2030 Metric (rezoned acres)	2040 Metric	2050 Metric	2030 Annual VMT Reduced	2040 Annual VMT Reduced	2050 Annual VMT Reduced
77,800	3,585	7,185	7,545	278,913,000	558,993,000	587,001,000

High density TOD

Annual VMT reduced per metric	2030 Metric (rezoned acres)	2040 Metric	2050 Metric	2030 Annual VMT Reduced	2040 Annual VMT Reduced	2050 Annual VMT Reduced
174,706	650	1,850	2,075	113,558,900	323,206,100	362,514,950

Medium density TOD

Annual VMT reduced per metric	2030 Metric (rezoned acres)	2040 Metric	2050 Metric	2030 Annual VMT Reduced	2040 Annual VMT Reduced	2050 Annual VMT Reduced
109,269	650	1,750	2,565	71,024,850	191,220,750	280,274,985

Increase job density

Annual VMT reduced per metric	2040 Metric (rezoned acres)	2050 Metric	2040 Annual VMT Reduced	2050 Annual VMT Reduced
64,525	5,000	5,360	322,625,000	345,854,000

Pollutants Avoided	Estimated Kg avoided annually 2030 - High-density rezonings	Estimated Kg avoided annually 2030 - High-density TOD	Estimated Kg avoided annually 2030 - Medium-density TOD
CO	633,199	257,864	210,068
NOx	17,372	7,075	5,763
PM 2.5	1,810	737	601
SO2	493	201	164
VOCs	13,160	5,359	4,366

Pollutants Avoided	Estimated Kg avoided annually 2040 - High-density rezonings	Estimated Kg avoided annually 2040 - Increase job density	Estimated Kg avoided annually 2040 - High-density TOD	Estimated Kg avoided annually 2040 - Medium-density TOD
CO	565,563	326,574	327,079	252,051
NOx	2,883	3,337	3,342	2,575
PM 2.5	1,598	1,849	1,852	1,427
SO2	303	350	351	270
VOCs	7,717	8,931	8,945	6,893

Pollutants Avoided	Estimated Kg avoided annually	Estimated Kg avoided annually	Estimated Kg avoided annually	Estimated Kg avoided annually

	(see nested table below)
Benefits to Disproportionately Impacted Communities	CDOT will be working in the coming months to outline how benefits to Disproportionately Impacted Communities should be quantified. When that work is completed CDOT will include updated information in the annual MAP.
Measure Origin and History	CDOT recognizes rezoning authority rests with local entities, and also recognizes that transportation facilities play a significant role in the feasibility of the built environment. In order to maximize the benefits associated with state transit and multimodal investments, CDOT has developed opportunities to support rezonings through infrastructure programs that provide multimodal investments. This process began in 2021 when CDOT initiated a series of new programs including the Revitalizing Main Streets and Safer Main Streets Programs aiming to better link transportation investments to job and housing opportunities. Additionally, in 2022 CDOT committed to record levels of investment in rural transit through mobility hubs and expanded Bustang service.
Funding/ Resources/ Partnerships	Funding Sources: While the rezonings that will be used as a measure will not be directly funded by CDOT, SB21-260, SB22-180, and 10-Year Plan Strategic funds will be used to fund the transportation programs, projects and grants that seek to encourage and support such built environment changes. Partnerships: Municipalities, Counties, and other state agencies such as DOLA and CEO
Other Info As Needed	N/A

	2050 - High-density rezonings	2040 - Increase job density	2050 - High-density TOD	2050 - medium-density TOD
CO	97,346	120,768	126,554	127,442
NOx	1,025	1,272	1,333	1,342
PM 2.5	1,338	1,660	1,739	1,752
SO2	133	165	173	175
VOCs	3,599	4,465	4,679	4,712

Table A1-5.1: Electric transit buses

Component	Description of information to be submitted with application.
Measure Description	The replacement of 25 diesel transit buses with electric transit buses in non-MPO areas.
Timing	Between January 2020 and present day (July 2022), 11 electric transit buses have become operational in Eagle County, Summit County, Estes Park, and Vail. Between present day and 2030, 14 additional electric transit buses will become operational.
GHG Reductions	**2030: 2125** (see table below)
Co-benefits	(see table below)

GHG Reductions:

Mitigation Project Type	Metric (per new vehicle)	Points per Metric	Total
Replace diesel transit buses with battery-electric buses	25	85	2,125

Co-benefits:

Pollutants Avoided	Estimated Kg avoided annually (2030)
CO	3,420
NOx	3,656
PM 2.5	90

<table>
<tr><td></td><td><table><tr><td>SO_2</td><td>5</td></tr><tr><td>VOCs</td><td>246</td></tr></table></td></tr>
<tr><td>Benefits to Disproportionately Impacted Communities</td><td>CDOT will be working in the coming months to outline how benefits to Disproportionately Impacted Communities should be quantified. When that work is completed CDOT will include updated information in the annual MAP.</td></tr>
<tr><td>Measure Origin and History</td><td>The CDOT Division of Transit & Rail (DTR) has helped to support the regular replacement of transit vehicles reaching the end of their service life with new transit vehicles (including hybrid and zero-emission models) for many years. In 2018, Colorado adopted its state Beneficiary Mitigation Plan (BMP) for the approximate $68.7 million allocation of the national Volkswagen Diesel Emission Settlement, which dedicated $30.6 million in the state’s funding for the Settlement Program transit bus replacement grants. Settlement Program grants can fund up to 110% of the incremental cost of replacing an existing diesel vehicle with a zero-emission alternative, and since 2019 more than $21 million of the original amount has been awarded. This funding compliments direct FTA grants for zero-emission vehicles, such as FTA 5339(b) ad 5339(c), and will be further supplemented by the new grant programs created by the Clean Transit Enterprise (CTE) in 2022 and beyond.</td></tr>
<tr><td>Funding/ Resources/ Partnerships</td><td>Current and future planned battery electric buses in non-MPO areas:
<table>
<tr><th>Location</th><th>Operational</th><th>Awarded</th><th>Procured/Bus Build</th><th>Funding</th></tr>
<tr><td>Eagle County</td><td>3</td><td>2</td><td></td><td>Settlement Program, 5339(b), and 5339(c)</td></tr>
<tr><td>Summit County</td><td>3</td><td>3</td><td>1</td><td>Settlement Program, 5339(a), and 5339(c)</td></tr>
<tr><td>Avon</td><td></td><td></td><td>2</td><td>5339(c)</td></tr>
</table></td></tr>
</table>

	<table><tr><td>Breckenridge</td><td>2</td><td>1</td><td></td><td>Settlement Program, 5339(c)</td></tr><tr><td>Estes Park</td><td>1</td><td>1</td><td></td><td>5339(b) and 5339(c)</td></tr><tr><td>Vail</td><td>4</td><td>4</td><td></td><td>Local funds, VW settlement, and 5339(c)</td></tr></table>
Other Info As Needed	n/a

Table A1-6.1 - Roundabouts in the Updated 10 Year Plan

Component	Description of information to be submitted with application.
Measure Description	The following roundabouts were updated in the 10 Year Plan, occurring entirely in Region 4: ● US 36 and Community Drive ● CO 52/CR 59 Roundabout and Safety Improvements ● CO 1 Safety Improvements
Timing	The three roundabouts are all prioritized for funding as indicated below: <table><tr><td>Project</td><td>Year Funded</td></tr></table>

<table>
<tr><td></td><td>
<table>
<tr><td>US 36 and Community Drive roundabout</td><td>FY 23-26</td></tr>
<tr><td>CO 52/CR 59 Roundabout and Safety Improvements</td><td>FY 23-26</td></tr>
<tr><td>CO 1 Safety Improvements</td><td>FY 23-26</td></tr>
</table>
</td></tr>
<tr><td>GHG Reductions</td><td>
2030: 336
<table>
<tr><th>Project Name</th><th>AADT</th><th># of roundabouts</th><th>Points per Metric 2030</th><th>Points per Metric 2040</th><th>Points per Metric 2050</th></tr>
<tr><td>US 36 and Community Drive</td><td>7,500</td><td>1</td><td>155</td><td>91</td><td>38</td></tr>
<tr><td>CO 52/CR 59 Roundabout and Safety Improvements</td><td>3,000</td><td>1</td><td>62</td><td>36</td><td>15</td></tr>
<tr><td>CO 1 Safety Improvements</td><td>5,800</td><td>1</td><td>119</td><td>70</td><td>29</td></tr>
<tr><td colspan="3">TOTAL</td><td>336</td><td>197</td><td>82</td></tr>
</table>
</td></tr>
<tr><td>Co-benefits</td><td>Roundabouts do not typically provide reduced VMT benefits, rather their GHG savings come from the more efficient flow of traffic through an intersection.

Calculating the co-pollution emission benefits of roundabouts is an area that will need further analysis, as the benefits would not be based on VMT reduction. It is likely that project level traffic simulation modeling would be a helpful tool to determine the co-pollutant reduction benefits of these projects.</td></tr>
</table>

Benefits to Disproportionately Impacted Communities	CDOT will be working in the coming months to outline how benefits to Disproportionately Impacted Communities should be quantified. When that work is completed CDOT will include updated information in the annual MAP.
Measure Origin and History	While the safety and mobility benefits of roundabouts have been widely accepted in the transportation sector, in developing the GHG rule in 2021 CDOT also began to explore how roundabouts have the potential to lower GHG emissions. Through extensive analysis, CDOT has established that in addition the extensive set of safety and mobility benefits roundabouts also go a long way towards reducing emissions. As such, CDOT has updated its 10 year plan to include more roundabouts to improve safety, mobility, and air quality.
Funding/ Resources/ Partnerships	(see table below)
Other Info As Needed	The statewide model is not currently able to differentiate roundabout traffic movements (merging, weaving, yielding) from those of more conventional at-grade intersections.

Funding/ Resources/ Partnerships:

Project Name	Region	Total Project Cost	Strategic Funding Secured
US 36 and Community Drive	Region 4	$5 million	$550,000
CO 52/CR 59 Roundabout and Safety Improvements	Region 4	$12 million	$7,600,000
CO 1 Safety Improvements	Region 4	$6 million	$4,000,000

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Appendix 2 Modeling Technical Details and Methodology

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Appendix 2.1: Model Technical Details and Methodology

CDOT's statewide activity-based model (ABM) meets all minimum modeling standards as described in the memo "Modeling Requirements to Meet Greenhouse Gas Standards", prepared by the Statewide Model Coordination Group (SMCG). CDOT's model:

- Has been extensively calibrated and validated against large databases of traffic counts (from CDOT's count program), transit boarding counts (from numerous transit operators around the state), and traffic speed data (from the "big data" firm INRIX);
- Uses all the credible and official data sources as inputs, including the 2010 Front Range Travel Counts survey for model estimation; the state demographer's office estimates and forecasts of population/households/jobs; the Colorado Department of Labor and Employment (CDLE) Quarterly Census of Employment and Wages (QCEW) employment data; Census Transportation Planning Package (CTPP); origin-destination data from the firm Streetlight Data; and other sources;
- Is supported by a detailed set of operational documentation, and a highly detailed set of model design and estimation documentation that exceeds 400 pages in length;
- Uses a household/person input dataset generated by the population synthesizer PopGen, a widely-used product of the Arizona State University's faculty;
- Includes in its mode choice models the complete basic set of active transportation modes, including separate bicycle and pedestrian modes;
- And depicts the location of jobs and households individually, at specific address locations.

As an ABM, CDOT's model possesses a number of important capabilities not well-supported by earlier model forms:

- It models work location choice, including an "at-home" choice;
- It derives travel from each person's choice of daily activities, providing a realistic depiction of changes in people travel behavior as travel conditions change;
- It includes "accessibility variables" in all the model components that need them, providing sensitivity of various travel choices to travel conditions (e.g., travel time/delay/cost);

- It depicts trips in "tours" (round trips), including depiction of multiple stops on tours, again a realistic depiction of travel that leads to more accurate model outcomes.
- These and other features permit CDOT's statewide model to support sensitivity to "induced demand", again much better than older model forms.

Figure A2-1 provides a diagram of CDOT's statewide model components.

Appendix 2.2 Model Component Descriptions

- Regular / no regular workplace choice. For employed people, does the person have a regular location of employment (like an office worker) or not (like a plumber.)
- Regular workplace location choice. For workers who have a regular workplace location, where is it (home, or one of many possible locations in the state.)
- Home schooled or not. For people who are students, as the name implies.
- Regular school location choice. For students who are not home-schooled, where is their regular school.
- Auto availability choice. For each household, how many automobiles do they own / have available.
- Daily activity pattern choice. Out of a set of seven activity categories, which activities will each person choose to do in the day.
- Exact number of tours choice. For each activity category in the person's day, how many tours (round trips) will the person make for that activity.
- Work tour destination type choice. For workers who have a regular workplace location, are they going there to work, or to some other place.
- Work-based subtour choice. For workers who work out of the home, how many tours (round trips) will the person make to/from the workplace, and for what purpose(es)?
- Tour primary destination choice. For all tours whose destination isn't already known, select the location.
- Tour main mode choice. The primary mode for the tour (round trip).
- Tour time of day choice. The time that the tour starts, paired with the time the tour ends.
- Intermediate stop generation choice. How many (and for what purpose) other stops are on the tour (besides the main stop/purpose.)
- Intermediate stop location choice. The destination location for each intermediate stop.
- Trip time of day choice. The time of day at which the person arrives at each stop on the tour.

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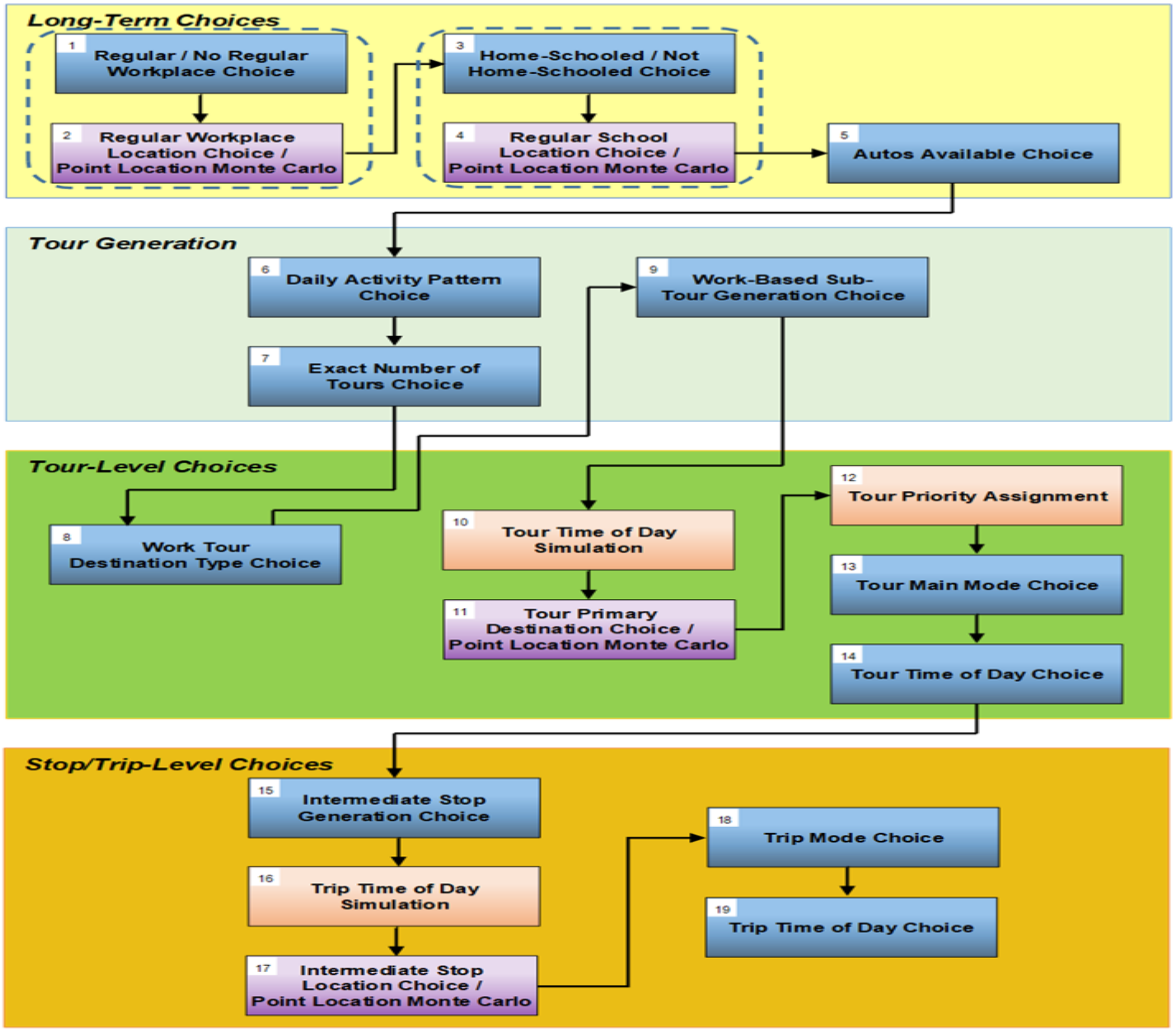
Figure A2-1: CDOT's Statewide Activity-Based Model



Appendix 2.3 Modeling Induced Demand

Induced demand typically is viewed as having six components. CDOT's ABM handles five of these "endogenously", meaning internally to the model. Endogenous components interact with one another naturally in the model, as a person considers all of them as he or she reacts to changes in the transportation environment. The six components are described below, together with how a common change in a road network (adding freeway lanes) might affect them:

- Change of route: added lanes to a congested freeway can cause traffic to divert from parallel roads, increasing volume on the freeway.
- Change of destination: improved travel times can cause drivers to select more distant destinations, increasing overall system miles driven.
- Change of daily activity pattern. Reduced congestion due to freeway expansion can cause people to make trips they would not have made under more congested conditions.
- Change of mode. Reduced congestion can cause people to divert from transit to automobile trips.
- Change of time of day. Drivers avoiding peak periods due to congestion may shift back into peak periods if congestion is reduced.
- Change of development pattern. Over the medium-to-long term, adding capacity to a freeway corridor can attract additional development to the corridor, reducing or eliminating any initial reduction in congestion in the corridor due to the capacity expansion.

Note that CDOT's ABM does not model changes in development pattern endogenously. However, the model can be used to examine the effects of land use scenarios (with the planners and modelers developing different possible development pattern futures, and inputting them to the model to test their effects.)

Table A2-1 shows key model inputs and outputs for the model scenarios run in support of GHG analysis under the rule, including both statewide and Non-MPO Areas, the latter being the area for which CDOT is responsible under this GHG rule.

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Table A2-1: Summary of Model Inputs and Outputs for GHG Compliance Runs - 2025/2030

Baseline and GHG Action Modeling Outputs	2025	2025	2030	2030
	Baseline	Action	Baseline	Action
Socioeconomic Data				
Population	6,554,729	6,554,729	**6,974,465**	**6,974,465**
Households	2,778,390	2,778,390	**2,950,775**	**2,950,775**
Employment	3,839,881	3,839,881	**3,995,831**	**3,995,831**
Work_at_Home	245,450	866,122	**259,652**	**915,712**
Vehicle and Transit Data – Typical Weekday				
Vehicle Miles Traveled (VMT)	176,467,429	160,975,241	**187,001,458**	**170,749,327**
VMT per capita	26.90	24.54	**26.81**	**24.48**
PMT	211,146,434	194,309,005	**223,974,165**	**206,455,210**
Average vehicle speed (mph)	35.06	35.67	**34.72**	**35.38**
Vehicle Hours Traveled (VHT)	5,116,675	4,690,720	**5,562,522**	**5,117,903**
Vehicle Hours Delay (VHD)	687,769	694,874	**869,585**	**861,413**
Transit boardings	591,614	641,549	**619,547**	**669,486**
Lane Miles by Roadway Type				
Interstate	5,231	5,231	**5,271**	**5,271**
Expressway	1,857	1,857	**1,878**	**1,878**
Principal Arterial	11,853	11,864	**11,964**	**11,964**
Minor Arterial	12,179	12,179	**12,318**	**12,318**
Collector/Other (CC included)	51,878	51,878	**52,533**	**52,533**
Total Lane Miles	82,998	83,009	**83,964**	**83,964**

VMT by Roadway Type				
Interstate	52,950,634	49,626,803	**55,341,392**	**52,044,120**
Expressway	14,359,498	12,847,733	**15,423,309**	**13,848,448**
Principal Arterial	53,144,870	47,988,129	**56,087,828**	**50,681,944**
Minor Arterial	21,649,775	19,355,353	**23,249,259**	**20,804,017**
Collector/Other (CC included)	34,361,695	31,159,321	**36,899,670**	**33,373,116**
Trip Mode Share				
Single occupancy vehicle	13,651,505	12,752,640	**14,438,839**	**13,463,739**
Shared ride trip	8,908,628	8,280,087	**9,450,298**	**8,805,118**
School Bus	505,587	473,348	**540,339**	**505,834**
Bicycle	506,038	674,563	**534,530**	**728,003**
Walk	1,387,839	2,446,700	**1,466,516**	**2,578,598**
Transit	396,111	482,287	**412,705**	**501,793**
Total Daily Person Trips	25,355,709	25,109,625	**26,843,227**	**26,583,085**

Table A2-2: Summary of Model Inputs and Outputs for GHG Compliance Runs - 2040/2050

Baseline and GHG Action Modeling Outputs	2040	2040	2050	2050
	Baseline	**Action**	**Baseline**	**Action**
Socioeconomic Data				
Population	7,813,938	7,813,938	8,653,410	8,653,410
Households	3,295,546	3,295,546	3,640,316	3,640,316
Employment	4,307,732	4,307,732	4,619,632	4,619,632
Work_at_Home	288,056	1,014,893	316,460	1,114,073
Vehicle and Transit Data – Typical Weekday				

Vehicle Miles Traveled (VMT)	208,069,515	190,297,500	229,137,573	209,845,672
VMT per capita	26.64	24.36	26.46	24.24
PMT	249,629,627	230,747,621	275,285,089	255,040,032
Average vehicle speed (mph)	34.04	34.79	33.36	34.20
Vehicle Hours Traveled (VHT)	6,454,215	5,972,268	7,345,909	6,826,634
Vehicle Hours Delay (VHD)	1,233,218	1,194,491	1,596,851	1,527,569
Transit boardings	675,413	725,361	731,279	781,235
Lane Miles by Roadway Type				
Interstate	5,351	5,351	5,431	5,431
Expressway	1,920	1,920	1,962	1,962
Principal Arterial	12,185	12,165	12,407	12,365
Minor Arterial	12,597	12,596	12,875	12,874
Collector/Other (CC included)	53,842	53,842	55,152	55,152
Total Lane Miles	85,895	85,873	87,827	87,783
VMT by Roadway Type				
Interstate	60,122,908	56,878,753	64,904,424	61,713,387
Expressway	17,550,932	15,849,878	19,678,554	17,851,308
Principal Arterial	61,973,743	56,069,575	67,859,659	61,457,205
Minor Arterial	26,448,228	23,701,345	29,647,196	26,598,673
Collector/Other (CC included)	41,975,621	37,800,707	47,051,571	42,228,297
Trip Mode Share				
Single occupancy vehicle	16,013,506	14,885,937	17,588,174	16,308,135
Shared ride trip	10,533,639	9,855,180	11,616,979	10,905,242
School Bus	609,843	570,807	679,347	635,779
Bicycle	591,513	834,883	648,497	941,763
Walk	1,623,869	2,842,395	1,781,223	3,106,191
Transit	445,892	540,804	479,080	579,816
Total Daily Person Trips	29,818,263	29,530,006	32,793,299	32,476,926

Appendix 2.4: Travel Model Calibration/Validation Process

When travel models are built, they go through a process of "estimation" (an economic modeling term), in which survey or other data are used to "estimate" the numerous relationships in the model between, for example, the likelihood of a particular travel mode being chosen given the characteristics of the person doing the choosing (e.g., age, gender, work status, etc.) and of the various modes available to that person (e.g., cost, travel time, etc.) The model estimated in this way produces a variety of results, such as numbers of transit boardings, volumes on roads, and travel patterns between parts of the state (e.g., total trips between the North Front Range Region and the Denver region), among many others.

After the model is initially built, it is subjected to a process of calibration and validation. In this process, rather than just assuming the model's results are accurate, we check them against other sources of information. These include:

- Automobile traffic counts. CDOT maintains an extensive program of acquiring such data, which are used for this purpose (and many other purposes).
- Transit boardings. CDOT obtains such data from numerous transit providers around the state.
- Travel pattern data. These data are available from a number of sources, including the US Census and private data vendors.
- Highway speed data. These data are primarily available today from private data vendors.

Models are estimated typically using survey data, which of course is taken in a particular year (in the CDOT model case, 2010.) A version of the complete model is built to depict that year (e.g., the road and transit systems as they existed then, the number and geographic distribution of people and jobs in that year, etc.) The model is then run, producing the results discussed above. Those results are compared to counts taken in the year 2010. If the model's results do not compare closely enough to the counts, adjustments are made to appropriate elements of the model in order to bring the results sufficiently close to the counts. This process is referred to as "calibration".

Well-developed models also are subjected to a process known as "validation". This process is much the same as calibration, but is carried out for a different calendar year. In CDOT's case, a version of the model was built depicting the year 2015 (again, road and transit systems for that year, people and jobs, etc.) The model is then run for this year, and again the results are compared to counts such as those described above. The point of doing model validation is to test whether the model, having been developed to do a good job of depicting reality in the calibration year (in this case the year 2010) can also do a good job with a different year (2015), when the region has changed (different development, different transportation networks, etc.) In this way, we test the model's ability to correctly respond to those differences/changes through time.

CDOT's travel modeling team has conducted extensive calibration/validation on the statewide model, most recently in the context of the Front Range Passenger Rail project. The table below is taken from the report "Front Range Rail Forecasting: Model Validation" by Cambridge Systematics, a consulting firm that provides assistance to CDOT's travel modeling team. This table is just one of numerous tables in the report evaluating many elements of the model's results. The table shows how closely the model matches the counts, aggregated into each of the facility types in the model. The table also shows how much data was used in making these comparisons.

The Model Documentation Report is posted on the GHG Program Website.

Table A2-2 : Difference Between Model Volumes and Counts

Facility Type	Number of Counts	Percent Difference Between Model and Counts	Target
Freeway	675	-8%	+/-7%
Expressway	202	7%	+/-7%
Principal Arterial	2,355	5%	+/-10%
Minor Arterial	2,056	-9%	+/-10%
Collector	2,163	-24%	+/-15%
Ramp	95	20%	
Total (Statewide)	7,546	-2%	+/-5%

Appendix 2.5: MOVES Analysis

In order to reduce the burden on APCD of multiple MOVES runs in support of the GHG process, CDOT hired the firm Felsberg Holt and Ullevig (FHU) to conduct the MOVES model runs. FHU staff worked with APCD's modeler to replicate his process and produce the same results:

- APCD provided standard MOVES model outputs and advised FHU to follow a process of reverse-engineering starting from that output.
- FHU worked with Colorado Open Records Act request data that included GHG modeling data for CDOT.
- APCD assisted FHU in identifying the relevant data in that set of information (e.g., input files in APCDs process, etc.)
- FHU staff spent approximately 100 hours checking and replicating the APCD process, and succeeded in reliably reproducing the results produced by the APCD modeler.
- FHU developed a memo describing the resultant MOVES operational method, "Draft MOVES3 Greenhouse Gas Modeling Methodology", January 21st, 2022. The memo is provided as an accompanying document to this report.

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Appendix 2.6: MOVES Memo

MEMORANDUM

TO: Ms. Marissa Gaughan, CDOT Multimodal Planning Branch Manager

FROM: Dale Tischmak and Jake Fritz

DATE: January 21, 2022

SUBJECT: DRAFT MOVES3 Greenhouse Gas Modeling Methodology (117429-32)

Introduction

This document summarizes the methodology used to calculate greenhouse gas (GHG) emissions for the CDOT Statewide Travel Demand Model (TDM). Previous GHG modeling to support CDOT was conducted by APCD. This methodology replicates APCD's modeling process as best as possible.

For more information about GHG modeling using MOVES, see the *Using MOVES for Estimating State and Local Inventories of On-road Greenhouse Gas Emissions and Energy Consumption* guidance document linked to in the references (i.e., EPA 2016).

The process begins with generating emission rates using the EPA's Motor Vehicle Emission Simulator version 3.0.1 (MOVES3). The emission rates are multiplied by the vehicle miles traveled from the TDM. The result is an emissions inventory. A series of data engineering steps are required to prepare the rates and VMT into desirable and compatible formats.

MOVES3 Run Specifications

The run specification (RunSpec) parameters outlined below were used to calculate GHG emission rates with MOVES. They are consistent with APCD's process to calculate GHG emissions.

The four modeled years 2025, 2030, 2040, and 2050 used the same run specifications except for where specified (e.g., the year being modeled). Each of the four modeled years has six related run specifications to separate the emission rates by vehicle type, as described in the On-road Vehicles section.

Scale

The "Scale" parameters define the model type (on-road or non-road), domain/scale, and calculation type.

Model Type

On-road was the model type selected. This estimates emissions from motorcycles, cars, buses, and trucks that operate on roads.

Non-road/off-network emissions were not included. These emissions are from equipment used in applications such as recreation, construction, lawn and garden, agriculture, mining, etc. and are outside of the scope of this analysis.

Domain/Scale

MOVES allows users to analyze mobile emissions at various scales: National, County, and Project. While the County scale is necessary to meet statutory and regulatory requirements for SIPs and transportation conformity, either the County or National scale can be used for GHG inventories. EPA recommends using the

County scale for GHG analysis. The County scale allows the user to enter county-specific data through the County Data Manager. Providing local data significantly improves the precision of the modeling results (EPA 2016).

The County scale was used.

Calculation Type

MOVES has two calculation types - Inventory (total emissions in units of mass) or Emissions Rates (emissions per unit of distance for running emissions or per vehicle for starts and hotelling emissions) in a look-up table format must be post-processed to produce an inventory. Either may be used to develop emissions estimates for GHGs (EPA 2016).

The Emission Rates calculation type was used.

Time Span

The "Time Span" parameters define the years, months, days, and hours that emissions are calculated.

When Emission Rates is chosen, users may choose to approach the selection of options in the Time Spans Panel differently than when running MOVES in Inventory mode. For example, when modeling running emission rates, instead of entering a diurnal temperature profile for 24 hours, users can enter a range of 24 temperatures in increments that represent the temperatures over a period of time. By selecting more than one month and using a different set of incremental temperatures for each month, users could create a table of running emission rates by all the possible temperatures over an entire season or year (EPA 2016).

When using Emission Rates instead of Inventory, the time aggregation level is automatically set to Hour and no other selections are available. Pre-aggregating time does not make sense when using Emission Rates and would produce emission rates that are not meaningful (EPA 2016). However, the year, month, and day must still be specified and will affect the emission rates calculated.

The time span parameters specified below were also used because the TDM outputs represent an annual average weekday.

Years

The County scale in MOVES allows only a single calendar year in a RunSpec. Users who want to model multiple calendar years using the County scale will need to create multiple RunSpecs, with local data specific to each calendar year, and run MOVES multiple times (EPA 2016).

The years used were 2025, 2030, 2040, and 2050. Emission rates for each of these years were calculated separately. This accounts for information such as a changing age distribution of vehicles and their corresponding fuel efficiency.

Months

MOVES allows users to calculate emissions for any or all months of the year. If the user has selected the Emission Rates option, the Month can be used to input groups of temperatures as a shortcut for generating rate tables for use in creating inventories for large geographic areas (EPA 2016).

The months used were January and July to match the process described by APCD. These represent winter and summer months and generally the extremes in annual weather conditions. This accounts for changes in fuel efficiency between warm and cold temperatures throughout the year. The arithmetic averages of emission rates from January and July were used for the final emissions inventory.

Days

Weekdays and weekend days can be modeled separately in MOVES. MOVES provides the option of supplying different speed and VMT information for weekdays and weekend days to allow the calculation of separate emissions estimates by type of day (EPA 2016).

The days used were weekdays to match the TDM output data. These represented the emission rates for an average weekday. The results were escalated later to approximate a full year.

Hours

The hours used were all 24 hours of the day (i.e., clock hours of 1 AM, 2 AM, 3 AM, etc.). These represent the emission rates for individual hours of a day. This accounts for changes in fuel efficiency between warm and cold temperatures throughout the day.

Geographic Bounds

The "Geographic Bounds" parameter defines the county(s) used. For a county-scale run, only one county can be selected per RunSpec. The county used was Adams County, Colorado. The county defines input parameters such as the meteorology data used to estimate emission rates.

On-road Vehicles

MOVES describes vehicles by a combination of vehicle characteristics (e.g., passenger car, passenger truck, light commercial truck, etc.) and the fuel that the vehicle is capable of using (gasoline, diesel, etc.). The [Panel] is used to specify the vehicle types included in the MOVES run (EPA 2016).

The "On-road Vehicles" parameter defines the source types (i.e., vehicle types) and their fuels (gasoline, diesel, electricity, etc.). All combinations of vehicle types and fuels available in MOVES3 were used to calculate the emission rates. APCD's process, which was being followed, assigns TDM mileage based on a modified HPMS category. To calculate aggregate emission rates for each HPMS category (i.e., merging all of the relevant source types and fuel types), each of the six HPMS categories used a separate RunSpec. It is important to note that APCD's modified HPMS category does not match the MOVES HPMS types for source types 21, 31, and 32. When this methodology document refers to HPMS categories, it is generally referring to APCD's HPMS categories. The figure below illustrates the HPMS categories.

	A	B	C	D	E
1	sourceTyp	sourceTypeName	HPMSVtypeID	HPMSVtypeName	**HPMS from APCD**
2	11	Motorcycle	10	Motorcycles	**10**
3	21	Passenger Car	25	Light Duty Vehicles	**20**
4	31	Passenger Truck	25	Light Duty Vehicles	**30**
5	32	Light Commercial Truck	25	Light Duty Vehicles	**30**
6	41	Other Buses	40	Buses	**40**
7	42	Transit Bus	40	Buses	**40**
8	43	School Bus	40	Buses	**40**
9	51	Refuse Truck	50	Single Unit Trucks	**50**
10	52	Single Unit Short-haul Truck	50	Single Unit Trucks	**50**
11	53	Single Unit Long-haul Truck	50	Single Unit Trucks	**50**
12	54	Motor Home	50	Single Unit Trucks	**50**
13	61	Combination Short-haul Truck	60	Combination Trucks	**60**
14	62	Combination Long-haul Truck	60	Combination Trucks	**60**

Road Type

The Road Type Panel is used to define the types of roads that are included in the run. MOVES defines five different road types as shown in Table 3-1. Generally, all road types should be selected including Off-Network. Selection of road types in the Road Type Panel determines the road types that will be included in the MOVES run results (EPA 2016).

Table 3-1: MOVES Road Types

Roadtypeid	Road type	Description
1	Off-Network	Locations where the predominant activity is vehicle starts, parking and idling (parking lots, truck stops, rest areas, freight or bus terminals)
2	Rural Restricted Access	Rural highways that can be accessed only by an on-ramp
3	Rural Unrestricted Access	All other rural roads (arterials, connectors, and local streets)
4	Urban Restricted Access	Urban highways that can be accessed only by an on-ramp
5	Urban Unrestricted Access	All other urban roads (arterials, connectors, and local streets)

All road types available in MOVES3 were used.

Pollutants and Processes

The Pollutants and Processes Panel allows users to select from various pollutants, types of energy consumption, and associated processes of interest. In MOVES, a pollutant refers to particular types of pollutants or precursors of a pollutant but also includes energy consumption choices. Processes refer to the mechanism by which emissions are released, such as running exhaust or start exhaust. Users should select all relevant processes associated with a particular pollutant to account for all emissions of that pollutant. Generally, for this project, that includes running emissions.

The CO2 Equivalent pollutant is the sum of the global warming potential of other greenhouse gases expressed as a unit of CO2 (EPA 2016) and CO2 Equivalents (CO2e) is the pollutant of interest for these GHG calculations. MOVES requires several other prerequisite pollutants for CO2e; however, only the emission rates for CO2e were needed for this project.

General Output

The "General Output" parameters define the output database, units, and activity.

Output Database

Results from the six related HPMS RunSpecs for a single emissions year can be stored in a single output database for convenience. The RunSpecs must have the same units and aggregation (EPA 2016). A different output database is needed for each year of emission rate calculations. A consistent and informative naming convention for all output databases is very valuable.

One output database was used for each year modeled (i.e., 2025, 2030, 2040, and 2050). Each output database contained results for six RunSpecs, where each RunSpec represented a different APCD HPMS type. The naming convention FHU used was as follows:

[firm]_[pollutant]_[year][region]_[description]_[database type]

[firm] = The company or agency performing the analysis.

[pollutant] = The pollutant(s) of interest.

[year] = The year that emission rates were generated for.

[region] = The geographic area that emission rates were generated for.

[description] = An abbreviated description of relevant notes for the RunSpec.

[database type] = Whether the database was an input or output database.

For example, the database "fhu_ghg_2025sw_wev_in" represented an input database for greenhouse gases, the year 2025, the Statewide Transportation Plan, with electric vehicles, and was performed by FHU.

Units

Users are free to choose any of the mass unit selection options but should generally choose a unit whose magnitude is appropriate for the parameters of the RunSpec (EPA 2016).

The units used for models were grams for mass, joules for energy, and miles for distance.

Activity

MOVES allows the user to select multiple activity output options (e.g., distance traveled, population, etc.). For Emission Rate calculations, distance and population are reported automatically, but the values in the output are intermediate steps in the rate calculation and do not represent the true activity (EPA 2016).

When calculating emission rates (as opposed to emission inventories), MOVES selects the activities hoteling hours, population, and starts without the option of changing them.

Output Emissions Detail

This panel allows the user to select the amount of detail provided in the output database. Certain selections on this panel are made by the MOVES software and cannot be changed, based on selections made on earlier panels. The more boxes checked on this panel, the more detail and segregation provided in the MOVES output database. More detail generally is not helpful for this process so no optional selections should be checked on this panel. For example, if Source Use Type were selected on this panel, emission rates for each of the MOVES vehicle Source Use Type categories would be reported in the output database, which would defeat the purpose of performing MOVES calculations based on consolidated HPMS category.

No optional aggregation selections were made on this panel. Source type detail was captured via the six HPMS RunSpecs for each year modeled, as described in the On-road Vehicles section. Since multiple source types were used for HPMS 30, 40, 50, and 60, emission rates were aggregated for into HPMS categories. That is, emission rates for MOVES source types 31 and 32 were aggregated into the HPMS 30 RunSpec, etc.

Input Database/County Data Manager

After completing the RunSpec, the next step is to supply MOVES with data to create an input database that is the basis for the emission rate calculations. When using the County scale, the County Data Manager (CDM) is used to create an input database and populate it with local data. Modelers can either rely on MOVES default information or local data that the user inputs, as is appropriate for the goals of the MOVES modeling. The data contained in the MOVES default database are typically not the most current or best available for any specific county. Therefore, with the exception of fuels, EPA recommends using local data for MOVES for GHG analyses when available to improve the accuracy of GHG emissions estimates. However, the MOVES default data (county level) may be the only or best source of that data readily available. Also consider that data consistency may be more important than data perfection for some GHG analyses. At a minimum, EPA strongly encourages the use of local VMT and vehicle population data. EPA believes these inputs have the greatest impact on the quality of results. However, if local data are not available, MOVES default data may be useful for some inputs without affecting the quality of the results (EPA 2016).

In Emissions Rates mode, a full gamut of input data must be provided, described below, for MOVES to run. Some of these inputs actually do not affect the ultimate emission rates (they would affect inventory mode output) but reasonable inputs in the CDM should be used for general data integrity. As a general rule, users should input accurate activity for the scenario being modeled regardless of whether MOVES is being used in Inventory or Emissions Rates mode (EPA 2016).

The "Create Input Database" parameters define the region-specific inputs such as distributions of road types, vehicle age distributions, and meteorology data. The parameters specified in RunSpecs pre-populate the input database with default data for some of the parameters. However, region-specific data should be used when available and not all parameters have default data.

One comprehensive input database was created for each year modeled. Each of the six HPMS RunSpecs for that year used that single input database and were saved to a single output database. The input data were entered with the MOVES County Data Manager window, as specified below.

Age Distribution

A typical vehicle fleet includes a mix of vehicles of different ages, referred to as Age Distribution in MOVES. MOVES covers a 31 year range of vehicle ages, with vehicles 30 years and older grouped together. MOVES allows the user to specify the fraction of vehicles in each of 30 vehicle ages for each of the 13 source types in the model. For estimating on-road GHG emissions, EPA recommends and encourages states to develop age distributions that are applicable to the area being analyzed (EPA 2016).

APCD has developed a vehicle age distribution, and it was used for each year modeled.

Average Speed Distribution

This input is more important for Inventory than Emission Rates. Vehicle power, speed, and acceleration have a significant effect on vehicle emissions, including GHG emissions. MOVES models those emission effects by assigning activity to specific drive cycles. The Average Speed Distribution Importer in MOVES calls for a speed distribution in VHT in 16 speed bins, by each road type, source type, and hour of the day included in the analysis. EPA urges users to develop the most detailed local speed information that is reasonable to obtain. However, EPA acknowledges that average speed distribution information may not be available at the level of detail that MOVES needs (EPA 2016).

The Emission Rates option in MOVES will produce a table of emission rates by road type for each speed bin. Total running emissions are then quantified outside of MOVES by multiplying the emission rates by the VMT for each source type in each vehicle speed category. Users should supply an appropriate speed distribution to produce the necessary emission rates (EPA 2016).

APCD uses MOVES default data for all years in emission rate mode for their GHG models. This was used for each year modeled. Since emission rates were calculated (as opposed to emission inventories), the average speed distribution used in MOVES will not change the emission rates calculated. The speeds are accounted for in the TDM data.

Fuel

Entering this input data into MOVES involves four tables – called FuelFormulation, FuelSupply, FuelUsageFraction, and AVFT (alternative vehicle fuels and technology) – that interact to define the fuels used in the area being modeled.

- The FuelSupply Table identifies the fuel formulations used in a region (the regionCounty Table defines which specific counties are included in these regions) and each formulation's respective market share;
- The FuelFormulation Table defines the properties (such as RVP, sulfur level, ethanol volume, etc.) of each fuel;
- The FuelUsageFraction Table defines the frequency at which E-85 capable (flex fuel) vehicles use E-85 vs. conventional gasoline; and
- The AVFT Table is used to specify the fraction (other than the default included in the sampleVehiclePopulation Table) of fuel types capable of being used (such as flex fuel vehicles) by model year and source type.

In general, users should review/use the default fuel formulation and fuel supply data provided in MOVES, with important exceptions noted below. EPA strongly recommends using the default fuel properties for a region unless a full local fuel property study exists.

The GHG effects of changes in the fuel mix used by vehicles can be modeled in MOVES. AVFT can be used to change the fraction of future vehicles using gasoline, diesel, CNG and electricity. These changes will be reflected in MOVES GHG emission rates.

The FuelUsageFraction Table allows the user to change the frequency at which E-85 capable vehicles use E-85 fuel vs. conventional fuel, when appropriate. MOVES contains default estimates of E-85 fuel usage for each county in the U.S. In most cases, users should rely on the default information.

The AVFT Table allows users to modify the fraction of vehicles using different fuels and technologies in each model year. In other words, the Fuel Tab allows users to define the split between diesel, gasoline, ethanol, CNG, and electricity, for each vehicle type and model year. For transit buses, the default table assumes that gasoline, diesel, and CNG buses are present in the fleet for most model years. If the user has information about the fuel used by the transit bus fleet in the county modeled, the user should be sure it is reflected in the AVFT Table (EPA 2016). ***NOTE: This tab can be critically important in CDOT's GHG calculations. This is where electric vehicle percentages, etc. are defined. This tab may vary among CDOT's scenarios and should not be overlooked.***

APCD uses MOVES default data for fuel supply, fuel formulation, and fuel usage fraction for all years in their GHG models. For AVFT, APCD uses custom inputs that includes electric vehicles for all years. These were used for each year modeled.

Meteorology

Ambient temperature and relative humidity data are important inputs for estimating on-road GHG emissions with MOVES. Ambient temperature and relative humidity are important for estimating GHG emissions from motor vehicles as these affect air conditioner use. MOVES requires a temperature (in degrees Fahrenheit) and relative humidity (in terms of a percentage, on a scale from 0 to 100) for each hour selected in the RunSpec. EPA recommends that users input the average daily temperature profile for each month if they are modeling all 12 months. Temperature assumptions used for estimating on-road GHG emissions should be based on the latest available information. The MOVES database includes default monthly temperature and humidity data for every county in the country. These default data are based on average monthly temperatures for each county from the National Climatic Data Center for the period from 2001 to 2011. These national defaults can be used for a GHG inventory, or more recent data can be used (EPA 2016).

If the Emission Rate calculation type is chosen in the RunSpec, users can enter a different temperature and humidity for each hour of the day to create an emission rate table that varies by temperature for running emissions processes. Emission rates for all running processes that vary by temperature can be post-processed outside of MOVES to calculate emissions for any mix of temperatures that can occur during a day. This creates the potential to create a lookup table of emission rates by temperature for the range of temperatures that can occur over a longer period of time such as a month or year from a single MOVES run (EPA 2016).

MOVES default meteorology data was used for all years. The county used was Adams County, Colorado for the months of January and July. Emission rates were post-processed to average winter and summer emission rates.

Road Type Distribution

MOVES does not have default data for this input, so it must be developed. The fraction of VMT by road type varies from area to area and can have a significant effect on GHG emissions from on-road mobile sources. EPA expects states to develop and use their own specific estimates of VMT by road type (EPA 2016).

If the Emission Rates option is used, MOVES will automatically produce a table of running emission rates by road type. Running emissions would then be quantified outside of MOVES by multiplying the emission rates by the VMT on each road type for each source type in each speed bin. In that case, data entered using the Road Type Distribution Importer is still required, but is not used by MOVES to calculate the rate. However, road type distribution inputs are important for Emission Rates runs involving non-running processes, because they are used by MOVES to calculate the relative amounts of running and non-running activity, which in turn affects the rates for the non-running processes (EPA 2016).

APCD uses a custom road type distribution for all years in their GHG models. This was used for each year modeled. Since emission rates were calculated (as opposed to emission inventories), the road type distribution used in MOVES will not change the emission rates calculated. The road types are accounted for in the TDM.

Source Type Population

MOVES does not have default data for this input, so it must be developed. APCD uses a custom source type distribution for all years in their GHG models. These data were used for each year modeled. The source type populations used in MOVES will not change the emission rates calculated. However, source population data are still needed as inputs for an emission rates MOVES run.

Vehicle Type VMT

MOVES does not have default data for this input, so it must be developed. EPA believes VMT inputs have the greatest impact on the results of a state or local GHG or energy consumption analysis. Regardless of calculation type, MOVES requires VMT as an input. MOVES can accommodate whatever VMT data is available: annual or average daily VMT, by HPMS class or MOVES source type. Therefore, there are four possible ways to enter VMT, allowing users the flexibility to enter VMT data in whatever form they have. EPA recommends that the same approach be used in any analysis that compares two or more cases (e.g., the base year and a future year) in a GHG analysis (EPA 2016).

The Output Emission Detail panel determines the detail with which MOVES will produce emission rates for running emissions, such as by source type and/or road type in terms of grams per mile. Total emissions are quantified outside of MOVES by multiplying the emission rates by the VMT for each source type and road type. However, users will still need to enter data using the Vehicle Type VMT Importer that reflects the VMT in the total area where the lookup table results will be applied. This is necessary because MOVES uses the relationship between source type population and VMT to determine the relative amount of time vehicles spend parked vs. running (EPA 2016).

APCD uses HPMS as the source type and annual as the time span for their GHG models. This was used for each year modeled. Since emission rates were calculated (as opposed to emission inventories), the VMT used in MOVES will not change the emission rates calculated. The VMT values are in the TDM data. However, VMT data are still needed as inputs for an emissions rate MOVES run.

Inspection/Maintenance Program

If a model is examining any nonattainment/maintenance areas, an inspection and maintenance (I/M) program may apply. I/M program inputs should be those used for SIP and conformity analyses and are generally available as defaults within MOVES. However, if a user is modeling CO2, N2O, and/or elemental carbon emissions only, or modeling area where no I/M program applies, the user should check the box on this tab (EPA 2016).

APCD uses the check box for "No I/M Program" for the Statewide Transportation Plan, since there is not a statewide emissions program that applies in these areas. This was used for each year modeled.

Others

APCD assumes MOVES default values for the starts, hoteling, idle, retrofit data, and generic tabs. This was left as is for each modeled year.

Output Database

When a RunSpec is executed in MOVES, the results are stored in the output database specified in the "General Output" parameters. HeidiSQL (or equivalent software) can be used to view and export the calculated emission rates.

MOVES Rate per Distance Table

The critical table in the output database with the calculated emission rates was the "rateperdistance" table. It contained emission rates for each combination of month, hour, pollutant, road type, speed bin, and vehicle type as specified in the RunSpec. The MOVESScenarioID field was the mechanism used by FHU to identify the HPMS source type.

The table was filtered to include only CO2e (i.e., pollutant ID 98) emission rates and exported to a comma-separated value (CSV) file. Because the table included emission rates for both January and July, and MOVES speed bins are not discrete speeds in miles per hour, post-processing of the emission rates was required to calculate emission inventories.

Processed Emission Rates

APCD provided several Access databases with calculation tools for processing the MOVES and TDM data. These Access databases are the basis for the post-MOVES data processing. The instructions contained below provide a narrative of what occurs, but these actions are already built into the Access databases.

The MOVES rate per distance output table needed to be manipulated to produce emission rates that could be related to the calculated vehicle speeds for road links in the TDM data. The emission rates for January and July needed to be averaged to create composite emission rates. The emission rates for the 16 speed bins (which cover 5 MPH ranges) in MOVES were linearly interpolated to provide emission rates for every mile per hour speed from 1 to 75, which is how speed data are presented in the TDM data.

The resulting table includes a total of 43,776 unique emission rates. That is, an emission rate for each combination of:

- MOVES Road Types 2-5
- HPMS Types 10/20/30/40/50/60
- Hours 1-24
- Speeds 1-75

Processing Annual Average Emission Rates

For each year/rate per distance table (i.e., this process must be repeated for 2025, 2030, 2040, and 2050):

- Filter to include only CO2e (pollutant ID 98) emission rates
- There were unique emission rates for each combination of:
  - Road type
  - HPMS type
  - Speed Bin
  - Hour
  - Month
- To get the average emission rates per year, each combination of road type, HPMS type, average speed bin, and hour were summed and divided by two (to average the corresponding emission rates for January and July)
- Seasonally averaged emission rate = (Winter Rate + Summer Rate)/2

Interpolating Emission Rates from Speed Bin to Integer Speeds

After seasonally averaging the emission rates, these rates were used to interpolate (linearly) between speed bins to get an emission of rate for every mile per hour for the speeds of 1 to 75 miles per hour. In general, the process used was:

- For adjacent speed bins, subtract the lower bin number emission rate from the higher bin number emission rate and divide by five to calculate a per mile per hour change in the emission rate (NOTE: emission rates generally decrease with increased speed)
- Add the appropriate emission rate change to the lower bin avgBinSpeed value to interpolate each mile per hour emission rate between the avgBinSpeed values
- For reference, the table below illustrates the MOVES speed bins
- Example for interpolating emission rate of 11 mph:
  - Speed per mph = 11 mph
  - Speed of Lower Speed Bin = 10 mph
  - Number of Speeds per Speed Bin = 5 (= 2.5 for speed bin 1; = 5 for all other speed bins)
  - ER of Lower Speed Bin = 4055 g/m (dummy data)
  - ER of Upper Speed Bin = 3421 g/m (dummy data)
  - 4055 + (3421 – 4055) * (11 – 10)/5 = 3928

avgSpeedBinID	avgBinSpeed	avgSpeedBinDesc
1	2.5	speed < 2.5mph
2	5	2.5mph <= speed < 7.5mph
3	10	7.5mph <= speed < 12.5mph
4	15	12.5mph <= speed < 17.5mph
5	20	17.5mph <= speed <22.5mph
6	25	22.5mph <= speed < 27.5mph
7	30	27.5mph <= speed < 32.5mph
8	35	32.5mph <= speed < 37.5mph
9	40	37.5mph <= speed < 42.5mph
10	45	42.5mph <= speed < 47.5mph
11	50	47.5mph <= speed < 52.5mph
12	55	52.5mph <= speed < 57.5mph
13	60	57.5mph <= speed < 62.5mph
14	65	62.5mph <= speed < 67.5mph
15	70	67.5mph <= speed < 72.5mph
16	75	72.5mph <= speed

Processed TDM

The TDM data are usually presented as an ESRI polyline shapefile format with each traffic link represented as one record (feature) and attributed with distances, total volumes, volumes per time period, and speeds per time period. A series of post-processing steps were performed to relate the relevant TDM data with the appropriate MOVES emission rates, as described below. The first step described below was done using ArcGIS. The other steps were done using the tools in the Access databases.

The resulting table includes aggregated VMT for each combination of:

- MOVES Road Types 2-5
- HPMS Types 10/20/30/40/50/60
- Hours 1-24
- Speeds 2.5-75

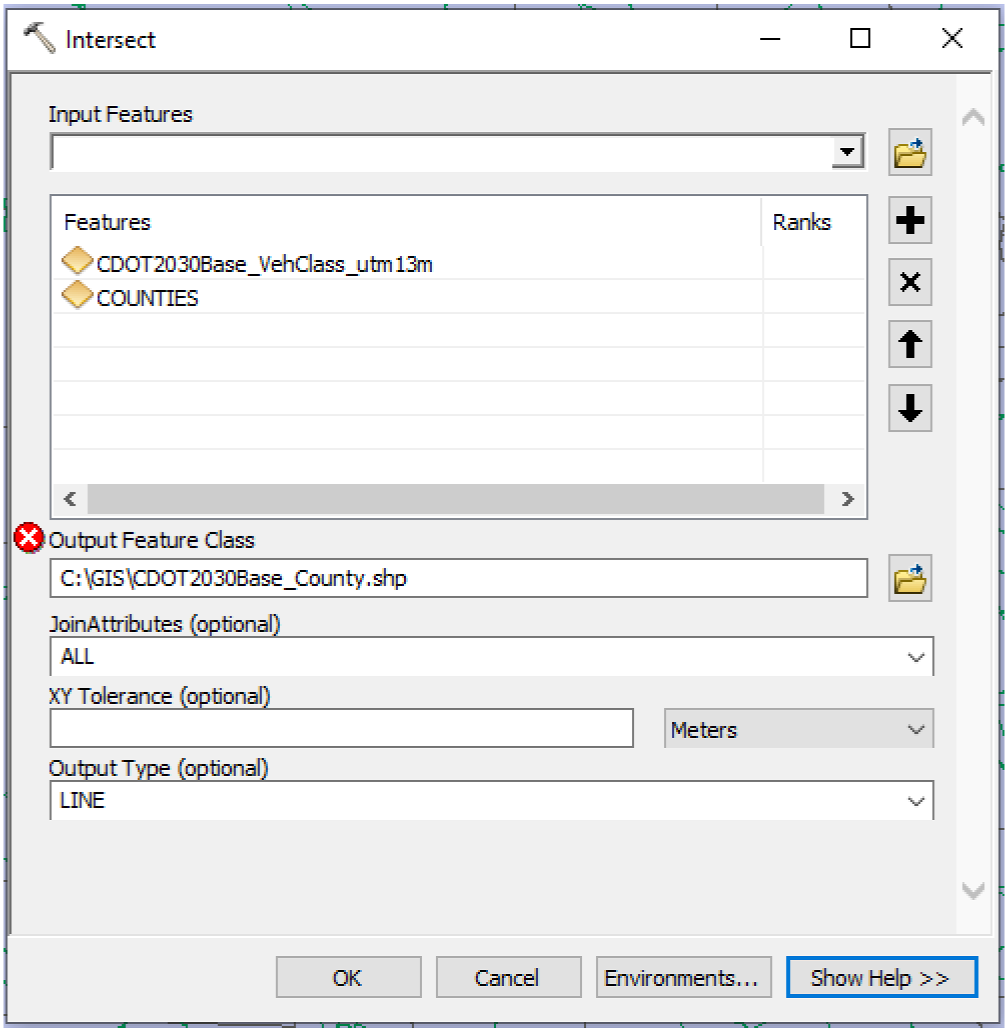
This process provides respective county names for each link to aggregate VMT by geography/region.

Attribute TDM with County Name

The first step was to attribute each link with the county name. The county information was necessary because it was used later in the process to filter VMT (and thus, on-road emissions inventory) by geography/region (e.g., MPO or non-MPO traffic). Performing this step later in the process would require significant modifications to the process.

The ArcGIS geoprocessing tool "Intersect" was used to attribute the TDM shapefile with county names for each roadway link (feature). The Input Features were the TDM shapefile and CDOT's "COUNTIES" shapefile that can be downloaded from OTIS. Unnecessary fields in the counties shapefile were deleted, so that the fields remaining were FID, Shape*, COUNTY, and CO_FIPS. The Output Feature Class name and file path could change, depending on the user's preference. The Join Attributes parameter was set to "ALL" which kept attributes from both input features. The Output Type parameter was set to "LINE" which set the output feature class to be the geometry of the TDM shapefile. The Environment was defaults except for the Output

Coordinate System. That was set to the projected coordinate system, "GRS_1980_UTM_Zone_13N" which matched the TDM shapefile's coordinate system.



The resulting output feature class had the same geometry and attributes as the TDM shapefile except for the following changes:

- Each link was attributed with the county name and FIPS number.
- Links within multiple counties were split (divided) into separate features at the county line(s). In these cases:
  - Both features still had the same attributes except for the county name and FIPS.
  - The distance attribute in the "DIST" field was now invalid since the feature was split.

To account for changes in distances for links that were in multiple counties, a new field "cntyMiles" was added to the output feature class. The geoprocessing tool "Calculate Geometry" was used on the "cntyMiles" field to calculate the distance of each link in miles. The "cntyMiles" field, rather than the "DIST" field, was used later in Access to calculate VMT.

The resulting attribute table was saved as a CSV file and used in the following steps.

Access Database

The TDM CSV file from the step above was imported into an Access database. The remaining post-processing steps were performed in this Access database, as described below.

Speeds

The TDM speeds were in floating decimal format and rounded to the nearest integer. Speeds less than 2.75 mph were rounded to 2.5 mph. This was because emission rates for speeds of 2.5 mph or less were the same, as described in the Processed Emission Rates section.

Time Periods

The TDM model provides aggregated data for 10 blocks of time for a day, not hour by hour—see the "name" column below. The data for these TDM periods were recategorized/interpolated into data for discrete clock hours 1-24 based on methodology from APCD.

The PeriodHour24 table below was used to split the TDM data for different time periods (AM1, PM2, OP1, etc.) into 24 clock hour time periods. VMT was calculated for each combination of integer speed (2.5 – 75mph), interstate (yes or no), road functional class (1-8), rural (yes or no), periodCog (1-10), and county.

The periodCog 1-10 were related to hours 1-24 as shown in the "hour" column. That provided a VMT per clock hour for each combination of speed and functional class. This was used to relate the VMT to fractions of VMT by HPMS per functional class and hour.

The cVMT was divided by the number of "periods" corresponding with each clock hour to calculate the VMT.

PeriodHour24

Interval	periodCog	name	hour	hrsT	periods
11:00 PM - 6:30AM	7	Op1.bin	1	7.5	7
11:00 PM - 6:30AM	7	Op1.bin	2	7.5	7
11:00 PM - 6:30AM	7	Op1.bin	3	7.5	7
11:00 PM - 6:30AM	7	Op1.bin	4	7.5	7
11:00 PM - 6:30AM	7	Op1.bin	5	7.5	7
11:00 PM - 6:30AM	7	Op1.bin	6	15	7
6:30-7:00 AM	1	Am1.bin	7	1	1
7:00-8:00 AM	2	Am2.bin	8	1	1
8:00-9:00 AM	3	Am3.bin	9	1	1
9:00 AM - 11:30 AM	8	Op2.bin	10	2.5	2.5
9:00 AM - 11:30 AM	8	Op2.bin	11	2.5	2.5
	9	Op3.bin	12	3.5	7
	8	Op2.bin	12	2.5	5
11:30 AM - 3:00 PM	9	Op3.bin	13	3.5	3.5
	9	Op3.bin	14	3.5	3.5
	9	Op3.bin	15	3.5	3.5
3:00-5:00 PM	4	Pm1.bin	16	2	2
3:00-5:00 PM	4	Pm1.bin	17	2	2
5:00-6:00 PM	5	Pm2.bin	18	1	1
6:00-7:00 PM	6	Pm3.bin	19	1	1
7:00-11:00 PM	10	Op4.bin	20	4	4
7:00-11:00 PM	10	Op4.bin	21	4	4
7:00-11:00 PM	10	Op4.bin	22	4	4
7:00-11:00 PM	10	Op4.bin	23	4	4
11:00 PM - 6:30AM	7	Op1.bin	24	7.5	7

Fraction of VMT by HPMS

Once VMT was calculated for each road functional class and clock hour, the fractions of VMT by HPMS for each corresponding functional class and clock hour were applied. This calculated the VMT for HPMS 10-60. The fractions used were from APCD and were consistent with their methodology.

FractionsByHourHPMSnaaT

NAA?	Weld?	Rural?	FC	Hr	10f	20f	30f	40f	50f	60f
-1	W	R	1	1	1.12494375281236E-03	0.442984079764564	0.408981870287873	8.24958752062397E-04	3.60606876834793E-03	0.14247807867434
-1	W	R	1	2	6.50325162581291E-04	0.418107821883677	0.388118179039889	1.40070035017509E-03	5.57032759041272E-03	0.186152645973265
-1	W	R	1	3	1.1907462009526E-03	0.402448608970853	0.376594285267901	1.9278748015423E-03	8.86488378110699E-03	0.208973600977645
-1	W	R	1	4	1.88772529102432E-03	0.400795540811441	0.375296865809669	3.5956672209987E-03	8.74568726325532E-03	0.209678513603612
-1	W	R	1	5	1.27600843728028E-03	0.438002933384539	0.406922735865401	8.59352621025494E-04	5.91653137282429E-03	0.14702243831893
-1	W	R	1	6	9.86892049192773E-04	0.462978652961131	0.429325812630245	1.88521686320158E-03	5.20852159466524E-03	9.96149039015637E-02
-1	W	R	1	7	8.56477631797771E-04	0.47063947538398	0.437825973989187	1.19740562115417E-03	7.50554404406707E-03	8.19751233298142E-02

Road Types

The TDM used roadway functional classes that were recategorized to MOVES road types. That allowed the road types from the TDM to be related to the emission rates.

RTt

DRCOG Facil	FHWA facility type	rural?	FHWA	Urban	MOVESrt	fhwaRT	fcCode	Intestate
1	Principal Arterial - Interstate	-1	R	R	2	1	1	1
1	Principal Arterial - Interstate	-1	R	R	2	1	1	0
1	Principal Arterial - Interstate	0	N	U	4	11	1	0
1	Principal Arterial - Interstate	0	N	U	4	11	1	1
2	Principal Arterial - Other	-1	N	R	3	2	2	0
2	Principal Arterial - Other Freeways or Expressway	0	N	U	4	12	2	0
3	Principal Arterial - Other	-1	N	R	3	2	3	0
3	Principal Arterial - Other	0	N	U	5	14	3	0
4	Minor Arterial	-1	N	R	3	6	4	0
4	Minor Arterial	0	N	U	5	16	4	0
5	Major Collector	-1	N	R	3	7	5	0
5	Collector	0	N	U	5	17	5	0
6	Principal Arterial	-1	R	R	2	1	1	0
6	Principal Arterial	0	N	U	4	11	1	0
8	Local System	-1	N	R	3	9	7	0
8	Local System	0	N	U	5	19	7	0

Filter by Geography/Region

The statewide GHG inventory was filtered to contain VMT for all counties in Colorado except for the nine-county region in the ozone non-attainment area. The nine counties excluded were Adams, Arapahoe, Boulder, Broomfield, Denver, Douglas, Jefferson, Larimer, and Weld. The statewide results were subdivided further into Pikes Peak area and the rest of the state.

Emissions Inventory

The processed emission rates table and the processed VMT table were related by road type, HPMS type, hour, and speed. This relate was used to multiply the emission rate (g/mi) by the VMT (mi) to get a total in grams of CO2e for an average weekday. The formula used was:

- CO2e (g/day) = SUM(Emission Rate (g/mi) * VMT (mi))
- CO2e (MMt/day) = CO2e (g/day) * 1 (MMt) / 1e+12 (g)
- CO2e (MMt/year) = CO2e (MMt/day) * 338 (TDM weekdays/calendar year)

The calculated emissions inventory was for on-road emissions. Non-road emissions were not included in this calculation.

References

EPA. 2016. *Using MOVES for Estimating State and Local Inventories of On-road Greenhouse Gas Emissions and Energy Consumption*. June. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100OW0B.pdf