ITEM 11 – Information
December 15, 2021

Draft Results of the TPB Climate Change Mitigation Study

Background: The TPB Climate Change Mitigation Study of 2021 (CCMS) is a scenario study whose goal is to identify potential pathways for the region to reduce on-road, transportation-sector greenhouse gas emissions to meet COG's regional greenhouse gas (GHG) reduction goals associated with 2030 and 2050. The analysis phase of the study is now complete and includes three "top-down" scenarios and 10 "bottom-up" scenarios that explore single and combination pathways to reduce on-road, transportation-sector greenhouse gas emissions. The board received a detailed briefing on the results of the analysis during a special TPB work session, held Monday, December 13 at 3 PM. Today, the board will receive an abbreviated recap of results from the analysis.

   

TPB Climate Change Mitigation Study of 2021

Scenario Analysis Findings

DRAFT Report

December 9, 2021

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Prepared for

National Capital Region Transportation Planning Board

Executive Summary

Introduction and Purpose

The Metropolitan Washington Council of Governments (COG) set ambitious goals for reducing regional greenhouse gas (GHG) emissions across all sectors[1] to 50% below the 2005 level by 2030 and 80% below the 2005 level by 2050. While these are non-sector-specific regional goals, it is recognized that transportation contributes a large share of regional GHG emissions, with on-road mobile sources contributing about 34% of total regional GHG emissions in 2018, the year of the latest regional inventory. Consequently, the National Capital Region Transportation Planning Board (TPB), which is the metropolitan planning organization (MPO) for the metropolitan Washington region, is seeking ways to achieve significant reductions of on-road transportation related GHG emissions, commensurate with the overall regional goals for GHG reduction.

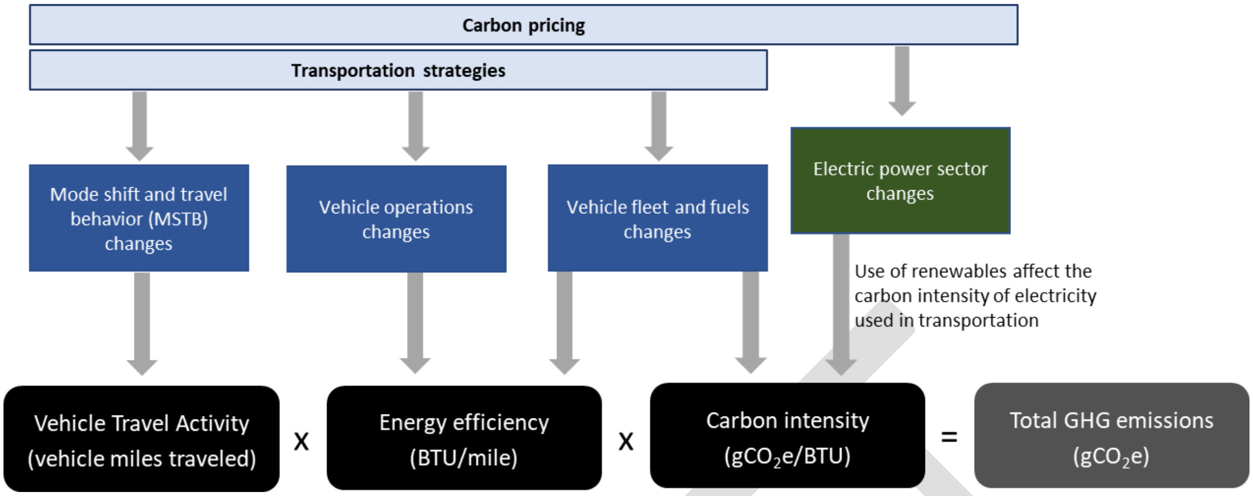
The purpose of this study is to help answer the question, "What would it take to reduce on-road transportation sector GHG emissions by 50% by 2030 and by 80% by 2050, compared to the 2005 level?" This study addressed this question through a scenario analysis that involved exploring the estimated GHG impacts of different on-road transportation strategies and combinations of strategies. The study found that none of the simulated scenarios would meet the 2030 goal of reducing GHG emissions to 50% below the 2005 level for on-road transportation sources. The 2050 goal of reducing GHG emissions to 80% below the 2005 level could only be achieved in one scenario with the most aggressive combination of strategies under a reference electricity grid assumption (which accounts for implementation of existing "on the books" policies related to renewable fuels in the power sector). When assuming cleaner electricity grid emissions profiles, however, more scenarios can meet the 2050 goal, as long as they incorporate substantial shifts to electric vehicles (EVs).

Figure ES-1 illustrates the ways in which transportation strategies affect on-road transportation GHG emissions. In this study, on-road transportation GHG emissions are defined as tailpipe emissions coming directly from combustion of fossil fuels in motor vehicles (called "on-road mobile sources" in most GHG inventories), plus GHG emissions from electricity associated with EVs. Note that while this study explored vehicle technology shifts to EVs charged through plugging into the electric grid, there are other forms of zero emission vehicles (ZEVs) (when considering only tailpipe emissions), such as hydrogen fuel cell electric vehicles.[2]

[1] This includes residential and commercial buildings, transportation and mobile emissions, wastewater treatment, agriculture, and solid waste treatment sectors.

[2] For simplicity, this study focused on EVs using the electric grid. Note that this analysis does not account for full fuel-cycle emissions, which would include the upstream emissions associated with the extraction, transport, and distribution of fuels used in transportation, and does not account for other emissions associated with transportation infrastructure development and maintenance, nor production of vehicles. It also does not account for emissions associated with non-road transportation sources, such as rail (e.g., Metrorail, commuter rail, freight rail) or aviation.

Figure ES-1. Strategies and Pathways for Reducing GHG Emissions from Transportation



As shown in Figure ES-1, on-road transportation GHG emissions are a function of vehicle travel, the energy efficiency of vehicles, and the carbon intensity of fuels used. The scenarios explored in this analysis included a broad array of strategies under **three primary pathways** for reducing GHGs from on-road transportation sources:

1) **Vehicle Technologies and Fuels:** Strategies to shift the fleet of motor vehicles to electric vehicles (EVs) and increase the share of lower carbon fuels (e.g., biofuels).

2) **Mode Shift and Travel Behavior (MSTB):** Strategies to reduce motor vehicle travel, typically measured as vehicle miles of travel (VMT), by shifting travel from driving alone to more efficient modes, such as transit, ridesharing, bicycling, and walking; reducing vehicle trip lengths, such as through land use strategies; or reducing trip-making entirely, such as through telework. These strategies primarily affect passenger travel, rather than freight.

3) **Transportation Systems Management and Operations (TSMO):** Strategies to optimize the efficiency of travel by reducing vehicle travel delay and/or encourage more eco-friendly driving patterns.

The use of renewable fuels in the electric power grid influences how much GHGs are emitted from EVs, and this study explored three different possible cases for future electric power GHG emissions factors, recognizing the movement toward a decarbonized power sector:

1. A Reference Case, which incorporates all "on-the-books" policies, including renewable portfolio standards (RPSs) in the District of Columbia, Maryland, and Virginia.
2. A Modified Reference Case, which is slightly more aggressive than the Reference Case, resulting in a near zero carbon grid by 2040.
3. A Clean Grid Case, assuming a 100% carbon free grid by 2035.

As transportation power sources move toward electricity, utility electricity grid emissions become increasingly important in decarbonization of the sector.

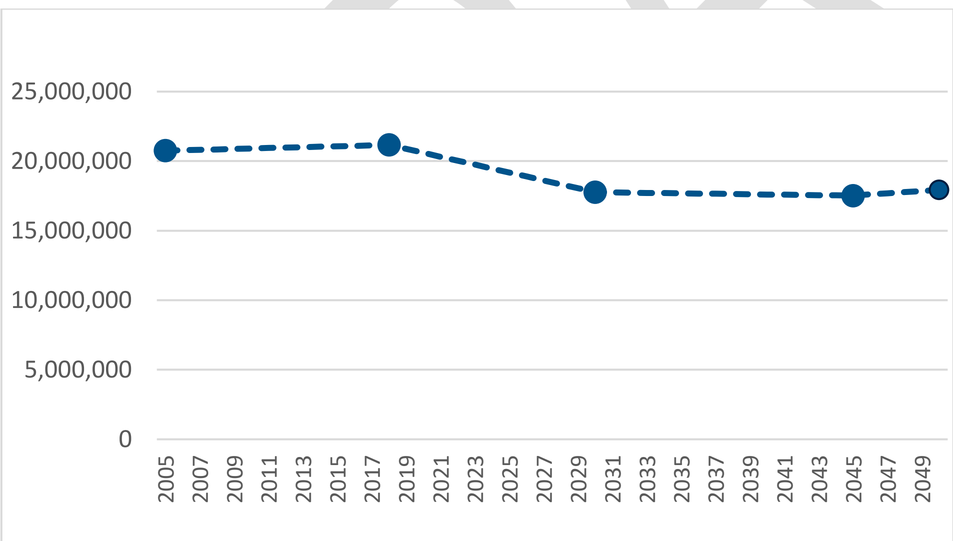
Carbon pricing – in the form of a fee on carbon emissions or market-based mechanisms such as cap-and-trade or cap-and-invest programs – has been identified as a potentially promising overarching strategy, but this study did not explicitly analyze carbon pricing. However, carbon pricing may be a mechanism that would help to support other strategies analyzed under this study, such as shifts toward EVs and less-carbon intensive modes of travel.

Study Baseline Forecast

The baseline scenario for this study is based on the VMT and tailpipe GHG emissions projections consistent with TPB's Visualize 2045 Long-Range Transportation Plan and COG's 2030 Climate and Energy Action Plan (2030 CEAP). To calculate 2050 VMT and emissions, the 2045 passenger VMT projections were extrapolated to 2050 using estimated population growth rates and forecast reductions in VMT per capita estimated for the period 2030 to 2045 extended to 2050. VMT from light-duty commercial trucks, heavy-duty trucks, and combination trucks was assumed to continue increasing at the same annual rate as the period between 2030 and 2045. A total increase in VMT between 2045 and 2050 of 2.5% was calculated across all vehicle types.

The GHG emissions estimates developed for the performance analysis of past TPB's long-range transportation plans, including Visualize 2045, include only tailpipe emissions, while this study also accounts for the emissions generated to charge EVs. The baseline estimates shown in Figure ES-2 are a sum of the tailpipe emissions plus electricity emissions, calculated based on the National Renewable Energy Lab (NREL) reference case penetration of EVs.[3]

Figure ES-2. Baseline On-Road GHG Emissions ($MTCO_2e$)



It is important to note that the baseline GHG emissions totals show lower total emissions in 2030 and 2050 compared to 2005, approximately 14% lower in both cases. This is because the projected improvements in fuel economy, leading to decreased emissions, offset increases in VMT. Note that these reductions in on-road

[3] NREL. (2018). Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States

transportation GHG emissions are estimated to occur over a time when population in the region is projected to increase about 25% (to 6.25 million) by 2030 and about 43% by 2050 (to 7.15 million) compared to the 2005 level (4.99 million).

Scenario Approach

The study involved **two different types of analysis**:

1) Three "top-down" scenarios were developed and analyzed to identify what level of vehicle miles traveled (VMT) would need to be reduced, or what level of EV adoption would be needed, to meet the 50% and 80% reduction goals by 2030 and 2050, respectively; and
2) Ten "bottom-up" scenarios were developed to assess how much GHG reduction might be expected with implementation of different sets of strategies in order to determine which scenarios could meet the 2030 and 2050 GHG reduction goals.

The **"top-down" analysis** explored three key questions: 1) What level of VMT reduction would be needed to meet the regional 2030 and 2050 goals if VMT reduction were the sole focus of efforts? 2) What level of electric vehicle (EV) adoption would be needed to meet the regional 2030 and 2050 goals if vehicle technology were the sole focus of efforts? 3) What level of VMT reduction would be needed to meet the regional 2030 goal assuming vehicle technology assumptions in COG's 2030 Climate and Energy Action Plan (2030 CEAP)?[4]

The **"bottom-up" analysis** involved development and analysis of ten scenarios: six focused on individual pathways (e.g., vehicle technologies and fuels alone, MSTB alone, or TSMO alone), and four involving combinations of the other scenarios. Table ES-1 lists all ten scenarios that were explored. Each scenario was defined to incorporate an aggressive set of strategies or assumptions about changes in the vehicle fleet, fuels, or travel behavior (e.g., levels of telework) corresponding with aggressive strategy implementation. While each scenario was defined to be potentially feasible, they were generally designed with high-end assumptions (both in the base scenarios and amplified scenarios), without regard to political feasibility, and some with very optimistic assumptions about shifts in technology.

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

Table ES-1. Ten Scenarios Studied in "Bottom-Up" Analysis

Pathway	Scenario	Key Components / Assumptions
Vehicle Technology (VT) and Fuels	VT.1: Vehicle Technology and Fuels Improvement Scenario	Shifts to EVs (50% of new light-duty [LD] vehicle sales are EVs in 2030, with 100% by 2040; 30% of new medium/heavy-duty [M/HD] truck sales are EVs in 2030, with 100% by 2050; 50% of buses on the road are EVs in 2030, 100% in 2050; biodiesel/renewable diesel makes up 10% of diesel fuel use in 2030 and 20% in 2050)
	VT.2: Amplified Vehicle Technology and Fuels Improvement Scenario	More aggressive shifts to EVs: 100% of new LD vehicle sales are EVs in 2030; 50% of new M/HD truck sales are EVs in 2030, with 100% by 2040; 100% of buses on the road are EVs by 2030; biodiesel/renewable diesel makes up 20% of diesel fuel use in 2030 and 30% in 2050
Mode Shift and Travel Behavior (MSBT)	MS.1: Mode Shift Scenario	Land use changes focused on redistribution of future growth to activity centers and areas better served by transit across jurisdictions and 77,000 new households in the region by 2030 and 126,000 new households in the region by 2050 to support jobs-housing balance; enhanced bike/pedestrian/micromobility environment; transit fares reduced 50% by 2030 and 75% in 2050; all workplace parking in activity centers priced by 2030; transit enhancements (10% reduction in transit travel time by 2030 and 20% by 2050); 25% telework
	MS.2: Mode Shift Scenario + Road Pricing	Same strategies as MS.1, plus DC cordon pricing of $10 to enter downtown, and VMT-fees of $0.05 per mile in 2030 and $0.10 per mile in 2050
	MS.3: Amplified Mode Shift Scenario + Road Pricing	MS.2 with amplified strategies, including free transit; all workplace parking priced by 2050 (not just in activity centers), further transit enhancements (15% reduction in transit travel time by 2030 and 30% by 2050); 40% telework[5]
Transportation Systems Management & Operations (TSMO)	TSMO: Operations Improvement Scenario	Optimized operations through intelligent transportation systems (ITS) including ramp metering, incident management, active signal control, and active transportation demand management; assumed operational benefits from connected/automated vehicles (CAVs) in 2050
Combined Pathways	COMBO.1: Combined Scenario	VT.1 + MS.1 + TSMO
	COMBO.2: Combined Scenario with More Aggressive Technology Emphasis	VT.2 + MS.1 + TSMO
	COMBO.3: Combined Scenario with More Aggressive Mode Shift Emphasis	VT.1 + MS.3 + TSMO
	COMBO.4: Combined Scenario with Aggressive Actions Across All Pathways and Shared CAV Future	VT.2 + MS.3 + TSMO + shared CAV assumptions

[5] Since only 50% of jobs in the metropolitan Washington region are telework capable, 40% telework implies that 80% of employees who work in telework-capable jobs would be teleworking on a typical workday, which is a very aggressive assumption.

Scenario Analysis Results

Top-Down Analysis: What would it take to reach the GHG reduction goals solely through VMT reduction or EV adoption?

The "top down" analysis of what it would take to reach the 2030 or 2050 goals highlights how challenging it would be to reach the goals within the on-road transportation sector, particularly for 2030, through either VMT reduction alone or shifts to EVs alone. The analysis also highlights the challenge of meeting the 2030 goal even with vehicle technology assumptions in the 2030 CEAP. To meet the 50% emissions reduction goal by 2030 through VMT reduction alone, passenger VMT would need to drop by an estimated 57% from the 2018 level. This is an unprecedented level of VMT reduction that would mean traffic volumes in the region would need to shrink to the level seen at the height of the COVID-19 stay-at-home orders during April 2020 and not rebound, despite a forecasted 12% increase in regional population between 2018 and 2030.

Similarly, meeting the 2030 goal is extremely ambitious with vehicle technology improvements alone. To achieve the 50% emissions reduction goal by 2030 using vehicle technology alone, approximately 75% of vehicles on the road would need to be EVs by 2030 using "reference grid case" electric power assumptions (which assumes increases in use of renewable fuels consistent with existing policies) and about 48% would need to be EVs assuming a "clean grid case." These levels appear extremely difficult, given the length of time people generally hold onto vehicles,[6] and would likely require immediate shifts to all new vehicles sold as EVs combined with aggressive incentives to accelerate vehicle turnover and/or carbon or fuel pricing. The small number of years between today and 2030 means there is very limited time to achieve the large shifts in fleet technology that would be required to meet the goal for 2030.

Looking at combining technology enhancements with VMT reduction still provides an intense challenge for meeting the 2030 goal within the on-road transportation sector. Even with the 2030 CEAP technology assumptions[7], passenger VMT would need to drop by about 49% from the 2018 level, which is an unprecedented level of VMT reduction over a sustained time and would likely require that vehicles be subject to high levels of pricing (road, parking, and/or fuel), nearly complete telework, and restrictions on driving. There simply is too little time for the vehicle fleet to turn-over with enough EVs to allow for a more moderate level of reduction in VMT, particularly given that medium- and heavy-duty commercial vehicles made up about one-quarter of on-road transportation GHG emissions in 2018, and that there is limited potential to reduce VMT by commercial/freight vehicles, due to the necessity of freight and goods movement, combined with relatively limited opportunities to shift these vehicles to EVs on a broad scale in the near-term.

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[6] See, for example, Brad Plumer, Nadja Popovich, and Blacki Migliozzi, "Electric Cars Are Coming. How Long Until They Rule the Road?," *The New York Times*, March 10, 2021, sec. Climate, https://www.nytimes.com/interactive/2021/03/10/climate/electric-vehicle-fleet-turnover.html.

[7] The 2030 CEAP assumed that in 2030, 34% of light duty passenger car VMT, 17% of light duty passenger truck VMT, 34% of transit bus VMT, 7% of medium duty truck VMT, and 6% of heavy duty truck VMT would be driven by EVs.

Challenges remain for meeting the 2050 goal. Based on the ICF analysis, it would not be possible to attain the 80% reduction goal through passenger VMT reduction alone since estimated medium- and heavy-duty vehicle emissions exceed the goal level in 2050. Similarly, the 2050 goal cannot be achieved even if all vehicles were converted to EVs under "reference case" assumptions for electricity carbon intensity. However, the goal could be met with a completely carbon-free electric grid if about 79% of vehicles on the road were EVs in 2050. These findings highlight the importance of large-scale shifts to EVs (zero emissions from the tailpipe) combined with a clean electric power grid in order to decarbonize the on-road transportation sector.

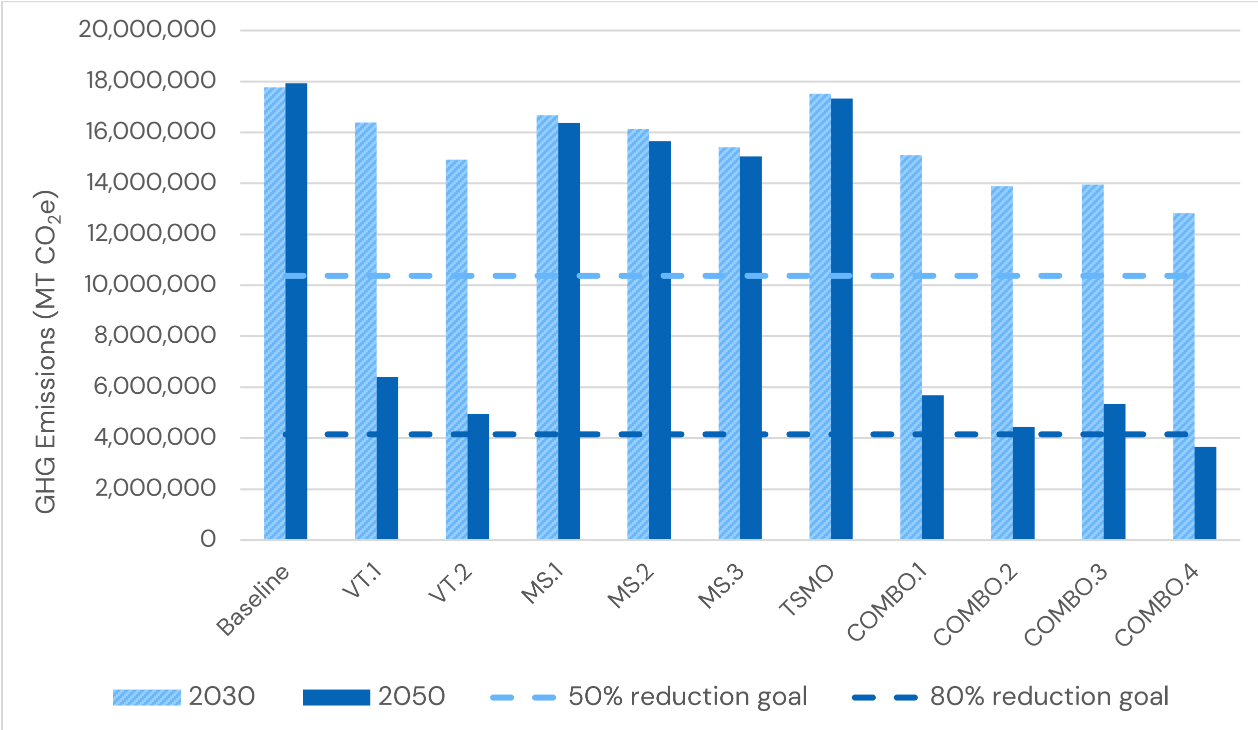
Bottom-Up Analysis: Which scenarios achieve the goals?

In short, none of the simulated scenarios meet the 2030 goal of reducing GHG emissions to 50% below 2005 levels, and only one scenario provides enough emissions reductions to meet the 2050 goal of 80% below 2005 levels under the "reference case" electric grid. When conducting the analysis with cleaner electricity grid emissions profiles, more scenarios are able to meet the 2050 goal of 80% below 2005 levels; however, still no scenarios were able to meet the 2030 goal of 50% below 2005 levels. This finding is consistent with results of the "top-down" analysis, which showed the challenge of meeting the 2030 goal within the on-road transportation sector.

The results of the "bottom up" scenario analysis conducted under the "reference grid" case are shown in Figure ES-3. As expected, the scenarios that combine multiple types of strategies (COMBO scenarios) are more effective than those that simply focus on individual strategies. The on-road transportation GHG emission reductions across all scenarios range from 16% (TSMO) to 38% (COMBO.4) in 2030 (note that, in the baseline forecast for this study, on-road transportation GHG emissions are estimated to be 14% below the 2005 level in 2030). It should be noted, however, that the 50% reduction goal is a multisector goal for the region, with expected contributions from residential and commercial buildings, waste, aviation, and other sectors. Several of the combination scenarios provide estimated on-road GHG emission reductions at levels assumed in COG's multisector 2030 CEAP, suggesting that the multisector goal could potentially be met with these levels of on-road transportation GHG reductions if other sectors also implement aggressive strategies.

In 2050, only the most aggressive scenario with a combination of the most aggressive strategies across each pathway – COMBO.4 – provides enough emission reductions to reach the 80% reduction goal, assuming the reference grid case. Among the individual scenarios, the amplified vehicle technology and fuels improvement scenario – VT.2 – gets the closest to the 2050 goals by providing a 76% GHG emission reduction, demonstrating the importance of vehicle technology improvements. Under the VT.2 scenario, by 2050, nearly all light-duty vehicles are estimated to be EVs, and over three-quarters of all medium- and heavy-duty vehicles are EVs, resulting in a dramatic (approximately 93%) reduction in on-road tailpipe and evaporative emissions. While the reference grid case assumes a substantial increase in renewable electricity consistent with existing "on-the-books" standards, the offsetting electricity-related emissions mean that even this level of conversion to EVs is not enough to meet the goal. While the emissions benefit for every VMT reduced is much lower in 2050 than today, the most aggressive scenario for VMT reduction is also needed in combination with the technology improvements to meet the goal.

Figure ES-3. On-Road Transportation GHG Emissions Estimated for the Reference Grid Case



The Reference Grid Case is based on current "on-the-books" power sector policies in the District of Columbia, Maryland, and Virginia, and represents a reduction in carbon intensity compared to the current electric power grid.

Table ES-2 shows the full result of the analysis of each of the ten bottom-up scenarios (and the baseline scenario) performed under the different electric grid scenarios. In the case of a clean electric grid, which assumes 100% carbon free grid by 2035, the GHG emissions from the vehicle technology and fuels improvement scenarios are reduced further since there are no off-setting electricity emissions from EVs. Under these assumptions, both the VT scenarios meet the 80% reduction goal. Under the clean grid assumption, MSTB strategies have limited additional effects since most passenger vehicles are assumed to be 100% clean and TSMO enhancements generate small additional benefits for the remaining largely medium- and heavy-duty vehicles that are not EVs. Table cells with values that meet the GHG reduction goals are shaded light green.

Table ES-2. Summary of GHG Reductions Estimated for All Transportation Scenarios Under all Electric Grid Cases (% Reductions from 2005 Level)

Scenario	Key Components	2030			2050		
		Ref. Grid	Mod. Grid	Clean Grid	Ref. Grid	Mod. Grid	Clean Grid
Baseline	Projects, programs, and plans in the Visualize 2045 plan; base assumptions for vehicle technology; population growth through 2050	-14%	-15%	-15%	-14%	-14%	-15%
VT.1	50% of new LD vehicle sales are EVs in 2030, with 100% by 2040; 30% of new M/HD truck sales are EVs in 2030, with 100% by 2050; 50% of buses on the road are EVs in 2030, 100% in 2050; biofuels/renewable diesel make up 10% of diesel fuel use in 2030 and 20% in 2050	-21%	-21%	-24%	-69%	-75%	-84%
VT.2	100% of new LD vehicle sales are EVs in 2030; 50% of new M/HD truck sales are EVs in 2030, with 100% by 2040; 100% of buses on the road are EVs by 2030; biofuels/renewable diesel make up 20% of diesel fuel use in 2030 and 30% in 2050	-28%	-29%	-34%	-76%	-83%	-93%
MS.1	Land use changes, including new housing in the region; transit fares reduced 50% by 2030 and 75% in 2050; all workplace parking in activity centers priced by 2030; 10% reduction in transit travel time by 2030 and 20% by 2050; 25% telework; increased bike/ped/mobility	-20%	-20%	-20%	-21%	-21%	-22%
MS.2	MS.1 + DC core cordon pricing + VMT-fees of $0.05 per mile in 2030 and $0.10 per mile in 2050	-22%	-22%	-23%	-25%	-25%	-25%
MS.3	MS.2 with amplified strategies, including free transit; all workplace parking priced by 2050 (not just in activity centers), 15% reduction in transit travel time by 2030 and 30% by 2050; 40% telework	-26%	-26%	-26%	-27%	-28%	-28%
TSMO	Optimized ITS/TSMO, with benefits from connected/automated vehicles (CAVs) by 2050	-16%	-16%	-17%	-16%	-17%	-18%
COMBO.1	Combined scenario: VT.1+ MS.1 + TSMO	-27%	-28%	-30%	-73%	-78%	-86%
COMBO.2	Combined scenario with more aggressive technology emphasis: VT.2 + MS.1 + TSMO	-33%	-34%	-38%	-79%	-85%	-94%
COMBO.3	Combined scenario with more aggressive mode shift emphasis: VT.1 + MS.3 + TSMO	-33%	-33%	-36%	-74%	-79%	-87%
COMBO.4	Combined scenario with aggressive actions across all pathways and shared CAV future: VT.2+MS.3+TSMO+additional sharing	-38%	-39%	-43%	-82%	-87%	-95%

Implications and Policy Considerations

The scenario analysis results emphasize the difficulty of meeting the 2030 goal within the on-road transportation sector. The results, however, suggest that combining vehicle technology, MSTB, and TSMO strategies together results in the largest emissions benefits, and could achieve levels of emissions benefits that are consistent with assumptions in the 2030 CEAP at a level that would be needed to meet the overall regional goal, if other sectors contribute at levels estimated in the 2030 CEAP. The study suggests that both rapid shifts toward lower emissions vehicles/fuels and vehicle travel reduction strategies are needed to achieve the near-term goal. By 2050, shifts to EVs and a clean electric grid are expected to be the most important factors in meeting the 80% reduction goal, and MSTB strategies will be less important in meeting the goals if the vehicle fleet becomes nearly carbon-free. That said, MSTB strategies likely will play a valuable role over the intervening years and would be helpful in case the vehicle fleet does not convert to zero-emissions as quickly; MSTB strategies could also help to reduce the potential that shifting to EVs and/or connected and automated vehicles (CAVs) might encourage more vehicle travel if the cost or burden of driving is decreased.

Many of the transportation strategies explored in the scenarios have co-benefits for the region, including improving air quality, enhancing mobility, and improving the reliability and safety of the transportation system. In particular, many MSTB strategies, including land use efforts to bring jobs and housing closer together, transit enhancements, free or reduced cost transit, and bicycle/pedestrian/micromobility enhancements also offer significant potential to enhance equity by supporting more equitable access to jobs and other opportunities across racial, ethnic, and income levels. At the same time, some potentially effective MSTB strategies, such as road pricing may be regressive, unless designed appropriately to consider equity, such as by taking factors such as household income into account and using funds for transit and equity-focused services. Telework is not applicable for workers in many lower-income service industries and may have adverse impacts on businesses with low-income workers, such as restaurants and some services, particularly in downtown areas.

In moving forward, it will be important for the region's policy makers to consider the roles of regional, state, and federal government policy, as well as the private sector. Intergovernmental cooperation and working together with the private sector will likely be critical to achieving the goals, as spurring adoption of EV technology and clean energy is so vital in this process, and land use and telework policies are dependent on decisions by the private sector and employers. Policy makers will need to consider the costs, revenue implications, benefits, and equity implications of policy actions, and consider how transportation investments can best move toward GHG reduction goals while supporting the region's mobility, safety, economic, community, and other environmental goals.

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Transportation Climate Change Mitigation Scenarios Analysis

1 Introduction and Purpose

The Metropolitan Washington Council of Governments (COG) has set ambitious goals for reducing regional greenhouse gas (GHG) emissions to 50% below 2005 levels by 2030 and 80% below 2005 levels by 2050. While these are non-sector-specific regional goals, it is recognized that transportation contributes a large share of regional GHG emissions, with on-road mobile sources contributing about 34% of total regional GHG emissions in 2018, the year of the latest regional inventory.[1] Consequently, the National Capital Region Transportation Planning Board (TPB), which is the metropolitan planning organization (MPO) for the metropolitan Washington region and is one of several policy boards that meets at COG, is interested in studying ways to achieve significant reductions of on-road transportation related emissions, commensurate with the overall regional goals for GHG reduction.

The purpose of this study is to help answer the question, "What would it take to reduce on-road transportation sector GHG emissions commensurate with the region's 50% by 2030 and 80% by 2050 reduction goals?" In addition, TPB members have also expressed interest in exploring goals that go beyond 80% reduction to reflect carbon neutral goals that are being discussed and advanced within the region.[2]

Study Approach

This study involved several components:

1) **A review of previous climate change mitigation studies in the COG region** – Conducted by TPB staff, the Phase I study involved a review of studies by COG and TPB that quantified GHG reductions from regional on-road transportation projects, programs, and policies, including the "What Would it Take?" Scenario

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

[2] For instance, the 2021 Maryland Department of the Environment Greenhouse Gas Emissions Reduction Act (GGRA) committed to a statewide goal of 50% below 2005 levels by 2030 and net zero by 2045; and the District of Columbia has set a goal to reach 50% GHG emission reduction below 2006 levels by 2032, and to be carbon neutral by 2050.

Study, the Multi-Sector Working Group (MSWG) study, and the Long-Range Plan Task Force (LRPTF) study. The Phase I effort, resulting in a report[3] dated March 2, 2021, also discussed the collaborative actions proposed to reduce GHG emissions from the on-road transportation sector that were identified in the Metropolitan Washington 2030 Climate and Energy Action Plan (2030 CEAP) to support the region in achieving its 2030 GHG emission reduction goals.[4]

2) **A literature review of climate change mitigation studies and climate action plans both from within the region and across the world** – The literature review outlined a variety of potential strategies for achieving reductions of on-road transportation GHG emissions. The document reviewed climate change mitigation plans and studies conducted within the metropolitan Washington region, in other areas across the country, and around the world. The literature review also summarized research on transportation GHG strategies and their effectiveness. The literature review[5] findings provided a basis for identifying transportation GHG strategies to include in scenarios and to consider for modeling and analysis.

3) **Analysis of a set of "top-down" scenarios, exploring what would it take for the on-road transportation sector to achieve the regional goals if focusing <u>solely</u> on reducing vehicle travel reduction or vehicle technology adoption** - This analysis was designed to identify what level of vehicle miles traveled (VMT) reduction would be required to meet the goals if mode shift and travel behavior strategies were the sole focus, and what level of electric vehicle (EV) adoption would be needed to meet the goals if technology deployment were the sole focus of efforts. At the request of the TPB Technical Committee, a supplemental, top-down analysis was also conducted to explore what level of VMT reduction would be needed to meet the 50% reduction goal by 2030 using the technology strategy assumptions in the region's 2030 Climate and Energy Action Plan (2030 CEAP).

4) **Analysis of a set of "bottom-up" scenarios, exploring different combinations of strategies to assess their potential to reduce GHG emissions from on-road transportation to meet the 2030 and 2050 regional goals** – This effort involved development of a set of ten (10) scenarios for analysis, defined to include different sets of GHG reduction strategies, building on the information from the literature review on potentially promising strategies being considered as part of climate action planning efforts within the region or in other regions, as well as those identified in the research as potentially promising. The scenarios were defined to address a full array of pathways for GHG reduction from on-road

[3] "TPB Climate Change Mitigation Study of 2021 Phase 1 Report: Greenhouse Gas Emissions Reductions Strategies: Findings from Past Studies." National Capital Region Transportation Planning Board, Metropolitan Washington Council of Governments, March 2, 2021. https://www.mwcog.org/documents/2021/07/15/tpb-climate-change-mitigation-study-of-2021-climate-change-greenhouse-gas-scenario-planning/

[4] The Phase I study, and other associated documents with the Phase II effort are available on the COG website at https://www.mwcog.org/documents/2021/07/15/tpb-climate-change-mitigation-study-of-2021-climate-change-greenhouse-gas-scenario-planning/.

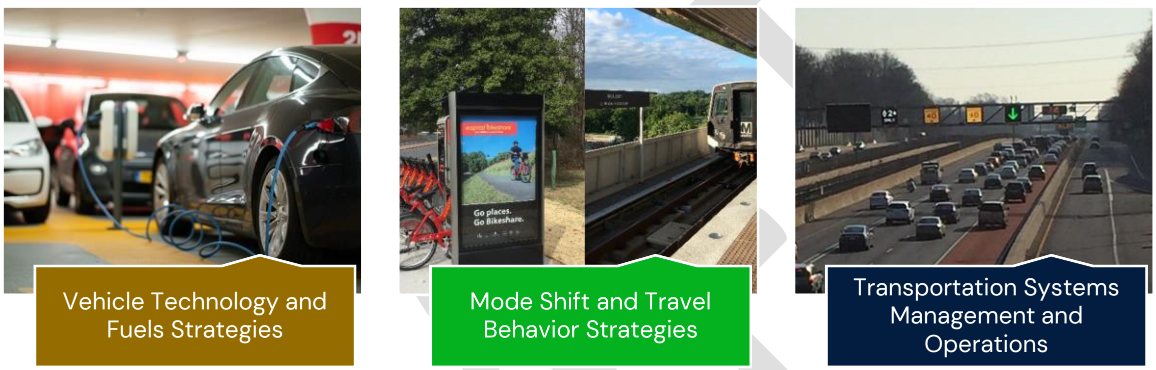
[5] ICF. "TPB Climate Change Mitigation Study of 2021: A Review of Climate Action Plans and Literature on Transportation Greenhouse Gas Emissions Reduction Strategies and their Effectiveness." National Capital Region Transportation Planning Board, Metropolitan Washington Council of Governments, July 8, 2021. https://www.mwcog.org/documents/2021/07/15/tpb-climate-change-mitigation-study-of-2021-climate-change-greenhouse-gas-scenario-planning/

transportation and represent aggressive levels of action, well beyond current plans. These scenarios were then analyzed using a wide array of sketch-planning tools and techniques, along with limited use of the region's travel demand forecasting model, and the results form the bulk of this study report.

Pathways to GHG Reduction from On-Road Transportation

The ICF team addressed the primary study questions through a scenario analysis approach relying on a set of GHG reduction strategies and implementation levels. The strategies covered three primary areas of intervention or pathways to reduce GHG emissions:

Figure 1: GHG Reduction Pathways



- **Vehicle technology (VT) and fuels strategies** seeking to reduce the carbon-intensity of vehicle travel by shifting to EVs (zero emissions from the tailpipe) and lower carbon fuels (emitting less carbon per unit of energy) and increasing the fuel efficiency of vehicles (less energy used per VMT).
- **Mode Shift and Travel Behavior (MSTB) strategies** seeking to shift travel to more efficient modes and reduce VMT, often through improving public transit, active transportation options, travel demand management programs, land use planning, and road pricing or other pricing strategies.
- **Transportation Systems Management and Operations (TSMO) strategies** seeking to reduce vehicle travel delay and/or encourage more fuel-efficient driving patterns, since GHG emissions from conventional vehicles are highest during idling and during stop-and-go congested conditions.

The strategies were analyzed both separately and in combination to provide a more realistic picture of the different solutions available to try achieving the GHG reduction targets by taking action at multiple levels. This document describes in detail the analysis approach and assumptions, illustrates the results of the analysis in terms of GHG reduction for each scenario, and provides implementation considerations inclusive of co-benefits and equity outcomes.

Electric Grid Assumptions

As transportation power sources move toward electricity, utility electricity grid emissions become increasingly important in decarbonization of the sector. This analysis modeled several electricity grid possibilities based on existing and potential state and national polices related to the electricity grid. The model was completed using

ICF's Integrated Planning Model[6], a multi-regional, dynamic, deterministic linear programming model of the U.S. electric power sector developed by ICF. It provides forecasts of least-cost capacity expansion, electricity dispatch, and emission control strategies while meeting energy demand, environmental, transmission, dispatch, and reliability constraints. IPM's grid factor projections include state-specific electricity decarbonization policies. The grid factor projections also weigh in the emission intensity of imports to the states based on each state's imports in 2019 (from EIA data). The electricity emissions factors estimated from IPM for the modeled region were used to calculate emissions associated with EV charging.

Three alternative cases are used for the electricity GHG analysis, reflecting the projected changes in grid-emission intensity over time based on decarbonization policies:

1. **A Reference Case**, which incorporates all "on-the-books" policies, including renewable portfolio standards (RPSs) in the District of Columbia, Maryland, and Virginia. These policies include those defined in Virginia's Clean Economic Act (100% clean power by 2045, assuming Dominion as the dominant utility), Maryland's Renewable Portfolio Standard (50% renewable energy by 2030) and DC's Renewable Portfolio Standard (100% renewable energy by 2032).
2. **A Modified Reference Case**, which is slightly more aggressive than the Reference Case, resulting in a near zero carbon grid by 2040 based on enhanced clean energy policies in Maryland that more closely match those from DC and Virginia.
3. **A Clean Grid Case**, assuming a 100% carbon free grid by 2035.

Table below provides a summary of the estimated GHG emissions factors per unit of electricity use (Megawatt-Hours) under each of the three cases in comparison to 2018.

Table 1. Estimating Electric Power Generation Emissions Factors under Alternative Grid Assumptions (MT CO2e/MWh)

Grid Case	2018	2030	2050
Reference Case	0.337	0.249	0.137
Modified Reference Case	–	0.224	0.082
Clean Grid Case	–	0.050	0.000

It is important to note that the Reference Case assumes considerable reductions in in the carbon intensity of electricity compared to current electric grid conditions, not simply holding emissions rates constant. This case is somewhat similar to the assumptions in COG's Climate and Energy Action Plan's Clean Energy case, by incorporating and counting all "on the books" RPS policies. These values may differ slightly since IPM accounts for imports from out of state and the 2030 CEAP also included two policies which are difficult to account for:

[6] https://www.icf.com/technology/ipm

Distributed generation (> 200,000 additional solar systems, equivalent to 24 percent of single-family homes), and green power purchases (continued 10 percent annual growth).

Baseline Forecast Scenario

What's Included in the Scenario

The baseline scenario includes the most recent COG VMT and emissions projections[7] through 2045. To calculate 2050 VMT and emissions, the 2045 passenger VMT projections were extrapolated to 2050 based on the population growth rate between 2040 and 2045 as reported in the TPB Round 9.1a Cooperative Forecast[8], and assumed continued trends of reduced VMT per capita. VMT from Light-Duty Commercial Trucks, Heavy-Duty Trucks, and Combination Trucks was assumed to continue increasing at the same annual rate as the period between 2030 and 2045. Between 2045 and 2050, this represents a total increase in VMT for these categories of 2.7%, 3.4%, and 3.5%, respectively. Then, the emissions rates of ICE vehicles from 2045 were assumed to be held constant in 2050 to obtain tailpipe emissions for 2050 from extrapolated 2050 VMT. On top of tailpipe emissions, the NREL[9] reference case of EV penetration of VMT was multiplied by the reference electric grid case emission rates and assumed vehicle energy use per mile to obtain electricity emissions from energy required to power EVs. The Baseline estimates are a sum of the tailpipe emissions plus electricity emissions for the reference case penetration of EVs. No EVs were assumed to be in the fleet in 2005. The baseline total emissions are shown in Figure 2 and Table 2.

[7] 2005, 2018 and 2030 VMT and emissions projections are based on the Round 9.1 Cooperative Forecasts, MOVES2014b, and the Regional Travel Demand Model Version 2.3.75. 2045 VMT and emissions projections, developed upon completion of the 2030 CEAP, are based on MOVES2014b, as well as the Round 9.1a Cooperative Forecasts and the Regional Travel Demand Model Version 2.3.78, which do not differ substantially from the assumptions and tools that were used in development of estimates for 2005, 2018, and 2030.

[8] https://www.mwcog.org/documents/2021/12/02/cooperative-forecasts-employment-population-and-household-forecasts-by-transportation-analysis-zone-cooperative-forecast-demographics-housing-population/

[9] NREL. (2018). Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States

Figure 2. Baseline On-Road GHG Emissions (MTCO2e)

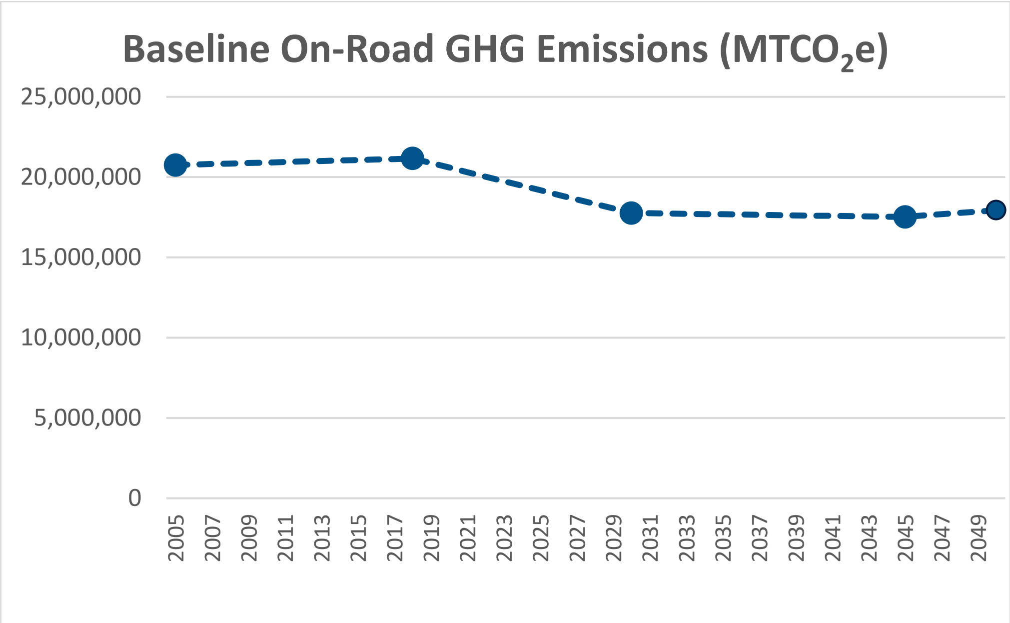


Table 2. Baseline GHG emissions

GHG Emissions (MMT CO2e)	2005	2018	2030	2045	2050
Baseline Emissions (tailpipe)	20.75	21.12	17.53	17.31	17.72
Baseline Emissions (electricity)	0	0.04	0.24	0.21	0.21
Total Baseline Emissions	**20.75**	**21.16**	**17.77**	**17.52**	**17.93**

Note: Electricity usage increases in the baseline forecast but the electricity grid gets cleaner in the reference case forecast.

It is important to note that the baseline emissions totals show lower total emissions in 2030 and 2050 compared to 2018, approximately 14% lower in both cases. This is because projected improvements in fuel economy, leading to decreased emissions, offset increases in VMT. Fuel economy improvements in MOVES 2014[10] reflect standards[11] for cars and light trucks beginning with model year 2017 and standards[12] for heavy duty GHG Phase 1 emissions beginning with model years 2014. Note that these decreases are estimated, despite

[10] https://www.epa.gov/moves/what-does-moves-assume-future-year-fleet-fuel-efficiency

[11] USEPA (2012). 2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards (77 FR No. 199, October 15, 2012)

[12] USEPA (2011). Greenhouse Gas Emission Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles (76 FR 57106, September 15, 2011)

projected population growth in the region. The GHG emissions associated with generating electricity to support EV usage is zero in 2005 because essentially there were no EVs in the vehicle fleet in 2005.

2 What Would it Take to Achieve the Regional Goals within the On-Road Transportation Sector? ("Top Down" Analysis)

In response to questions about what it would take to meet the regional GHG reduction goals within the on-road transportation sector, the study team conducted a "top-down" analysis to identify what would be required to achieve the 2030 and 2050 GHG reduction goals through two of the three pathways previously described - VMT reduction alone and vehicle technology/fuel changes alone. This effort explored three key questions posed by the TPB:

1) What level of VMT reduction would be needed to meet the regional 2030 and 2050 goals if VMT reduction were the sole focus of efforts?
2) What level of electric vehicle (EV) adoption would be needed to meet the regional 2030 and 2050 goals if vehicle technology were the sole focus of efforts?
3) What level of VMT reduction would be needed to meet the regional 2030 goal assuming vehicle technology assumptions in the Climate and Energy Action Plan (2030 CEAP)?

This "top-down" analysis was not intended to identify how such levels of reductions could be achieved or how feasible such outcomes would be, but simply to identify what level of change would be needed in terms of VMT and/or EV adoption to meet the goals. Based on a request from the TPB Technical Committee, the research team also conducted an analysis of VMT reduction that would be needed to meet the regional 2030 goal using vehicle technology assumptions in the 2030 CEAP. The TSMO pathway was not analyzed as a stand-alone strategy as part of the "top-down" analysis since the literature review suggested that the levels of GHG reduction required to meet the region's aggressive 2030 and 2050 goals would not be possible through TSMO strategies alone.

The analysis relied primarily on simple assumptions about vehicle travel and emissions rates under the baseline forecast for 2030 and 2050 (this baseline forecast is described in the Executive Summary and in Section 1), and mathematically calculated the level of VMT or EV adoption that would be needed, holding other factors constant (note that the baseline forecast assumes reductions in VMT per capita associated with the region's Long-Range Transportation Plan, *Visualize 2045*, as well as some improvements in vehicle technology). The analysis was conducted focusing on both direct tailpipe and evaporative emissions from motor vehicles (often described as "mobile source" emissions) and upstream emissions associated with electricity use for EVs, which makes this study different from the performance analysis conducted on Visualize 2045.[13]

[13] The goal level for transportation emissions was calculated based on the 2005 inventory estimate of 20.75 million metric tons of carbon dioxide equivalent (MMT CO_2 Eq.) emissions from on-road sources, yielding a 2030 goal of 10.38 MMT CO_2 Eq. (50% reduction) and a 2050 goal level of 4.15 MMT CO_2 Eq. (80% reduction). Rail emissions, including those from diesel trains (commuter rail, freight) and electricity used for transit, have been estimated but were not accounted for in calculating the goal level of emissions, given further work needed to forecast future rail activity and transit rail electricity consumption for 2030 and 2050. These emissions are approximately 1% of the on-road emissions in 2005.

VMT Reduction Alone

To explore what level of VMT reduction would be needed, the research team assumed that the emissions profile of the vehicle fleet for each category of vehicles would stay the same as under the baseline forecast. It was assumed that VMT reduction would occur for passenger travel (in passenger cars and light-duty trucks, which include sport utility vehicles, minivans, and pickup trucks), but not among buses or medium- and heavy-duty vehicles such as commercial trucks, freight trucks, or garbage trucks. Most MSTB strategies focus on passenger travel by encouraging shifts from driving alone to transit, ridesharing, bicycling, or walking, or by reducing trip-making through telework and other substitutes for travel.

The analysis suggests that achieving the 50% and 80% GHG reduction goals compared to 2005 levels solely through VMT reduction would require the following:

- In 2030, **passenger VMT would need to be reduced by 57% from the 2018 level.** Total passenger travel in light-duty vehicles (including passenger cars, light-duty trucks, and motorcycles),[14] would need to be held to no more than 16.27 billion vehicle miles annually in 2030, down from an estimated 38.11 billion vehicle miles in 2018. Given that the region's population is forecast to grow from about 5.57 million in 2018 to 6.25 million in 2030 and VMT otherwise is expected to increase, this equates to a 61% reduction in passenger VMT compared to the forecast levels in 2030 (forecast to be 42.23 billion VMT in 2030). Passenger VMT per capita would need to drop from an average of 18.74 vehicle miles daily in 2018 to 7.13 vehicle miles daily in 2030 – a 62% reduction (compared to a forecast level of 18.52 vehicle miles daily in 2030).
- In 2050, it is **not possible to get to the 80% reduction goal through passenger VMT reduction alone**. Even if all passenger VMT were eliminated, emissions from medium- and heavy-duty vehicles, including light-commercial trucks, freight/refuse trucks, and buses, are estimated to exceed the 2050 goal level of emissions of 4.15 million metric tons by 2.24 million metric tons.[15] Because these vehicles perform essential commercial functions, VMT reduction from public and commercial vehicles are not generally expected to occur, and MSTB strategies generally focus on shifting people from driving to transit, ridesharing, walking, bicycling, and other modes, rather than reducing travel from freight/commercial trucks and buses.

Figure 3 shows that while VMT per capita is forecast to decline in the region under existing plans, the level of reduction in passenger VMT per capita needed to meet the goal through VMT reduction alone would be extremely large. Figure 4 shows the total passenger VMT reduction required in the region to meet the 2030 and 2050 goals. These figures illustrate that it is not possible to meet the 2050 goal through passenger VMT reduction alone.

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[14] These figures do not include VMT by light commercial trucks, medium- and heavy-duty trucks (such as those used in freight, refuse collection, and construction), or buses. Note that passenger travel in this analysis includes all travel in light-duty passenger vehicles, including those used by households and for business purposes.

[15] The 2050 figures were calculated using the 2045 forecasts of VMT and on-road emissions from the region's Visualize 2045 plan and extrapolated to 2050, with no further improvement in emissions rates.

Figure 3. Daily Passenger VMT per Capita Required to Meet GHG Goals through VMT Reduction Alone[16]

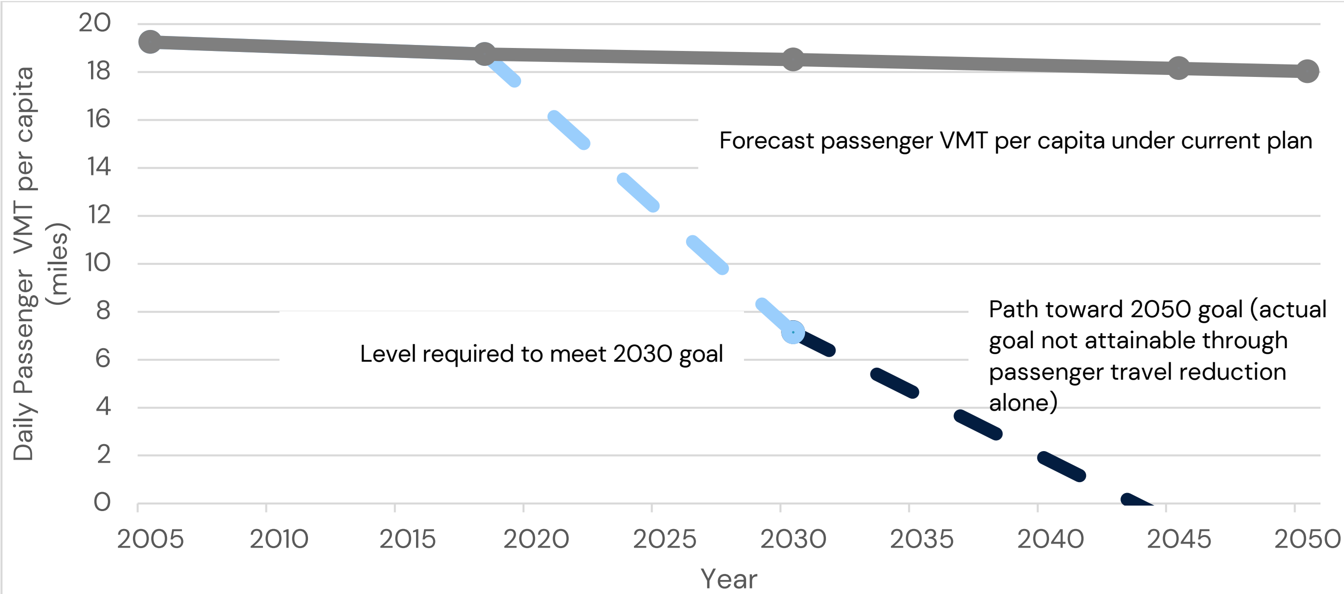
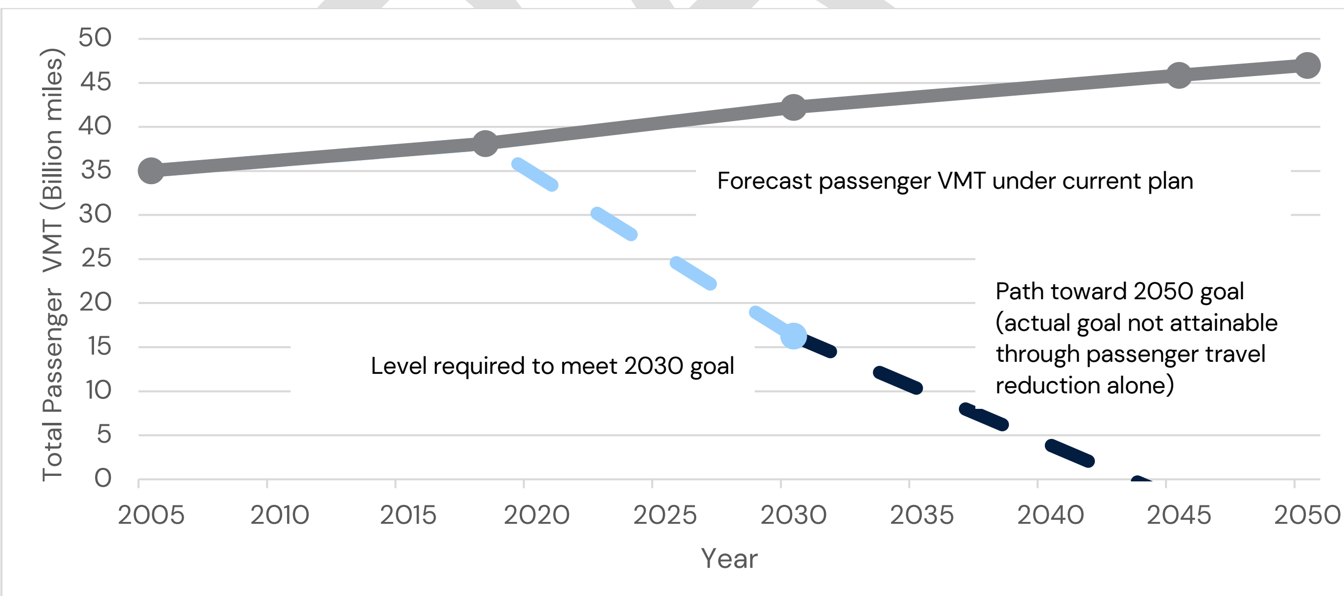


Figure 4. Annual Total Passenger VMT Required to Meet GHG Goals through VMT Reduction Alone



[16] Baseline passenger VMT per capita was calculated based on COG population and VMT projections for passenger cars and passenger trucks. Required per capita VMT was calculated by solving for the passenger VMT level needed to achieve the 50% emissions reduction by 2030 and 80% emissions reduction by 2050 using average passenger vehicle emissions rates in the target year. This VMT was then divided by the projected COG population in the target year.

These results suggest that it would be extremely challenging, if not unrealistic, to meet the 2030 goal with VMT reduction strategies without further vehicle technology improvements. Particularly for 2030, just nine years away, the levels of VMT reduction needed (if that pathway alone were pursued) to achieve the goal would require unprecedented levels of reduction in driving – slightly larger reductions than seen at the peak of pandemic stay-at-home orders in April 2020, when all schools and many businesses were closed or employees told to stay home, and regional traffic volume dropped by about 50% temporarily (by July 2020, while most schools and businesses continued to be on-line/remote-only, traffic volumes had recovered to about 80% of pre-pandemic levels).[17] Sustained traffic reductions at such a level would likely require very high levels of pricing (parking pricing, road pricing, and/or fuel pricing), near complete telework for eligible workers, and/or restrictions on driving. Moreover, the reduction in VMT would need to be occurring over a time when the region's population is forecast to increase by 12% (between 2018 and 2030).

As a point of comparison, California metropolitan planning organizations (MPOs) have VMT reduction goals with targets generally ranging from a 13% to 19% reduction in VMT per capita by 2035 relative to 2005,[18] and these MPOs have faced challenges demonstrating how such levels of reductions in VMT per capita could be met. Also note that these are VMT per capita targets for California MPOs, and regional levels of VMT for large MPOs are forecast to increase due to population growth even if the VMT per capita targets are met.

Vehicle Technology Alone

Based on an analysis of vehicle stock and GHG emissions, the research team estimated what level of EVs (or other forms of ZEVs such as fuel cells) in the fleet would be necessary to achieve the 50% and 80% GHG reduction goals solely through technology adoption, without any changes in forecast VMT. This analysis used very simplified assumptions (such as assuming proportionate EV adoption across vehicle classes) and no other improvements in low-carbon fuels. Fuel economy improvements for internal combustion engine (ICE) vehicles from the baseline forecast were preserved. The simplified analysis suggests that the following would be required, with results shown in Figure 5 for the reference electricity emissions case (which assumes some improvements in carbon intensity from electricity generation) and Figure 6 for the clean grid electricity emissions case (which assumes a path to net zero emissions from electricity generation by 2035).[19] Assumptions for the Reference Case and Clean Grid Case are described further in Section1.

- In 2030, the **average emissions rate of all vehicles** (across light-, medium-, and heavy-duty vehicle classes) **would need to be reduced by 56% compared to the 2018 level**, while in the baseline forecast,

[17] Canan, Tim. "Transportation Impacts of the COVID-19 Pandemic in the National Capital Region." Presented at the January meeting of the National Capital Region Transportation Planning Board, held at the Metropolitan Washington Council of Governments, January 21, 2021. https://www.mwcog.org/events/2021/1/21/transportation-planning-board/.

[18] California Air Resources Board. "SB 375 Regional Plan Climate Targets."2021 https://ww2.arb.ca.gov/our-work/programs/sustainable-communities-program/regional-plan-targets.

[19] This calculation involved estimating the percent of VMT that would be needed from EVs in 2030 and 2050, calculated using estimated net emissions benefits of switching to EVs for each vehicle type weighted by the estimated VMT distribution.

emissions rates are expected to decline by about 25% over this time period (reflecting policies[20] expected to improve the average fuel economy of the fleet, including increased EV adoption in the baseline forecast). These figures essentially mean that average vehicle fuel economy of vehicles on the road must more than double between 2018 and 2030. To get to these levels, only considering direct mobile source emissions (not accounting for emissions from electricity consumption), approximately 44% of vehicles on the road would need to be EVs in 2030 (compared to 2018 levels of less than 1%), assuming proportionate reductions across vehicle classes (passenger cars and trucks, buses, medium- and heavy-duty trucks, etc.) and no other improvements in low-carbon fuels or vehicle fuel economy in the rest of the fleet.[21] When accounting for emissions from electricity used to charge electric vehicles, achieving a 50% overall reduction in GHG emissions compared to 2005 levels would require **approximately 75% of the vehicles on the road to be EVs** in 2030,[22] based on ICF's assumed Reference Case for carbon intensity of electricity, which assumes improvements in electricity carbon intensity based on current on-the-books policies. The share of vehicles that need to be EVs would be lower with an even cleaner electric grid. In the Clean Grid Case, achieving a 50% overall reduction in GHG emissions compared to 2005 levels would require approximately 48% of the vehicles on the road to be EVs in 2030.[23] ICF's assumptions for the Reference Case and Clean Grid Case are described in Section1.

- In 2050, the **average emissions rate of all vehicles** (across light-, medium-, and heavy-duty vehicle classes) **would need to be reduced by 84% compared to the 2018 level,** while in the baseline forecast, emissions rates are expected to be reduced by about 32% over this time period (as the most significant benefits of existing fuel economy standards have largely already been achieved well before 2050). When accounting for emissions from electricity generation, **achieving the 2050 goal level would not be attainable, based on ICF's assumed Reference Case electricity emissions factors** for the region.[24] In the Clean Grid Case, achieving an 80% reduction in GHG emissions compared to 2005 levels would require approximately 79% of the vehicles on the road to be EVs in 2050.

[20] Emissions rates were derived from MOVES2014b outputs for 2005, 2018, and 2030 from the 2030 CEAP, for 2045 from the 2020 Amendment to Visualize 2045, and for 2050, the same 2045 emissions rates were assumed for internal combustion engine vehicles. These reflect the 2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards promulgated in 2012, rather than the Safer Affordable Fuel Efficient (SAFE) Vehicles Final Rule for Model Years 2021-2026, promulgated in 2020 and currently under review and consideration for replacement with more stringent standards.

[21] If only focusing on passenger cars and trucks, about 64% of passenger cars and trucks on the road would need to be EVs, assuming other classes of vehicles follow the baseline forecast, if only accounting for tailpipe emissions.

[22] For purpose of this analysis and the figures reported, we assume that the average mileage driven is similar for EVs and internal combustion engine vehicles. These calculations assume proportional EV deployment across all vehicle types for simplicity of presentation. The bottom-up scenarios explored different assumptions regarding the shares of EVs across different types of vehicles (passenger cars and trucks, buses, medium- and heavy-duty trucks, etc.).

[23] Note that VMT is forecast to increase between 2005 and 2030, while emissions rates from internal combustion engine vehicles are anticipated to decline over this period due to improvements in vehicle fuel economy; this clean grid case does not assume an entirely zero emissions electric grid by 2030 but by 2035.

[24] Assumptions are similar to those for 2030.

Figure 5. Forecast VMT by Technology Type Required to Meet GHG Goals through Shifts to EVs Alone, Reference Case for Electricity Carbon Intensity

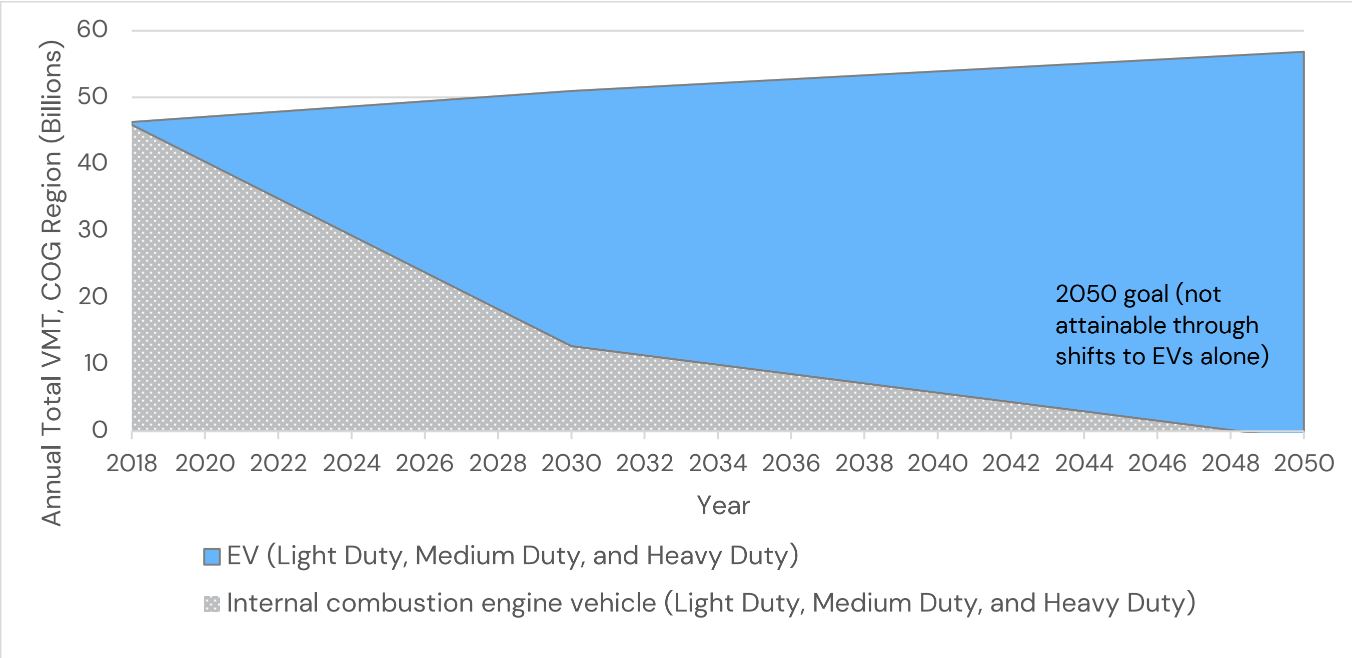
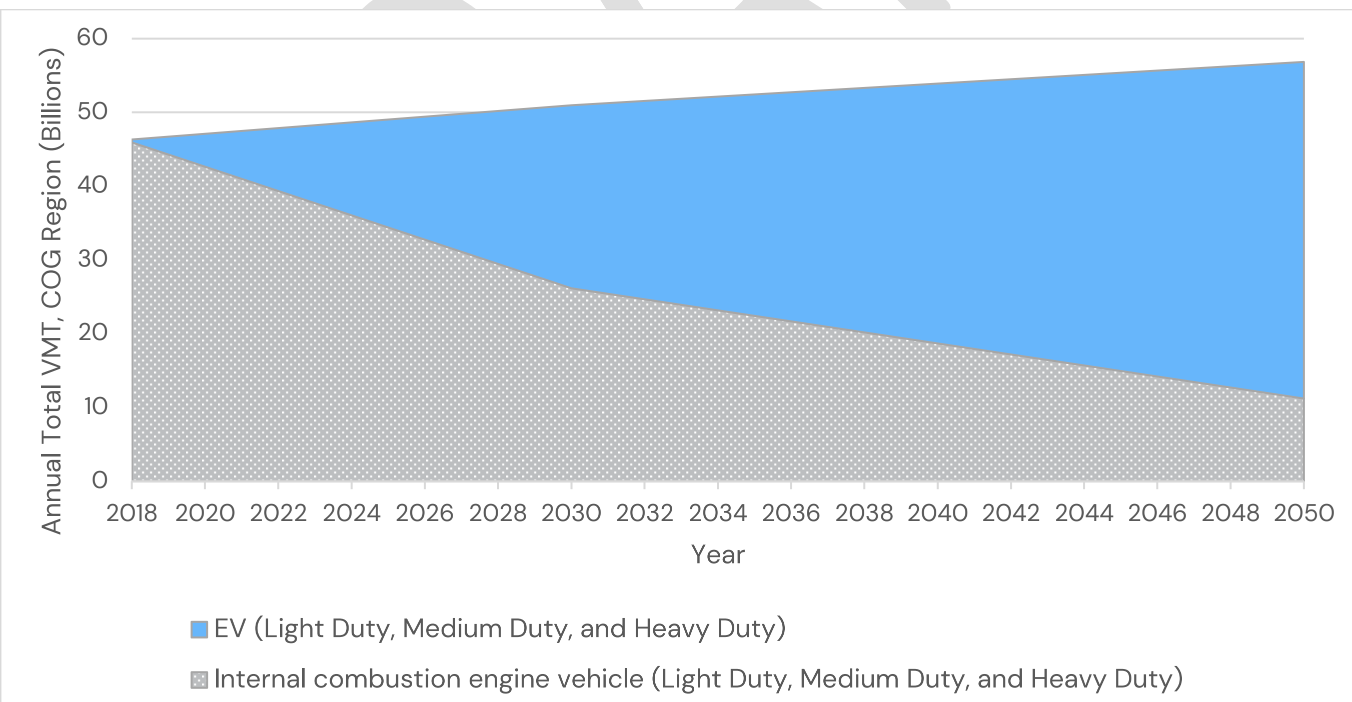


Figure 6. Forecast VMT by Technology Type Required to Meet GHG Goals through Shifts to EVs Alone, Clean Grid Case



Similar to the difficulty associated with VMT reduction needed by 2030, achieving the dramatic changes in the vehicle fleet by 2030 needed to achieve the 2030 GHG goal through shifts to EVs alone appears extremely challenging. The baseline forecast assumes that EVs would make up approximately 6% of VMT in 2030, so increasing that share to 75% is a dramatic change in the fleet. This level of fleet change would be very difficult to achieve by 2030 with the typical timeframes that vehicles are held and rate of turn-over in the fleet. Such an outcome would likely require nearly immediate shifts to having all new vehicles sold as EVs, combined with aggressive consumer incentives including buy-back programs for vehicles to accelerate the rate at which consumers opt for new vehicles, rapid deployment of EV-infrastructure, full public sector fleet conversions to EVs, and/or increases in carbon or fuel pricing to help spur demand. The literature review suggested that even under aggressive scenarios where EV sales ramp up to 100% of new passenger vehicles sold in 2030, EVs may still make up just about a quarter of all vehicles on the road, given the large number of conventional vehicles that would remain in the fleet.

Given the additional twenty years to meet the 80% reduction goal by 2050, it appears that a full-scale shift to EVs could potentially enable attainment of the goal to be met through vehicle technology changes (without new VMT reduction efforts) with assumptions for a clean power grid, through nearly universal shifts to EVs across most classes of vehicles. However, there are risks to meeting the goal with such an approach if the fleet does not turn-over as quickly as anticipated. Moreover, during the transition time period to EVs, reducing vehicle travel through strategies that enhance transit and other non-auto travel options is typically viewed as a "no regrets" approach that can yield multiple benefits. Importantly, given the cumulative nature of GHG emissions in the atmosphere, the level of emissions over the intervening time between now and 2050 is an important consideration, and MSTB strategies can play an important role in reducing emissions over the time period when the fleet is transitioning to EVs and the power grid is decarbonizing.

VMT Reduction under the 2030 CEAP Technology Assumptions

Following the initial analysis, the TPB requested to understand what level of VMT reduction would be required to meet the region's 2030 goal under the vehicle fleet technology assumptions used in the region's 2030 CEAP. Using the NREL[25] High Scenario EV penetration for the vehicle fleet and the Reference Case electric grid assumptions, which are similar to the improvements in the electric grid included in the 2030 CEAP, to meet the 50% emissions reduction goal in 2030 in on-road transportation sources, it is estimated that **passenger VMT would need to be reduced by 49% from the 2018 level**. Total passenger travel in light-duty vehicles, would need to be held to no more than 19.62 billion vehicle miles annually in 2030, down from an estimated 38.11 billion vehicle miles in 2018, as shown in Figure 7. Given that the region's population is forecast to grow by about 12% from 2018 to 2030, and VMT otherwise is expected to increase, this equates to a 54% reduction in passenger VMT compared to the forecast levels in 2030. Passenger VMT per capita would need to drop from an average of

[25] NREL. (2018). Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States

18.74 vehicle miles daily in 2018 to 9.6 vehicle miles daily in 2030 (compared to a forecast level of 18.52 vehicle miles daily in 2030), as shown in Figure 8.

Figure 7. Annual Total Passenger VMT Required to Meet GHG Goals, assuming 2030 CEAP EV Conversion and ICF Reference Electricity Emissions

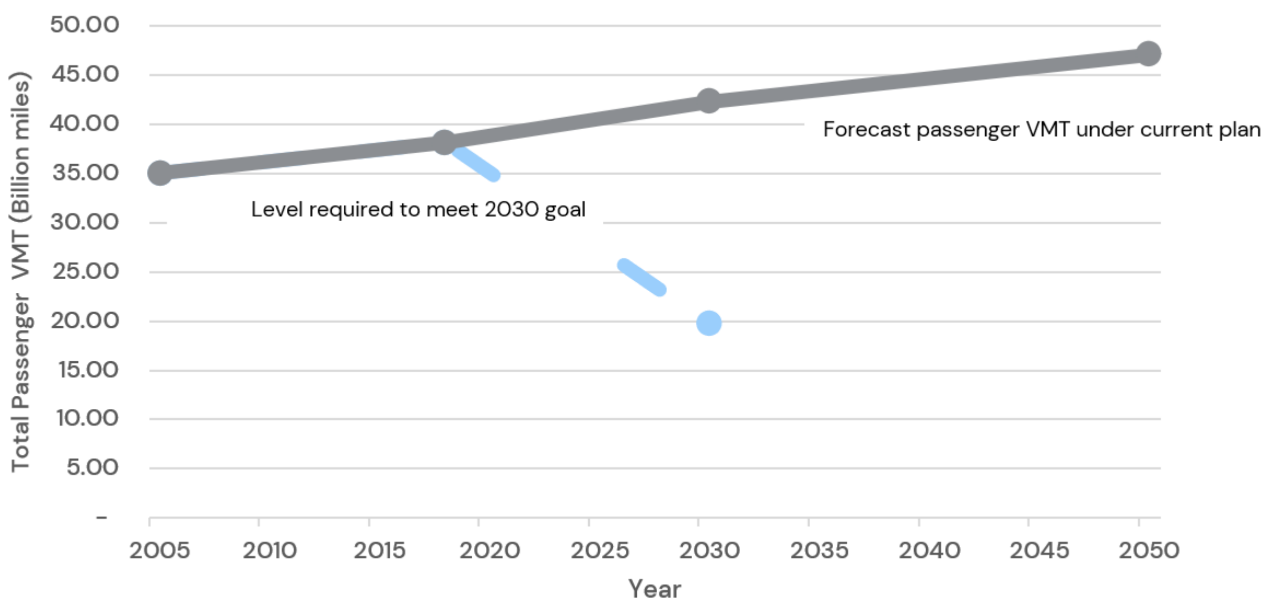
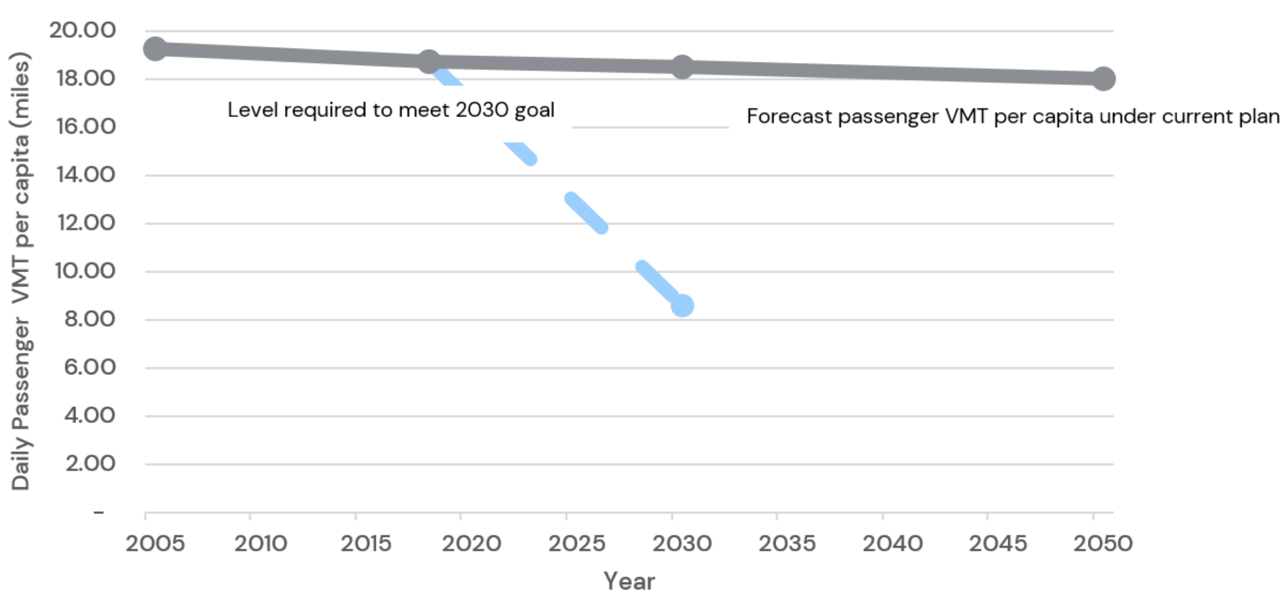


Figure 8. Daily Passenger VMT per Capita Required to Meet GHG Goals, Assuming 2030 CEAP EV Conversation and ICF Reference Electricity Emissions



Implications

The simple top-down analysis of what it would take to reach the 2030 or 2050 goals highlights how challenging it would be to reach the goals set, particularly for 2030, through either VMT reduction alone or shifts to EVs alone, and also highlights the overall challenge of meeting the goals even with technology assumptions in the 2030 CEAP. The small number of years between today and 2030 means there is very limited time to achieve the large shifts in fleet technology or VMT that would be required to meet the goal for 2030. However, by 2050, there is more time for the fleet to turn-over and for EVs to be brought into the fleet.

3 Scenario Development and Analysis Approach ("Bottom-Up" Analysis)

Following the "top-down" scenario analysis that helped to inform what it would take to reach the 2030 and 2050 goals through VMT reduction and EV adoption strategies, the study focused on developing and analyzing a set of ten "bottom-up" scenarios that include a variety of strategies and implementation levels across the three carbon reduction pathways. The purpose of this scenario analysis was to estimate the GHG reductions that might be achieved through implementation of different strategies, and combinations of strategies, to reach the goal of reducing on-road, transportation sector GHG emissions 50% by 2030 and 80% by 2050, compared to the 2005 level or emissions.

Development of Scenarios

The ten scenarios were defined with a focus on including promising strategies across each of the three primary carbon reduction pathways for on-road transportation sources – vehicle technology and fuels strategies, mode shift and travel behavior (MSTB) strategies, and transportation systems management and operations (TSMO) strategies – as well as including combinations of strategies across these pathways. To attempt to meet the goals, aggressive assumptions were selected regarding implementation of strategies and high-end estimates of potential for shifts of vehicle sales for EVs, telework adoption, transit enhancements, TSMO deployment, and other strategies over the timeframe through 2050. These assumptions generally went beyond assumptions used in prior regional studies, such as the "What Would it Take?" Scenario Study, the Multi-Sector Working Group study, and the Long-Range Plan Task Force study and were developed taking into consideration the strategies in the region's 2030 CEAP. Moreover, the literature review conducted for this study provided a basis for identifying GHG strategies to include in scenarios and to consider for modeling and analysis, based on research on potentially promising GHG reduction strategies.

Specifically, vehicle technologies and fuels strategies were defined by taking into consideration existing policies and goals including:

- President Biden's goals to have 50% of new passenger vehicle sales to be EV by 2030.
- The California Air Resources Board (CARB) Zero-Emission Vehicle (ZEV) Program, adopted by Maryland and Virginia, which requires auto manufacturers to deliver a minimum percentage of passenger cars and light-duty trucks as ZEVs each year.
- The California Advanced Truck Rule Memorandum of Understanding (MOU), signed by 15 states including Maryland and the District of Columbia, which aims at making at least 30% of all new medium- and heavy-duty sales to be zero-emission by 2030.

- Incentives, such as Maryland's excise tax credit for EVs and plug-in hybrids and rebates on the cost of electric vehicle supply equipment; and the District of Columbia's tax exemption for EVs and high efficiency vehicles, as well as a tax credit for alternate fuel infrastructure.[26]
- The multi-state Transportation and Climate Initiative (TCI), which proposed a regional cap-and-invest program (TCI-P) that would set a decreasing cap for transportation emissions in the region and generate proceeds to advance clean transportation.[27]

For the MSTB and TSMO strategies, the team explored existing plans in the region, as well as national and international research on potentially effective investments and strategies related to land use, transit, bicycling and walking, telework, and other approaches, and considered possible future changes due to deployment of connected and automated vehicle (CAV) technologies.

Different scenarios with varying implementation levels of the strategies listed above were created under each pathway, both with aggressive and even more aggressive (or "amplified") strategy assumptions. Input from the TPB and its Technical Committee was used to refine the strategy assumptions for the scenarios.

In total, the analysis was performed on ten distinct scenarios, six focused on individual pathways (two vehicle technology and fuels focused [denoted as VT.1 and VT.2], three MSTB focused scenarios [denoted as MS.1, MS.2, and MS.3 below], and one TSMO scenario) and four combinations of the above scenarios. The combination scenarios were created in such a way to give equal weight to the moderate VT and MS scenarios (VT.1 + MS.1 + TSMO, or COMBO.1) or to emphasize either the vehicle technology (VT.2 + MS.1 + TSMO in COMBO.2) or the mode shift (VT.1 + MS.3 + TSMO in COMBO.3). A fourth combination scenario (COMBO.4) merged the most aggressive actions from all pathways and added assumptions for adoption of Connected and Automated Vehicles (CAVs).

Each scenario was analyzed to estimate GHG impacts in 2030 and 2050 under three different future electric grid scenarios, described further below. Table provides a summary of all scenarios considered under each of the three primary pathways, plus the combination scenarios.

[26] The Virginia EV Incentive Working Group has finalized a Feasibility Report in November 2020 that also highlights the need for Virginia to put in place strong incentives for clean vehicle technologies.

[27] Three states (Connecticut, Rhode Island, and Massachusetts) and the District of Columbia signed the Memorandum of Understanding to participate in TCI-P in December 2020. As of the time of the publication of this report, the District is the only remaining signatory to TCI-P, which requires at least three signatories to begin the program. There has been no announcement from TCI on the future of TCI-P or other initiatives that make take its place.

Table 3. Ten Scenarios Studied in "Bottom-Up" Analysis

Pathway	Scenario	Key Components / Assumptions
Vehicle Technology (VT) and Fuels	VT.1: Vehicle Technology and Fuels Improvement Scenario	Shifts to EVs (50% of new light-duty [LD] vehicle sales are EVs in 2030, with 100% by 2040; 30% of new medium/heavy-duty [M/HD] truck sales are EVs in 2030, with 100% by 2050; 50% of buses on the road are EVs in 2030, 100% in 2050; biodiesel/renewable diesel makes up 10% of diesel fuel use in 2030 and 20% in 2050)
	VT.2: Amplified Vehicle Technology and Fuels Improvement Scenario	More aggressive shifts to EVs: 100% of new LD vehicle sales are EVs in 2030; 50% of new M/HD truck sales are EVs in 2030, with 100% by 2040; 100% of buses on the road are EVs by 2030; biodiesel/renewable diesel makes up 20% of diesel fuel use in 2030 and 30% in 2050
Mode Shift and Travel Behavior (MSBT)	MS.1: Mode Shift Scenario	Land use changes focused on redistribution of future growth to activity centers and areas better served by transit across jurisdictions and 77,000 new households in the region by 2030 and 126,000 new households in the region by 2050 to support jobs-housing balance; enhanced bike/pedestrian/micromobility environment; transit fares reduced 50% by 2030 and 75% in 2050; all workplace parking in activity centers priced by 2030; transit enhancements (10% reduction in transit travel time by 2030 and 20% by 2050); 25% telework
	MS.2: Mode Shift Scenario + Road Pricing	Same strategies as MS.1, plus DC cordon pricing of $10 to enter downtown, and VMT-fees of $0.05 per mile in 2030 and $0.10 per mile in 2050
	MS.3: Amplified Mode Shift Scenario + Road Pricing	MS.2 with amplified strategies, including free transit; all workplace parking priced by 2050 (not just in activity centers), further transit enhancements (15% reduction in transit travel time by 2030 and 30% by 2050); 40% telework[28]
Transportation Systems Management & Operations (TSMO)	TSMO: Operations Improvement Scenario	Optimized operations through intelligent transportation systems (ITS) including ramp metering, incident management, active signal control, and active transportation demand management; assumed operational benefits from connected/automated vehicles (CAVs) in 2050
Combined Pathways	COMBO.1: Combined Scenario	VT.1 + MS.1 + TSMO
	COMBO.2: Combined Scenario with More Aggressive Technology Emphasis	VT.2 + MS.1 + TSMO
	COMBO.3: Combined Scenario with More Aggressive Mode Shift Emphasis	VT.1 + MS.3 + TSMO
	COMBO.4: Combined Scenario with Aggressive Actions Across All Pathways and Shared CAV Future	VT.2 + MS.3 + TSMO + shared CAV assumptions

[28] Since only 50% of jobs in the metropolitan Washington region are telework capable, 40% telework implies that 80% of employees who work in telework-capable jobs would be teleworking on a typical workday, which is a very aggressive assumption.

Analysis Approach

In selecting an analysis approach, the team evaluated several approaches and modeling tools to choose the best ones that could feasibly support the scenario analysis of different types of transportation strategies and vehicle GHG emission reductions. The team selected to use several analysis methods and tools whose outputs were integrated as depicted in Figure 9. A list of the primary tools and methods is provided below:

- The Argonne National Laboratory's VISION[29] model was used to estimate the market shares of alternative technologies (e.g., EVs) and fuels (e.g., renewable diesel and biofuels) across vehicle classes covering light-, medium-, and heavy-duty vehicle technologies. The market penetration of EVs and other flex fuels overtime was obtained using the new vehicle sale percentages defined by the ICF team for each VT scenario as inputs, compared in relation to a baseline forecast using the Energy Information Administration's (EIA's) Annual Energy Outlook projections ending in the year 2050. **The modeling performed with VISION provided fleet-level estimates of VMT for different vehicle classes across sectors.**
- The regional travel demand forecasting model was used to analyze land use changes as part of the MSTB scenarios. The ICF team used the COG/TPB Travel Demand Forecasting Model, Version 2.3.78 (March 18, 2020),[30] which has been previously used as part of the region's long-range transportation planning for the regional air quality conformity analysis of the 2020 Amendment to the Visualize 2045 Long-Range Transportation Plan. **The regional travel demand forecasting model produced VMT estimates for the land use strategies and provided other outputs (e.g., mode shares) used as inputs to sketch planning approaches used for other MSTB strategies.**
- The TRIMMS[31] (Trip Reduction Impacts of Mobility Management Strategies) sketch planning tool was chosen to estimate the impact of MSTB strategies that affect the cost of travel (VMT-fees, cordon pricing, parking pricing, transit pricing) and transit service enhancements. TRIMMS can handle interactions among multiple policy measures and levels of strategies, and it has been utilized in prior analysis for COG's Multisector Work Group (MSWG) and has been applied extensively in metropolitan areas around the country for analysis of transportation GHG reduction strategies. **The TRIMMS analysis provided VMT estimates for each of the modeled strategies, which were used to calculate GHG emissions.**

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[29] "VISION Model: Argonne National Laboratory." VISION Model. Argonne National Laboratory. Accessed August 23, 2021. https://www.anl.gov/es/vision-model.

[30] Ray Ngo, Feng Xie, and Mark S. Moran, "User's Guide for the COG/TPB Travel Demand Forecasting Model, Version 2.3.78" (Washington, D.C.: Metropolitan Washington Council of Governments, National Capital Region Transportation Planning Board, April 14, 2020), https://www.mwcog.org/transportation/data-and-tools/modeling/model-documentation/.

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

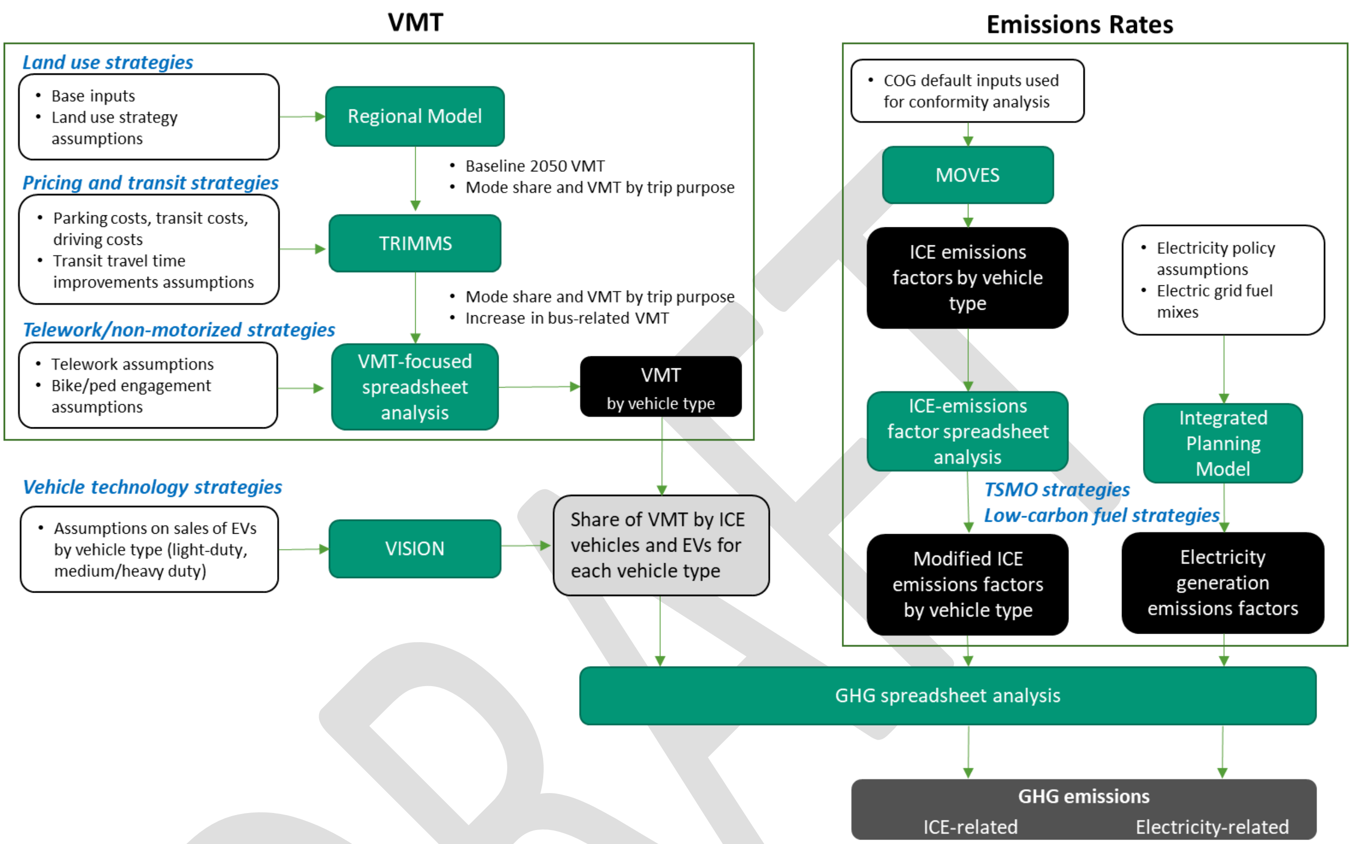
- Sketch planning and spreadsheet analysis was used to model the impacts of biofuels (under the VT scenarios) telework and bicycle/pedestrian/micromobility strategies (under the MS scenarios), and TSMO strategies such as extensive Intelligent Transportation Systems (ITS)/incident management deployment to optimize traffic flow and increased connected/automated vehicles (CAVs) in 2050. The analyses were based on literature findings regarding potential effects of these strategies. For instance, the effects of TSMO strategy deployment were based on previous simulation studies estimating the impacts of TSMO strategies and ecodriving on GHG emissions profiles for vehicles. Projections of CAV penetration based on early modeling by the Department of Energy were included in the 2050 results for the TSMO strategies. **The sketch modeling of various strategies produced estimations of changes in emissions factors and/or VMT, which were used to calculate GHG emissions estimates.**
- ICF's Integrated Planning Model (IPM) was used to calculate GHG emissions associated with electricity use for EV charging. IPM is a multi-regional, dynamic, deterministic linear programming model of the U.S. electric power sector developed by ICF. IPM allows forecasting future electric grid emissions rates based on energy demand as well as environmental, transmission, dispatch, and reliability constraints, and it was set up to incorporate region-specific electricity decarbonization policies such as the Virginia's Clean Economic Act (100% clean power by 2045), Maryland's Renewable Portfolio Standard (50% renewable energy by 2030) and the District of Columbia's Renewable Portfolio Standard (100% renewable energy by 2032). **The analysis performed with IPM provided grid emission factors that were applied to calculate EV-related GHG emissions.**

The VMT numbers resulting from these analyses were then collected into a master spreadsheet for conversion to GHG emissions (in MT of CO2 equivalent or CO2e) using vehicle and fuel specific fuel economy values, provided in the form of emission factors (EF, in g CO2/mile) for Internal Combustion Engines (ICE) vehicles and kilowatt-hours per mile (kWh/mi) for EVs. The EF values for conventional ICE fuels were obtained from the EPA's MOVES[32] (Motor Vehicle Emission Simulator) outputs, to remain consistent with baseline data used in COGs 2030 Climate and Energy Action Plan. The MOVES outputs provided by COG to ICF were generated using MOVES 2014b, the version that had been used for the Visualize 2045 plan (2018) and 2030 CEAP to remain consistent with previous analyses. The Argonne National Laboratory Alternative Fuel Life-cycle Environmental and Economic Transportation (AFLEET) Tool provided fuel economy values for most EV types; ICF supplemented values when needed for EVs and biofuels using industry data. All EV fuel economy values were then converted into EF values in g CO_2e/mile before being combined with electricity EF values from IPM to determine the GHG emissions associated with EV charging.

[32] The latest version of the MOVES model, MOVES3, was released in March 2021, and it includes updated data on vehicle populations, travel activity, and emission rates as well as updated fuel supply information at the county level. It also incorporates the impacts of the Heavy-Duty Greenhouse Gas Phase 2 rule and the Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule. "MOVES and Other Mobile Source Emissions Models." EPA. Environmental Protection Agency. Accessed August 23, 2021. https://www.epa.gov/moves.

The supplemental **Technical Appendix** describes in detail the analysis of the baseline forecast and steps for all scenarios (VT, MSTB, and TSMO). The Technical Appendix also includes the assumptions as well as the input parameters that were chosen when setting up the modeling tools used in the study.

Figure 9. Overview of Analysis Tools and Methods Used in the Study



The analyses for all scenarios involved analyses of individual vehicle classes (e.g., passenger vehicles, commercial vehicles, buses, etc.), reflecting different levels of VMT and emissions rates, and changes for each, as applicable. It should be noted that while the analysis provides a strong basis for estimating the GHG emissions effects of each of the scenarios, the analysis does not account for many indirect effects of strategies. For instance, the analysis did not explicitly account for improvements in vehicle fuel economy associated with MSTB strategies that are expected to yield significant improvements in traffic congestion and did not estimate potential induced vehicle travel demand from shifts to EVs, which may reduce the cost of driving, as it was assumed implicitly that additional revenue generation mechanisms would be applied for these vehicles.

Vehicle Technologies (VT) and Fuel Improvement Scenarios

The VT scenarios (VT.1 and VT.2) included interventions that improve the fuel economy of conventional vehicles, a shift to fuels with a lower carbon content (e.g., biodiesel, renewable diesel), and replacing internal combustion engine vehicles with EVs, thus eliminating tailpipe emissions. In this analysis, EVs included both battery electric vehicles, BEVs, and plug-in hybrid vehicles, PHEV.

The analysis for the VT scenarios relied on the combination of the VISION model and sketch modeling. The VISION model was used to estimate the fleet penetration (or share of VMT) by different vehicle technologies and alternative fuels in 2030 and 2050 based on vehicles sale assumptions. After determining the VMT share of each vehicle and fuel type, GHG emission reductions (in MT CO2e) were calculated for years 2030 and 2050 as the difference, in comparison with the baseline forecast. Calculations were performed with and without including the GHG emissions from electricity generation for EV charging, to extract the GHG reduction resulting from eliminating tailpipe emissions. For biofuels, ICF relied on a report to the Oregon Department of Environmental Quality rulemaking process of the Clean Fuels Program[33] to extract reasonable percentage market shares of biodiesel and renewable diesel fuel by 2030 for defining the share of biodiesel/renewable diesel in the fleet. Average lifecycle emissions factors (g CO_2e per mile) for diesel, biodiesel (B20), and renewable diesel were estimated for light-duty commercial trucks, medium-duty trucks, and heavy-duty trucks using standard fuel energy density assumptions and pathway carbon intensity assumptions released by CARB.[34] The CO_2e savings per mile between lifecycle carbon emissions factors of conventional diesel and renewable or biodiesel was then used as an emissions “credit” to account for reduced upstream emissions associated with these fuels.

Mode Shift and Travel Behavior (MSTB) Scenarios

The MSTB scenarios (MS.1, MS.2, and MS.3) included interventions focused on shifting travel activity to modes that reduce VMT, primarily by reducing single-occupant vehicle (SOV) use. These typically include land use policies, increases in public transit use, ridesharing, bicycling, walking, and telework, as well as road and parking pricing schemes that discourages private vehicles use. The MSTB interventions modeled for this study included land use strategies, transit enhancements, pricing schemes for parking and roads, as well as transit price changes, telework, and non-motorized micromobility.

To perform these calculations, ICF used baseline forecasts of VMT from COG’s outputs of Visualize 2045; the baseline value for 2030 was taken as is, while the forecast for 2050 had to be extrapolated using the regional travel demand forecasting model, since the out-year for Visualize 2045 was 2045. Similarly, the team modeled the incremental land use change between year 2045 and 2050 to create a baseline before applying the land-use strategies intended to reduce GHG emissions. The land use changes were modeled with the regional travel model and consisted of shifting population growth to activity centers and high-capacity transit (HCT) areas while adding new households to the region, using an approach similar to the analysis used for the Long-Range Plan Task Force. Pricing strategies involved changes in the price of vehicle travel (e.g., parking pricing and road pricing) and were incorporate along with changes in the cost of transit to assess potential synergistic effects. The analysis was performed by fine tuning model parameters to three different subareas (D.C. core, other activity centers, areas outside of activity centers) and two types of trips (work and non-work trips) to tailor the various MSTB strategies to different travel markets with unique trip characteristics and mode shares. Telework was assumed to reduce travel across all modes within the region including transit, bicycle, and walking trips

[33] https://www.oregon.gov/deq/rulemaking/Documents/cfp2021icf.pdf

[34] Average carbon intensities from LCFS certified pathways, 2019. https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities

proportionately to their mode share prior to the telework assumptions being added but assumed an increase in non-work trips for each teleworker and a small overall adjustment of VMT to reflect a rebound toward driving associated with significant improvements in travel speeds on the roadway network anticipated from large-scale reductions in peak-period driving. The effects of non-motorized micromobility strategies were estimated based on present uptake levels in Arlington, Virginia[35] of shared mobility devices applied across the region in 2030. This uptake level was doubled for 2050.

Transportation Systems Management and Operations (TSMO) Scenario

The Transportation Systems Management and Operations (TSMO) scenario assumed Intelligent Transportation Systems (ITS)/incident management deployment and increased Connected and Automated Vehicles (CAVs) adoption. CAVs offer the potential to improve traffic flows and enhance fuel economy through vehicle-to-vehicle and vehicle-to-infrastructure communications. An example of CAV application that is readily available is truck platooning, e.g., a platoon of two or more connected trucks traveling at the same speed and accelerating and braking together. However, for light-duty passenger vehicles, the impacts on CAVs have primarily been studied using model simulations of driving behaviors and small-scale proof of concept testing.

For the TSMO scenario analysis, ICF applied GHG emissions rate improvements to a portion of VMT through enhanced Intelligent Transportation Systems (ITS)/incident management and ecodriving using literature from simulation studies showing estimated effects of ITS and eco driving on vehicle emissions profiles, after accounting for potential increases in VMT. To model the effects of CAV, it was assumed that broad implementation of CAVs across all vehicle classes (light-, medium-, and heavy-duty) in 2050 yields fuel economy benefits similar to ecodriving.[36]

Combined Strategies

The scenarios COMBO.1, COMBO.2, COMBO.3, and COMBO.4 were created by coupling the VT, MS, and TSMO scenarios to explore the synergistic effects of combined pathways to reduce GHG emissions. The combined scenarios are particularly useful because they provide a realistic approach to what COG might be implementing to achieve the region's decarbonization goals, given that no single pathway can deliver the necessary GHG emission reductions. Furthermore, having a variety of transportation decarbonization options relying on a mix of vehicle technologies and travel demand management can better meet the diverse needs of the region's populations. Thus, the combined approaches offer a preview of what a decarbonized transportation future might look like in the COG jurisdictions.

For the analyses of combined strategies, the scenarios were layered to account for changes in VMT from the MSTB strategies (MS scenarios) combined with changes in vehicle emissions factors from the vehicle technology

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

[36] CDM Smith. "CAV Traffic Simulation Literature Review." Ohio Department of Transportation, November 9, 2019. https://transportation.ohio.gov/static/Programs/StatewidePlanning/Modeling-Forecasting/CAVTrafficSimulationLitReview.pdf

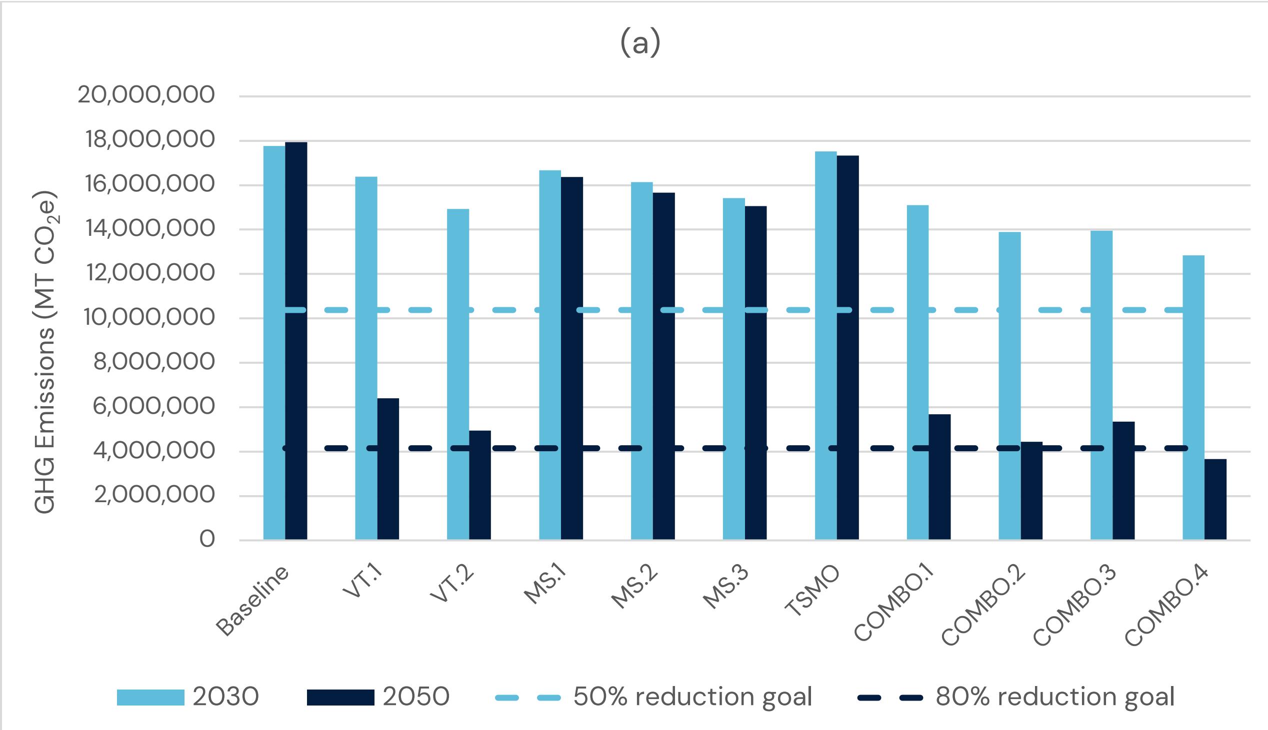
and fuels strategies (VT scenarios), and by changes in vehicle operations (TSMO scenario) for internal combustion engine vehicles. For the COMBO.4 scenario, ICF assumed additional shared use of CAVs by adjusting downward VMT based on assumptions about the penetration and uptake of shared and connected vehicles and shifting a portion of single-occupant vehicle (SOV) travel to shared modes.

4 Scenario Analysis Findings

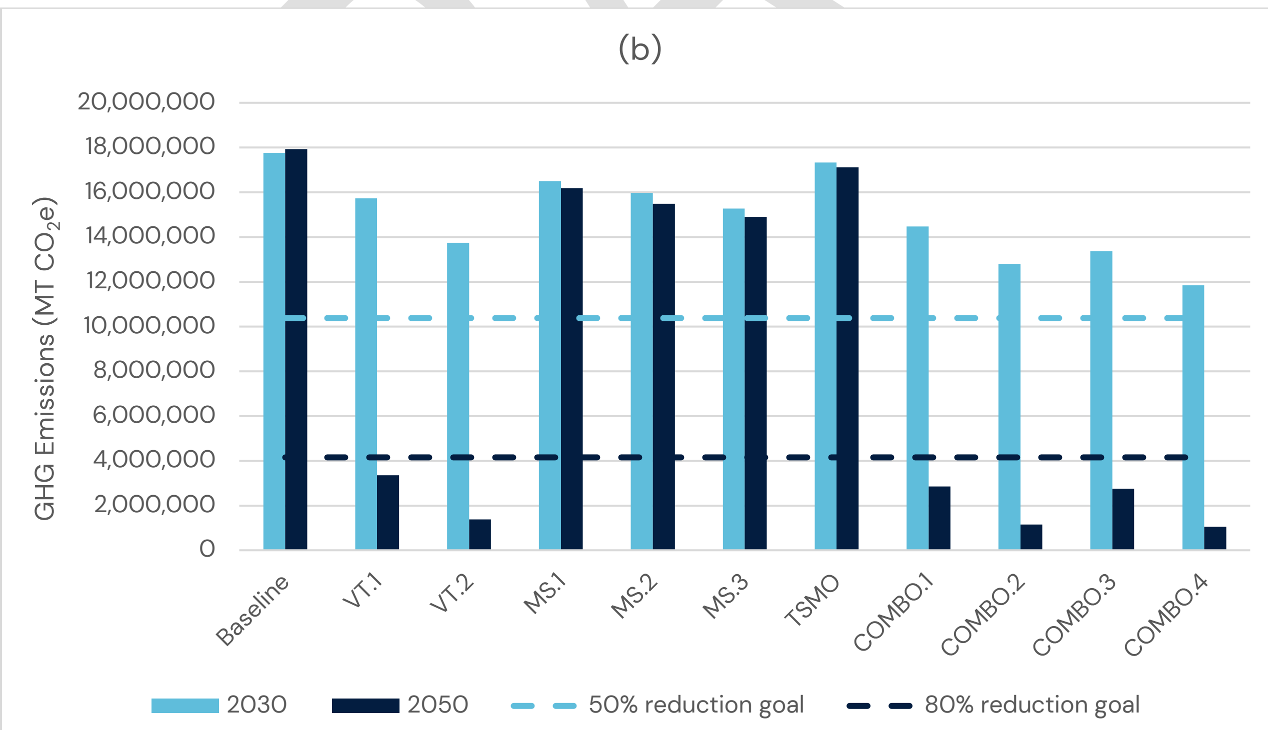
Overall Summary

The results of the scenario analysis conducted under the Reference Electric Grid Case are shown in Figure 10a. The results of the scenario analysis conducted under the Clean Electric Grid Case are shown in Figure 10b. As expected, the COMBO scenarios are more effective than the individual ones simulated in this study; however, none of the simulated scenarios meet the 2030 goals set by COG for reducing GHG emissions to 50% below 2005 levels (see Figure 10a and Figure 10b). The GHG emission reduction across all scenarios range from 14% (TSMO) to 38% (COMBO.4) in 2030, suggesting that several aggressive strategies need to be implemented simultaneously to achieve the 2030 goals. However, the analysis also shows that individual scenario VT.2 could provide the same GHG emission reductions as the COMBO.1 by 2030 (28% and 27%, respectively), providing COG with two different implementation pathways to reach a similar target. In 2050, two scenarios – COMBO.2 and COMBO.4 – can, under the Reference Electric Grid Case (Figure 10a), provide COG with the needed GHG emission reductions to reach their goal of 80% GHG reduction below 2005 levels. Among the individual scenarios, VT.2 gets the closest to the 2050 goals by providing a 76% GHG emission reduction. Overall, these results suggest that, in 2050, the effectiveness of the COMBO scenarios is mostly driven by the GHG emission reductions achieved under the individual VT scenarios, while small gains in GHG emission reductions are observed in the MS scenarios from 2030 to 2050. The MS scenarios depend exclusively upon reductions in VMT to realize GHG emissions reductions. Despite aggressive policy assumptions, the MS scenarios do not encourage, under the Reference Electric Grid Case (Figure 10a), enough VMT reduction to meet the 50% or 80% reduction thresholds.

Figure 10. (a) GHG Emissions Estimated for the Transportation Scenarios for the Reference Grid Case (b) GHG Emissions Estimates for the Transportation Scenarios for the Clean Grid Case.



Note: The Reference Grid Case is based on current power sector policies in the District of Columbia, Maryland, and Virginia.



Note: The Clean Grid Case assumes a 100% carbon-free grid by 2035.

Table 4 shows the full result of the simulations performed under the different electric grid scenarios. In a clean grid, which assumes 100% carbon free grid by 2035, the GHG emissions from the VT scenarios are further reduced by an additional 10-15%, improving the effectiveness of strategies relying on vehicle technology and alternative fuels. Note that in the absence of any actions beyond current plans, GHG emissions are forecast to decrease by about 14% in 2030 and by a similar level in 2050 compared to 2005 levels. Table cells are shaded green when the GHG reduction goals (50% in 2030 and 80% in 2050) are attained. Table cells are shaded yellow in cases where the GHG reduction goals were not obtained, but the level of reduction in GHG emissions was high enough that they met the assumed levels needed in the 2030 CEAP to attain the 2030 goal of 50% reduction in GHG emissions across all sectors combined (e.g., transportation, energy production, buildings).

Table 5 demonstrates the same results expressed as **percent reductions from the baseline** level of emissions expected for that year. In this way, the impacts of the scenarios are isolated from existing assumptions about marginal improvements in fuel economy and regional land use.

Table 4. Summary of GHG Reductions Estimated for All Transportation Scenarios Under all Electric Grid Cases (% Reductions from 2005 Level)

Scenario	Key Components	2030			2050		
		Ref. Grid	Mod. Grid	Clean Grid	Ref. Grid	Mod. Grid	Clean Grid
Baseline	Projects, programs, and plans in the Visualize 2045 plan; base assumptions for vehicle technology; population growth through 2050	-14%	-15%	-15%	-14%	-14%	-15%
VT.1	50% of new LD vehicle sales are EVs in 2030, with 100% by 2040; 30% of new M/HD truck sales are EVs in 2030, with 100% by 2050; 50% of buses on the road are EVs in 2030, 100% in 2050; biofuels/renewable diesel make up 10% of diesel fuel use in 2030 and 20% in 2050	-21%	-21%	-24%	-69%	-75%	-84%
VT.2	100% of new LD vehicle sales are EVs in 2030; 50% of new M/HD truck sales are EVs in 2030, with 100% by 2040; 100% of buses on the road are EVs by 2030; biofuels/renewable diesel make up 20% of diesel fuel use in 2030 and 30% in 2050	-28%	-29%	-34%	-76%	-83%	-93%
MS.1	Land use changes, including new housing in the region; transit fares reduced 50% by 2030 and 75% in 2050; all workplace parking in activity centers priced by 2030; 10% reduction in transit travel time by 2030 and 20% by 2050; 25% telework; increased bike/ped/mobility; reduction in vehicle trips to school	-20%	-20%	-20%	-21%	-21%	-22%
MS.2	MS.1 + DC core cordon pricing + VMT-fees of $0.05 per mile in 2030 and $0.10 per mile in 2050	-22%	-22%	-23%	-25%	-25%	-25%
MS.3	MS.2 with amplified strategies, including free transit; all workplace parking priced by 2050 (not just in activity centers), 15% reduction in transit travel time by 2030 and 30% by 2050; 40% telework	-26%	-26%	-26%	-27%	-28%	-28%
TSMO	Optimized ITS/TSMO, with benefits from connected/automated vehicles (CAVs) by 2050	-16%	-16%	-17%	-16%	-17%	-18%
COMBO.1	Combined scenario: VT.1+ MS.1 + TSMO	-27%	-28%	-30%	-73%	-78%	-86%
COMBO.2	Combined scenario with more aggressive technology emphasis: VT.2 + MS.1 + TSMO	-33%	-34%	-38%	-79%	-85%	-94%
COMBO.3	Combined scenario with more aggressive mode shift emphasis: VT.1 + MS.3 + TSMO	-33%	-33%	-36%	-74%	-79%	-87%
COMBO.4	Combined scenario with aggressive actions across all pathways and shared CAV future: VT.2+MS.3+TSMO+additional sharing	-38%	-39%	-43%	-82%	-87%	-95%

Table 5: Summary of GHG Reductions Estimated for All Transportation Scenarios Under all Electric Grid Cases (% Reductions from Baseline Level)

Scenario	Key Components	2030			2050		
		Ref. Grid	Mod. Grid	Clean Grid	Ref. Grid	Mod. Grid	Clean Grid
VT.1	50% of new LD vehicle sales are EVs in 2030, with 100% by 2040; 30% of new M/HD truck sales are EVs in 2030, with 100% by 2050; 50% of buses on the road are EVs in 2030, 100% in 2050; biofuels/renewable diesel make up 10% of diesel fuel use in 2030 and 20% in 2050	-8%	-8%	-11%	-64%	-71%	-81%
VT.2	100% of new LD vehicle sales are EVs in 2030; 50% of new M/HD truck sales are EVs in 2030, with 100% by 2040; 100% of buses on the road are EVs by 2030; biofuels/renewable diesel make up 20% of diesel fuel use in 2030 and 30% in 2050	-16%	-17%	-23%	-72%	-81%	-92%
MS.1	Land use changes, including new housing in the region; transit fares reduced 50% by 2030 and 75% in 2050; all workplace parking in activity centers priced by 2030; 10% reduction in transit travel time by 2030 and 20% by 2050; 25% telework; increased bike/ped/micromobility	-6%	-6%	-7%	-9%	-9%	-10%
MS.2	MS.1 + DC core cordon pricing + VMT-fees of $0.05 per mile in 2030 and $0.10 per mile in 2050 (analyzed for passenger vehicles)	-9%	-9%	-10%	-13%	-13%	-14%
MS.3	MS.2 with amplified strategies, including free transit; all workplace parking priced by 2050 (not just in activity centers), 15% reduction in transit travel time by 2030 and 30% by 2050; 40% telework	-13%	-13%	-14%	-16%	-16%	-17%
TSMO	Optimized ITS/TSMO, with benefits from connected/automated vehicles (CAVs) by 2050	-1%	-2%	-2%	-3%	-4%	-5%
COMBO.1	Combined scenario: VT.1+ MS.1 + TSMO	-15%	-15%	-19%	-68%	-75%	-84%
COMBO.2	Combined scenario with more aggressive technology emphasis: VT.2 + MS.1 + TSMO	-22%	-23%	-28%	-75%	-83%	-94%
COMBO.3	Combined scenario with more aggressive mode shift emphasis: VT.1 + MS.3 + TSMO	-21%	-22%	-25%	-70%	-76%	-85%
COMBO.4	Combined scenario with aggressive actions across all pathways and shared CAV future: VT.2+MS.3+TSMO+additional sharing in 2050	-28%	-28%	-33%	-80%	-85%	-94%

Scenario VT.1: Vehicle Technology and Fuels Scenario

What's Included in the Scenario

The Vehicle Technology and Fuels Improvement Scenario (VT.1) assumed the following:

- **50% of new light-duty passenger car and truck sales are EVs in 2030, ramping up to 100% of new vehicle sales by 2040**: These projections are consistent with President Biden's national goal for new vehicle sales by 2030.[37] Growth in EV sales is assumed to increase linearly over time between asserted sales ratios; however, EV fleet penetration is not linear and depends on the cumulative sales over time.
- **30% of new medium and heavy-duty truck sales are EVs in 2030, ramping up to 100% of new truck sales by 2050**: These projections are consistent with the multi-state Memorandum of Understanding (MOU) [38] signed by Maryland and the District of Columbia committing to achieve at least 30% of all new medium- and heavy-duty vehicle sales to be zero-emission vehicles by 2030, and 100% by 2050 (with sale rates adjusted for different vehicle classes).
- **50% of school and transit buses are EVs in 2030, and 100% are EVs in 2050**: These projections are consistent with a Washington Metropolitan Area Transit Authority (WMATA) plan to move to a fully zero-emission bus fleet by 2045,[39] and with goals set by Montgomery County to transition 300 school buses to electric in the next three years and plans to electrify all 1,422 buses in their fleet by 2035.[40] This scenario assumes that it will take beyond 2030 to get to complete replacement of the bus fleet and deploy the needed EV charging infrastructure.
- **A modest reduction in the carbon intensity of diesel, due to increased use of biodiesel and renewable diesel:** For the VT. 1 scenario, it was assumed that biofuels and renewable diesel would represent 10% of the residual conventional diesel fuel in 2030, and 20% in 2050.

Resulting Fleet Changes

The vehicle sale percentages defined in the VT.1 scenario were incorporated into the VISION model to estimate shares of VMT by vehicle type (e.g., passenger cars, light-duty trucks, etc.) and fuels (including internal combustion engine [ICE], battery electric vehicle [BEV], and plug-in electric vehicles [PHEVs]). Table 6 shows the PHEV and BEV fleet penetration estimates in 2030 and 2050 under the VT.1 scenario. For each vehicle class, the

[37] Ewing, Jack, "President Biden sets a goal of 50 percent electric vehicle sales by 2030." *The New York Times*. August 5, 2021. https://www.nytimes.com/2021/08/05/business/biden-electric-vehicles.html

[38] NESCAUM, "Multi-State Medium and Heavy-Duty Zero Emission Vehicle Memorandum of Understanding." Note that these goals include buses, which are addressed separately here.

[39] WMATA, Zero-Emission Bus Update, website.

[40] Steven Mufson and Kaplan, "Montgomery County School Board Seals Deal to Get 300 of the Buses," *The Washington Post*, February 24, 2021, sec. Climate Solutions, https://www.washingtonpost.com/climate-solutions/2021/02/24/climate-solutions-electric-schoolbuses/.

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residual non-EV fleet (e.g., 74% of passenger vehicles in 2030) is represented by conventional ICE vehicles, diesel or gasoline depending on vehicle type.

Table 6. Percentages of PHEV and BEV by Vehicle Type in 2030 and 2050 in the VT.1 Scenario

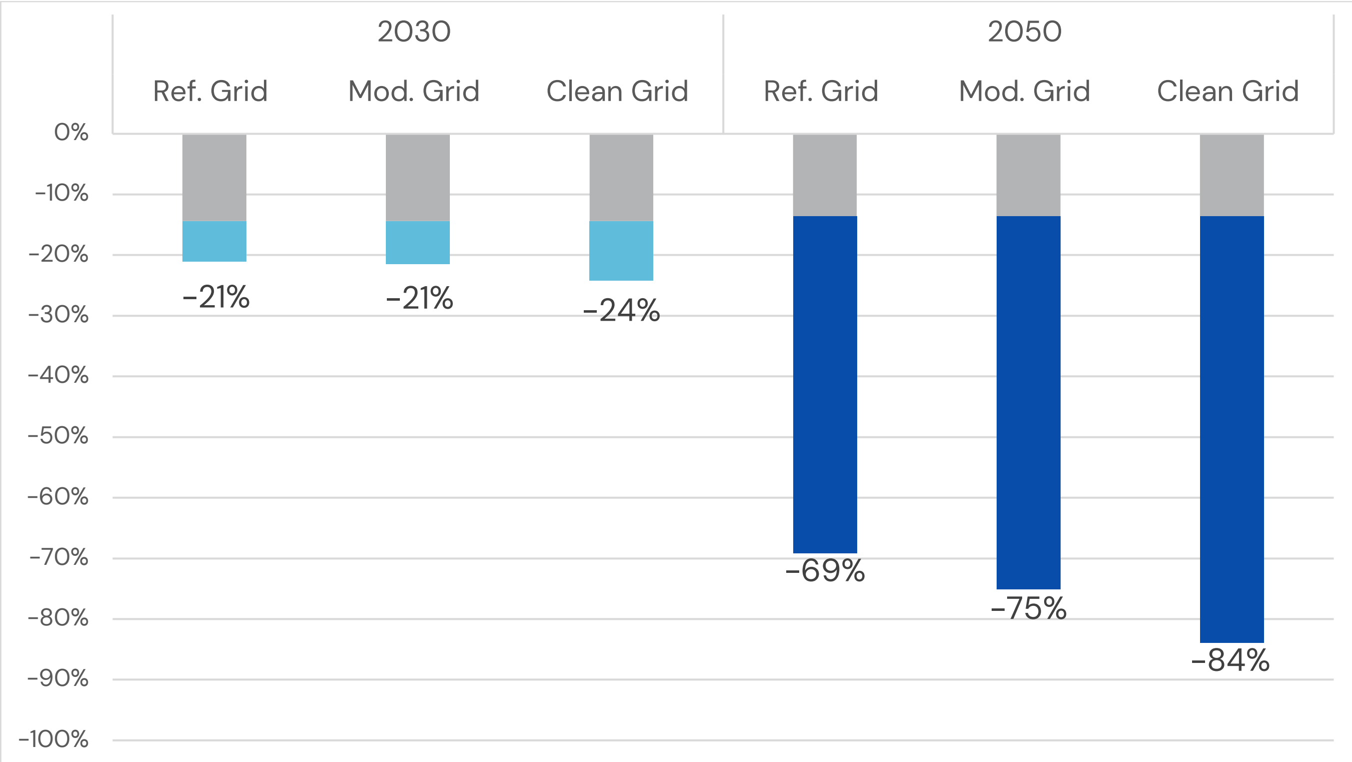
Vehicle Type	2030		2050	
	PHEV	BEV	PHEV	BEV
Light duty Passenger Vehicles	8%	18%	3%	93%
Light duty Passenger Trucks	3%	6%	1%	90%
Medium duty trucks	4%	6%	1%	65%
Heavy duty trucks	0%	3%	0%	47%
Buses	0%	50%	0%	100%

Compared to the 2030 CEAP study, the VT.1 EV fleet penetration percentages in 2030 are slightly lower than the 2030 CEAP High scenario for passenger cars and trucks (the 2030 CEAP High scenario forecasts that 34% of passenger cars and 17% of passenger trucks are EVs in 2030,) and for heavy trucks (the 2030 CEAP High scenario projects that 6% heavy trucks are EVs in 2030). However, the VT.1 scenario assumptions result in higher EV penetration for buses and medium-duty trucks than under the 2030 CEAP (the 2030 CEAP High scenario projects 34% electric transit buses and 7% medium-duty electric trucks in 2030).

GHG Emission Reductions

Figure 11 shows the results of the GHG emission reductions performed for the three different grid scenarios (Reference Case, Modified Reference Case, and Clean Grid Case). The grey bars represent the Baseline Forecast where in absence of any actions beyond current plans, GHG emissions are forecast to decrease by about 14% from the 2005 level in both 2030 and 2050. In the Reference Case, the shift to EVs and biofuels generate sizeable reductions in GHG emissions from motor vehicles in 2030 (about a 21% reduction from the 2005 level) and a very large reduction in 2050 (about a 69% reduction from the 2005 level). With an increasingly cleaner grid, however, the actions taken under the VT.1 scenario yield increasingly larger GHG reductions, going from 21% to 24% in 2030, and from 69% to 84% in 2050. The larger increment in GHG reduction in 2050 compared to what can be obtained in 2030 from the Clean Grid Case is explained by the fact that by 2050, a large share of ICE vehicles has been eliminated and most of the residual GHG emissions come from EV charging. Therefore, changes in the power grid have a large effect on net GHG emissions.

Figure 11. On-Road Transportation GHG Emission Reductions under Scenario VT.1 Compared to 2005



Note: The grey portion of the bars indicate GHG emissions reductions occurring in the baseline forecast.

Table 7 summarizes the GHG emission (in MMT CO2e) estimated for 2030 and 2050 from the implementation of the VT.1 scenario under the three different grid cases. The total GHG emission values are the sum of the tailpipe-only and EV-charging related emissions under each grid scenario. While in 2030 EV charging contributes only a small fraction of the total GHG emissions, in 2050 it represents almost 50% of the residual GHG emissions under the Reference Grid scenario, underscoring the importance of decarbonizing both the transportation and the power sector to achieve 2050 goals.

Table 7. GHG Emissions Estimated for 2030 and 2050 under the VT.1 Scenario Compared to 2005

GHG Emissions Results	2030			2050		
	Ref. Grid	Mod. Grid	Clean Grid	Ref. Grid	Mod. Grid	Clean Grid
On-road mobile (tailpipe) GHG Emissions (MMTCO_2e)	15.57			3.34		
EV-charging GHG Emissions (MMT CO2e)	0.81	0.73	0.16	3.06	1.82	0
Total GHG Emissions (MMT CO_2e)	16.39	16.30	15.74	6.40	5.17	3.34
% GHG reduction (tailpipe) from 2005	-25%			-84%		
% GHG reduction (total) from 2005	-21%	-21%	-24%	-69%	-75%	-84%

*Note: Totals may not match due to rounding.

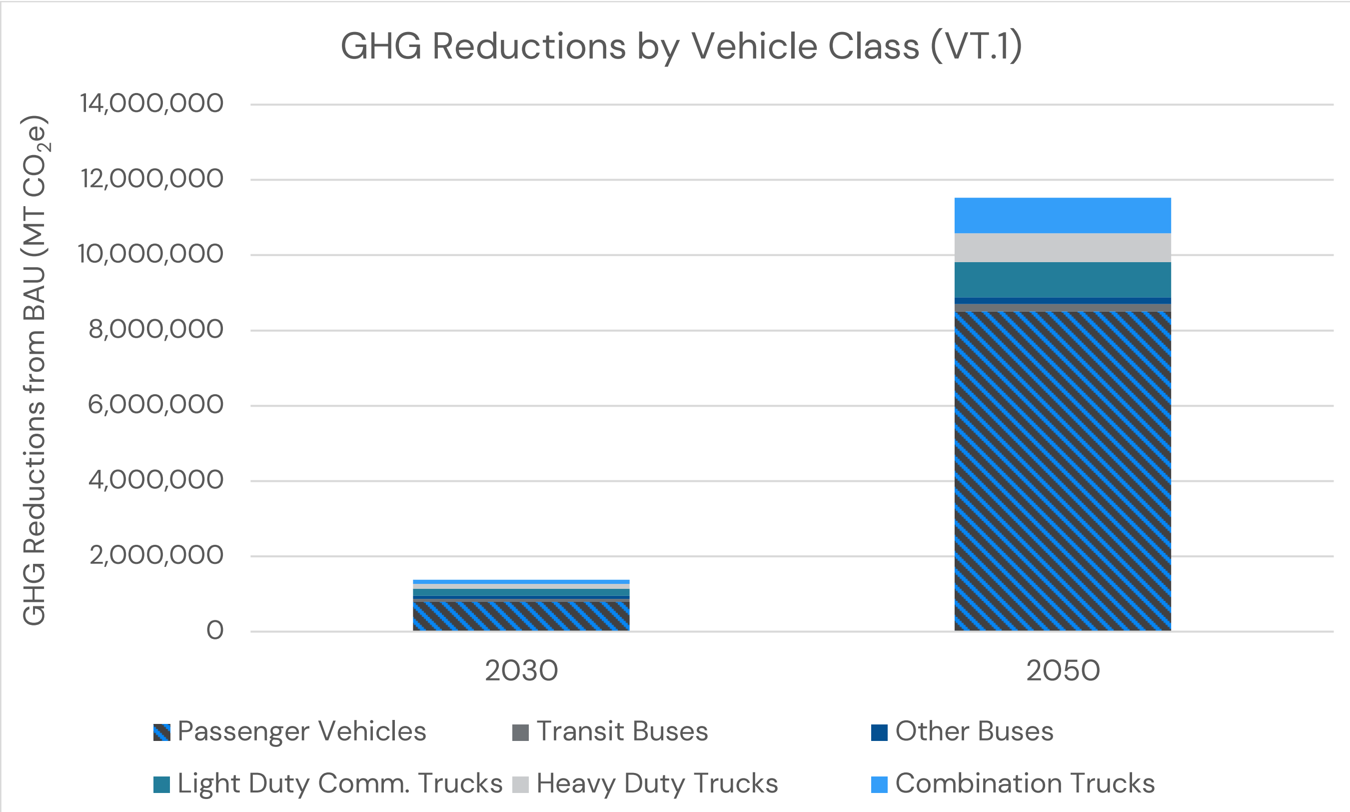
Table 8 shows the comparison of the VT.1 scenario against the baseline forecast. The implementation of the VT.1 scenario yields 8 to 11% GHG emission reduction compared to the baseline forecast in 2030, but a much larger reduction in 2050 (64 to 81% depending on the grid case) due to a more aggressive substitution of conventional vehicles with EVs.

Table 8. Comparison of the VT.1 Scenario GHG Emissions with the 2030 and 2050 Baseline Forecasts

Comparison to Baseline Forecast	2030			2050		
	Ref. Grid	Mod. Grid	Clean Grid	Ref. Grid	Mod. Grid	Clean Grid
Baseline GHG Emissions (MMT CO_2e)	17.77			17.93		
GHG Reduction Compared to Baseline Forecast (MMT CO_2e)	-1.38	-1.46	-2.03	-11.53	-12.77	-14.59
% Reduction from Baseline Forecast	-8%	-8%	-11%	-64%	-71%	-81%

Finally, Figure 12. shows the breakdown of the GHG emission reductions from the 2030 and 2050 Baseline Forecasts for the different vehicle classes in 2030 and 2050 under the Reference Grid Case (note that these GHG values include the emissions associated with electricity usage from vehicle charging). As shown by the stacked contributions to GHGs, the largest contribution to GHG emission reduction comes from converting passenger vehicles to EVs, both in 2030 and in 2050. This is expected as passenger vehicle electrification dominates GHG reduction because of the large share of total VMT and the more significant shifts toward EVs, particularly in 2050. Combination trucks and light-duty commercial trucks represent the second largest contribution to GHG reduction in 2050 and 2030, respectively, and result from a combination of electrification and use of biodiesel/renewable diesel.

Figure 12. GHG Emission Reductions from 2030 and 2050 Baseline Forecasts by Vehicle Class in the VT.1 Scenario.



Implementation Considerations

Reaching high level of market penetration for low- and zero-carbon fuels will require implementing a variety of different strategies to address existing and short-term obstacles and challenges. While implementation considerations vary across vehicle types, upfront costs of EVs are probably the biggest concern despite prices expected to continue dropping as more models become commercially available due to industry initiatives and policy forces. (As of November 2021, light-duty EV prices are close to reaching parity with conventional vehicles while medium- and heavy-duty EVs have a much higher upfront cost than their conventional counterparts). On the other hand, payback of EV adoption is expected to be quick as EV ownership generates lifetime savings in fuel and maintenance costs compared to conventional vehicles. Some of the federal, state, and local government interventions that could support the outcomes in the VT scenarios include:

- Continuation and expansion of incentive programs for purchasing EVs, but also other alternative fuels, and fuel-efficient vehicles;
- Vehicle buy-back programs to encourage more expeditious replacement of older vehicles;

- Expansion of public EV-charging infrastructure; the creation of programs to expand access to EV charging in residential buildings, especially multifamily housing, workplaces and commercial and retail, while streamlining permitting processes;
- Leveraging of zoning and land use codes to require the installation of EV-ready charging infrastructure in new residential and commercial buildings; and
- Outreach campaigns aiming at raising awareness around EVs, including outreach to auto dealers and others to promote EV purchases.

Federal or state policies such as carbon pricing and market-based mechanisms such as low-carbon fuel standards could greatly accelerate the deployment of low- and zero emission fuels, including biofuels, by providing a long-term, stable stream of funding for program implementation, thus positively contributing to achieving goals of the metropolitan Washington region. On the other hand, limitations in funding and available equipment could translate to longer implementation timeframes, especially for certain types of heavy-duty vehicles. In those cases, alternatives to low- or zero-carbon alternative fuels such as hybrid electric retrofits would need to be considered. Finally, given the broad scope of the VT scenarios, implementation would also require a high-level of collaborations between various facets of the public and private sectors, including utilities, to create an ecosystem that is favorable to reaching these goals.

Carbon pricing – in the form of a fee on carbon emissions or market-based mechanisms such as cap-and-trade or cap-and-invest programs – has been identified as a potentially promising overarching strategy, but this study did not explicitly analyze carbon pricing. However, carbon pricing may be a mechanism that would help to support other strategies analyzed under this study, such as shifts toward EVs and less-carbon intensive modes of travel. Carbon pricing is viewed by economists as one of the most efficient ways to lower GHG emissions and about 15% of emissions, across more than 80 countries or regions, are currently subject to a carbon price. This is set to grow to over 22%, upon the implementation of scheduled schemes in China, Germany, Virginia and the Mexican state of Tamaulipas.[41] Although carbon pricing is generally viewed as a regressive fee, some jurisdictions have developed ways to make carbon pricing more equitable. For example, in Canada, to compensate for the cost-of-living increase of carbon pricing, the government said it will continue to return most of the money collected by this program through rebates.[42]

Section 5 addresses equity, co-benefits, and cost considerations across all the scenario

[41] "G20 Zero-Carbon Policy Scoreboard," Executive Summary (BloombergNEF, February 2021), https://about.bnef.com/blog/g20-countries-climate-policies-fail-to-make-the-grade-on-paris-promises/.

[42] John Paul Tasker, "Ottawa to Hike Federal Carbon Tax to $170 a Tonne by 2030," Canadian Broadcasting Corporation, December 11, 2020, https://www.cbc.ca/news/politics/carbon-tax-hike-new-climate-plan-1.5837709.

Scenario VT.2: Amplified Vehicle Technology and Fuels Scenario

What's Included in the Scenario

The Amplified Vehicle Technology Improvement (VT.2) Scenario assumed a more rapid shift to EVs and increased use of biofuels. Specifically, the scenario assumed the following:

- **100% of new light-duty passenger car and truck sales are EVs by 2030**: These projections align with a Rocky Mountain Institute study[43] focusing on ways to limit cumulative GHG emissions compatible with 1.5-degree Celsius warming and are more aggressive than the 2021 order by California's Governor for the California Air Resources Board to develop regulations that mandate 100% of new passenger cars and trucks sold in the state to be zero-emission by 2035.[44,45]
- **50% of new medium and heavy-duty truck sales are EVs in 2030, ramping up to 100% of new truck sales by 2040**: These projections are consistent with the California Advanced Clean Trucks (ACT) rules, which would require zero-emission vehicle sales for 55% of the new Class 2b-3 trucks, 75% of new Class 4-8 trucks, and 40% of truck tractors by 2035.[46]
- **100% of transit and school buses are EVs by 2030**: Under this scenario, bus fleet conversion is accelerated more quickly than in the VT.1 scenario.
- **A more substantial increase in use of biofuels:** For the VT.2 scenario, it was assumed that biofuels and renewable diesel would represent 20% of the residual conventional diesel fuel in 2030, and 30% in 2050.

Resulting Fleet Changes

Similar to VT.1, the vehicle sale percentages defined in the VT.2 scenario were incorporated into the VISION model to estimate shares of VMT by vehicle type and fuels. Table 5 shows the PHEV and BEV fleet penetration estimates in 2030 and 2050 under the VT.2 scenario. For each vehicle class, the residual non-EV fleet is represented by conventional ICE vehicles, diesel or gasoline depending on vehicle type. Table 8 of the Technical Memo reports the full set of results from the VISION model.

[43] Energy System Transformation for a 1.5 Degree Celsius Future https://rmi.org/insight/1-5-degree-future/

[44] Office of Governor Gavin Newsom, "Governor Newsom Announces California Will Phase Out Gasoline-Powered Cars & Drastically Reduce Demand for Fossil Fuel in California's Fight Against Climate Change", September 23, 2020.

[45] The extent to which the overall light-duty fleet is converted to EVs will depend on the rate at which EV sales ramp up. According to the Rocky Mountain Institute Study, 100% of new light-duty vehicle sales at EVs in 2030 would likely equate to about 20% of light-duty vehicles on the road as EVs in 2030 and nearly 100% in 2050. To be consistent with COG's 2030 CEAP, we assume that 34% of light-duty vehicles on the road would be EVs in 2030, which would reflect a significantly higher level of vehicle turn-over than under typical conditions. This assumption seems very aggressive but is not as aggressive as the Montgomery County Climate Action Plan, which assumes 100% electrification of transportation options by 2035.

[46] California Air Resources Board, Advanced Clean Trucks Fact Sheet, June 25, 2020.

Table 9. Percentages of PHEV and BEV by Vehicle Type in 2030 and 2050 in the VT.2 Scenario

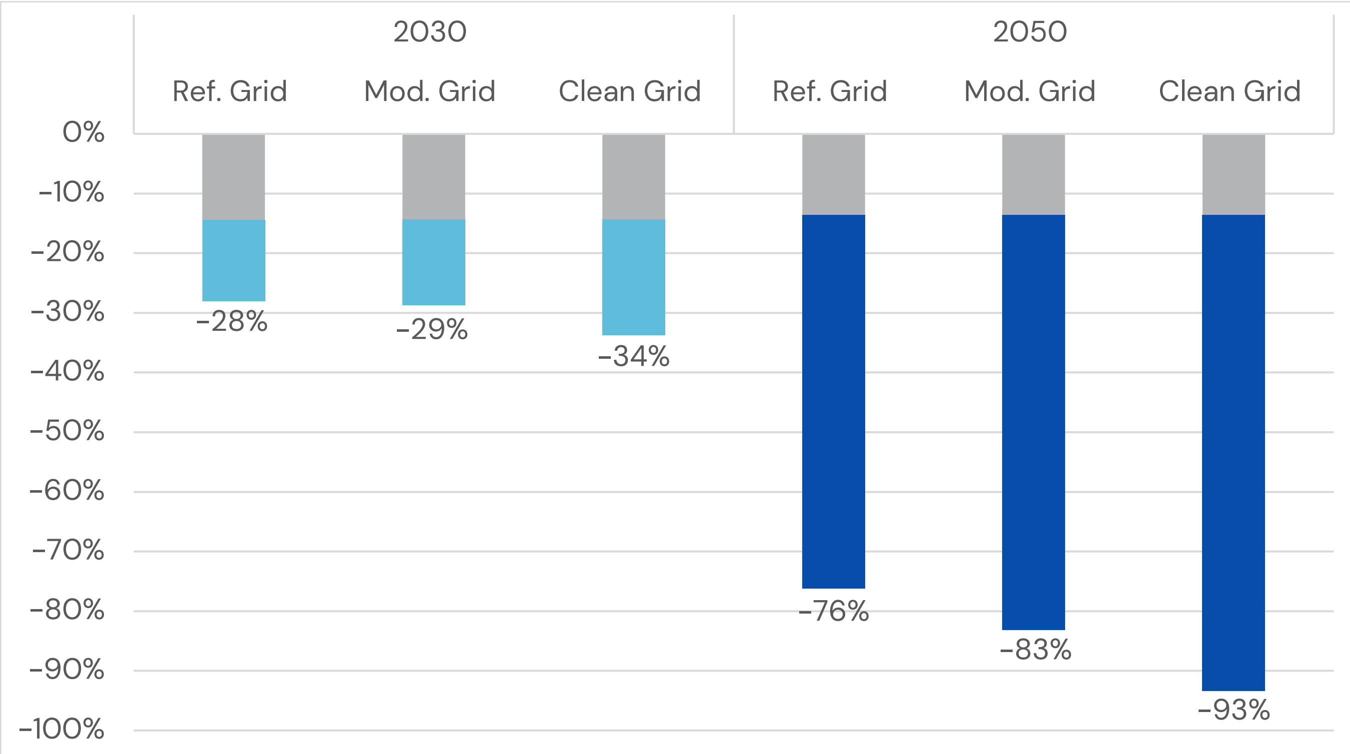
Vehicle Type	2030		2050	
	PHEV	BEV	PHEV	BEV
Light duty Passenger Vehicles	11%	25%	4%	96%
Light duty Passenger Trucks	8%	19%	3%	95%
Medium duty trucks	0%	14%	0%	85%
Heavy duty trucks	0%	5%	0%	76%
Buses	0%	100%	0%	100%

Compared to the previous 2030 CEAP study, the VT.2 EV + PHEV fleet penetration percentages in 2030 are higher than the 2030 CEAP High scenario for passenger cars and trucks (the 2030 CEAP High scenario projects that 34% passenger cars and 17% passenger trucks are EVs in 2030, compared to 36% and 27% BEV+PHEV estimated from the VT.2, respectively), but lower for heavy trucks (the 2030 CEAP High scenario projects that 6% heavy trucks are EVs in 2030 compared to 5% under VT.2). The VT.2 scenario assumptions result in higher EV penetration for buses and medium-duty trucks than under the 2030 CEAP (the 2030 CEAP High scenario projects 34% electric transit buses and 7% medium-duty electric trucks in 2030 compared to 100% and 14% under the VT.2 assumptions).

GHG Emission Reductions

Figure 13 shows the results of the GHG emission reductions performed for the three different grid scenarios (Reference Case, Modified Reference Case, and Clean Grid Case). The grey bars represent the Baseline Forecast where in absence of any actions beyond current plans, GHG emissions are forecast to decrease by about 14% from the 2005 level in both 2030 and 2050. In the Reference Case, the shift to EVs and biofuels generate sizeable reductions in GHG emissions from motor vehicles in 2030 (about a 28% reduction from the 2005 level) and a very large reduction in 2050 (about a 76% reduction from the 2005 level). Similar to what observed for VT.1, under the Clean Grid, the actions taken under the VT.2 scenario yield increasingly larger GHG reductions, going from 28% to 34% in 2030, and from 76% to 93% in 2050. Effectively, substituting more than 90% of the ICE vehicles with alternative fuels in 2050 and running the grid on clean energy yields to a near-complete elimination of GHG emissions from the transportation sector in the COG region.

Figure 13. GHG Emission Reductions under VT.2 for the three different grid scenarios (Reference Case, Modified Reference Case, and Clean Grid Case)



Note: The grey portion of the bars indicate GHG emissions reductions occurring in the baseline forecast.

Table 10 summarizes the GHG emission (in MMT CO2e) estimated for 2030 and 2050 from the implementation of the VT.2 scenario under the three different grid cases. The total GHG emission values are the sum of the tailpipe-only and EV-charging related emissions under each grid scenario. For both total GHG emissions and percentage reductions, separate values are reported for tailpipe only (that is, GHG emissions only associated with tailpipes) and electricity (that is, emission associated with electricity consumption for EV charging). In 2030, the GHG emissions under the VT.2 scenario are still dominated by tailpipes, while in 2050 most of the tailpipe emissions have been eliminated and electricity generation represents 70% to 100% of the residual GHG emissions resulting from the implementation of the VT.2 scenario.

Table 10. GHG Emissions Estimated for 2030 and 2050 under the VT.2 Scenario Compared to 2005

GHG Emissions Results	2030			2050		
	Ref. Grid	Mod. Grid	Clean Grid	Ref. Grid	Mod. Grid	Clean Grid
On-road mobile (tailpipe) GHG Emissions (MMTCO_2e)	13.45			1.37		
EV-charging GHG Emissions (MMT CO2e)	1.48	1.33	0.30	3.57	2.12	0
Total GHG Emissions (MMT CO_2e)	14.93	14.79	13.75	4.94	3.50	1.37
% GHG reduction (tailpipe-only) from 2005	-35%			-93%		
% GHG reduction (total) from 2005	-28%	-29%	-34%	-76%	-83%	-93%

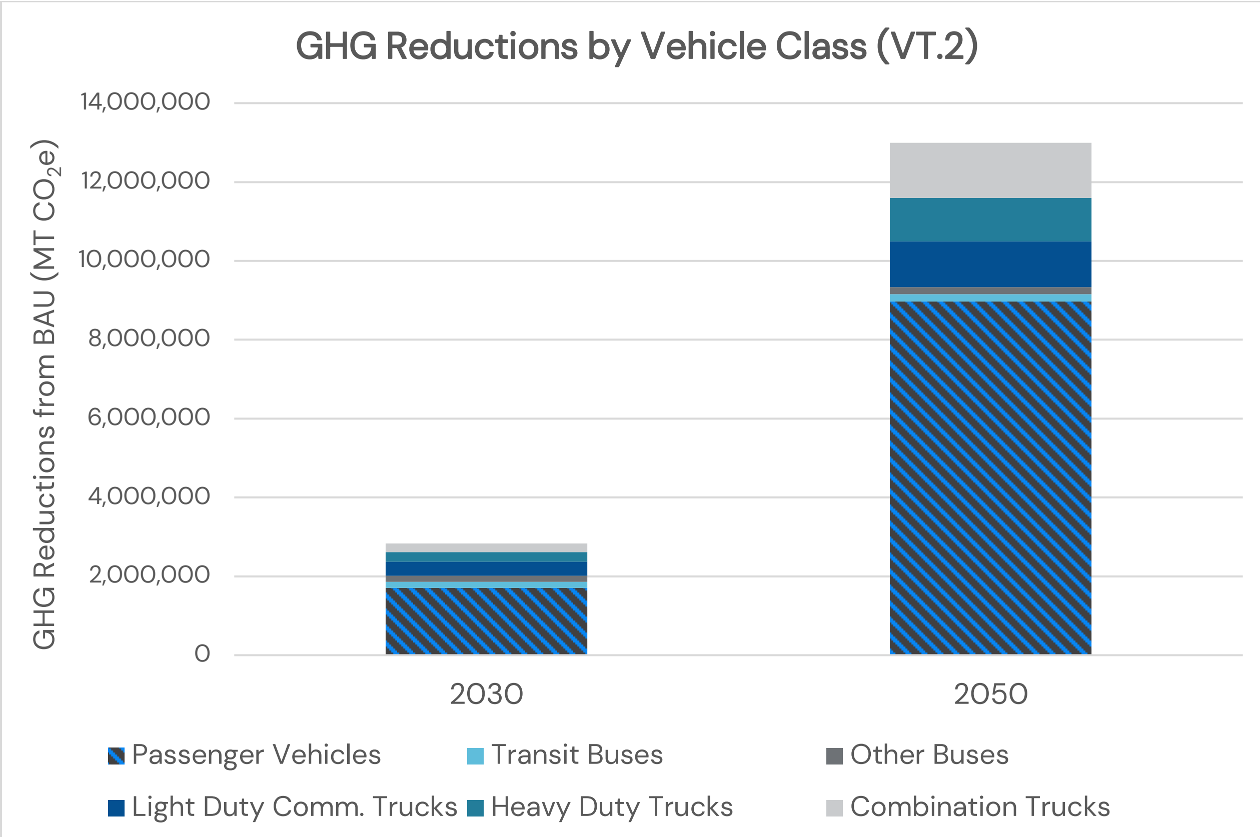
Table 11 shows the comparison of the VT.2 scenario against the baseline forecast. The implementation of the VT.2 scenario yields 16 to 23% GHG emission reduction compared to the baseline forecast in 2030, but a much larger reduction in 2050 (72 to 92% depending on the grid case) due to a more aggressive substitution of conventional vehicles with EVs.

Table 11. Comparison of the VT.1 Scenario GHG Emissions with the 2030 and 2050 Baseline Forecasts

Comparison to Baseline Forecast	2030			2050		
	Ref. Grid	Mod. Grid	Clean Grid	Ref. Grid	Mod. Grid	Clean Grid
Baseline GHG Emissions (MMT CO_2e)	17.77			17.93		
GHG Reduction Compared to Baseline Forecast (MMT CO_2e)	-2.83	-2.98	-4.02	-12.99	-14.44	-16.56
% Reduction from Baseline Forecast	-16%	-17%	-23%	-72%	-81%	-92%

Finally, Figure 14 shows the breakdown of the GHG emission reductions from the Baseline Forecast for the different vehicle classes in 2030 and 2050 under the Reference Grid Case (note that these GHG values include the emissions associated with electricity usage from vehicle charging). Similar to VT.1, the largest contribution to GHG emission reduction comes from converting passenger vehicles to EVs, both in 2030 and in 2050. However, combination trucks and light-duty commercial trucks have a larger contribution to GHG reduction in 2050 compared to VT.1, as a result of a more aggressive implementation of vehicle electrification and use of biodiesel/renewable diesel for the residual diesel-powered vehicles.

Figure 14. GHG Emission Reductions by Vehicle Class in the VT.2 Scenario.



Implementation Considerations

Implementation policies, incentives, and programs for the VT.2 scenario would be similar to those under VT.1 but require even faster implementation of shifts to EVs and biofuels. The even faster adoption of technologies and low-carbon fuels would presumably need to be advanced in part with federal support, such as more stringent fuel economy standards, incentives, and EV charging infrastructure, as well as state and regional initiatives.

Scenario MS.1: Mode Shift and Travel Behavior Scenario

What's Included in the Scenario

The Mode Shift (MS.1) Scenario relied heavily on the MSTB strategies included in past COG and TPB studies including the MSWG, LRPTF, and 2030 CEAP, and assumed the following:

- **Land use changes**: Land use changes were assumed so that incremental growth after 2025 (for 2030 and 2050) outside of Activity Centers is shifted to Activity Centers and areas with high-capacity transit stations, with a focus on improving jobs-housing balance both within a jurisdiction and across jurisdictions, similar to the LRPTF aspirational land use initiative.[47] In addition, it was assumed that 77,000 new households would be added to the region in 2030 and 126,000 new households in 2050 to increase jobs-housing balance and support a reduction in long-distance commute trips. This analysis relied largely upon the previous LRPTF assumptions/results, for modeling, as well as additional assumptions about mode shift to bicycle/ped/micro-mobility for short trips.
- **Transit fare reductions**: Transit fares reduced 50% by 2030 and 75% by 2050. This assumption is more aggressive than what was analyzed in the MSWG where transit fares were reduced regionally by 25% in 2040 and 40% in 2050. These fare reductions could be in the form of overall system-wide price reductions and/or subsidies provided by employers.
- **Travel demand management strategies**: 25% telework assumption on an average day (equates to about 50% telework for "office" employees, who make up about half of the workforce; this could be in the form of a hybrid work arrangement where employees on average work from home 2-3 days per week); all workplace parking in Activity Centers is priced by 2030. This assumption is more aggressive than assumptions in the MSWG and LRPTF studies. Parking prices were assumed to range between $6 per day in non-Activity Centers to $14 per day in the downtown DC Core. The analysis accounted for the existing share of employees that pay for parking, based on data on the percent of employees receiving free parking in different parts of the region in the region's State of the Commute Survey for 2019. It also accounted for the existing share of employees teleworking or on a compressed work week schedule (estimated at 9.7% working from home or on a day off due to compressed work weeks) based on the State of the Commute Survey for 2019.
- **Transit enhancements**: Enhancements generally equating to a reduction of transit travel times by about 10% by 2030 and 20% by 2050 (due to increased transit frequencies, improved transfer connections, and expanded bus rapid transit (BRT) networks), throughout the region.
- **Bicycle/pedestrian/micro-mobility enhancements**: Increased active transportation infrastructure leads to micromobility system uptake throughout the entire region by 2030 based on uptake levels seen in Arlington County, VA. This uptake level doubles by 2050.

[47] Note: this analysis will be conducted for 2045 using the COG's Cooperative Land Use Forecast and scaled to 2050.

Transportation System Impacts

The combination of strategies in the MS.1 scenario is estimated to reduce passenger VMT (in passenger cars and light-duty trucks) by approximately 10% in 2030 and by about 13% in 2050, compared to the baseline forecast, as shown in Table 12 below. The scenario also results in small reduction in commercial truck VMT due to land use modifications only. The analysis assumes no change in vehicle travel by other vehicles classes, such as buses or heavy-duty freight trucks, since the MSTB strategies focus on efforts to encourage people to drive less, largely through mode shifts to transit, ridesharing, bicycling, and walking; through reduced vehicle trip lengths by bringing jobs and housing closer together; and by replacing some vehicle trips through telework.

Table 12. Estimated Change in Passenger VMT from MS.1 Strategies

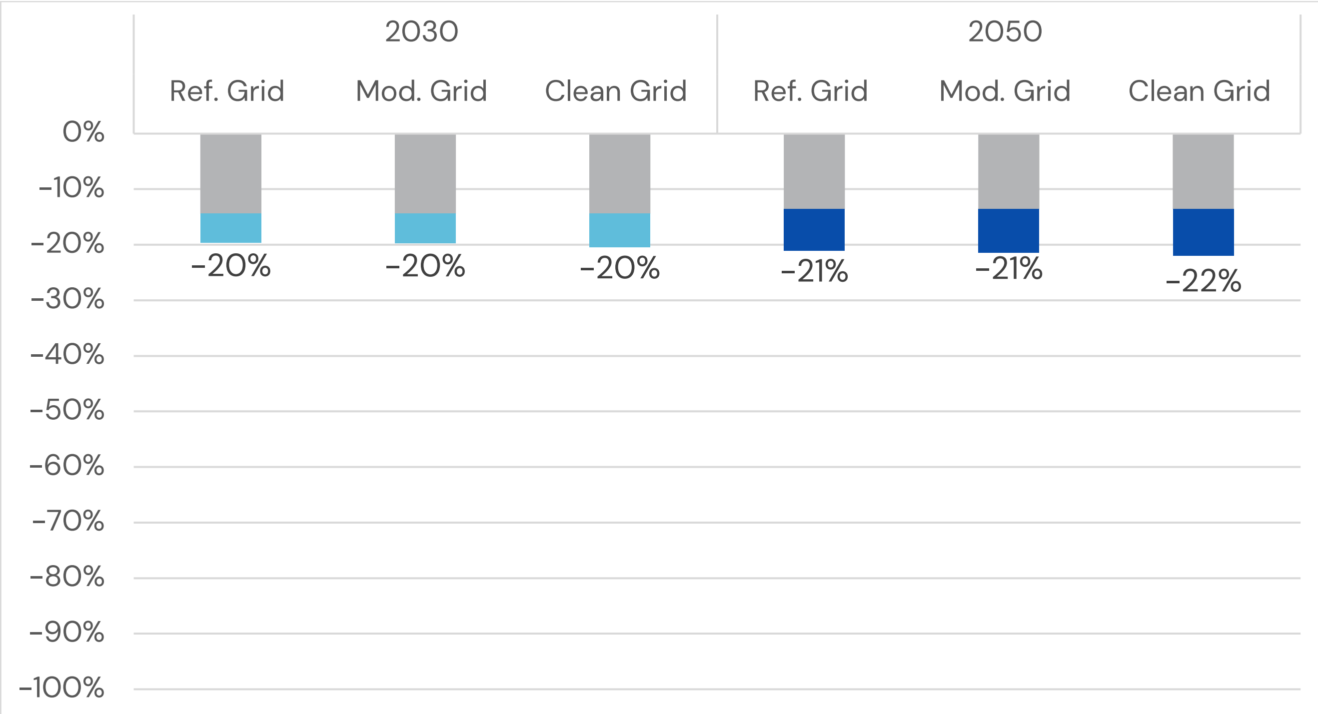
	2005	2018	2030 Baseline Forecast	2030 Under MS.1 Scenario	2050 Baseline Forecast	2050 Under MS.1 Scenario
Passenger car and truck VMT (billions)	35.04	38.11	42.23	38.20	47.01	40.74
% Reduction from baseline forecast				-10%		-13%

It is worth noting that some of the strategies under MS.1 focus on work trips, such as by increasing telework and increasing the application of parking pricing at worksites, while others - such as land use changes, transit fare reductions, transit enhancements, and bicycle/pedestrian/micro-mobility enhancements - have impacts on reducing vehicle travel for both work and non-work trips.

GHG Reductions Estimated

Figure 15 shows the estimated GHG emission reductions for the three different grid scenarios (Reference Case, Modified Reference Case, and Clean Grid Case). This scenario is estimated to result in on-road transportation GHG emissions that are 20% below the 2005 level in 2030, and about 21-22% below the 2005 level in 2050, depending on the grid assumptions. In this case, changes in the electric grid have a relatively small impact on overall emissions, since a small share of vehicles are assumed to be EVs. The level of emissions reduced off the baseline forecast grows over time as strategies such as land use policies have more effect over time.,

Figure 15. On-Road Transportation GHG Emission Reductions under Scenario MS.1 Compared to 2005



Note: The grey portion of the bars indicate GHG emissions reductions occurring in the baseline forecast.

Table 13 summarizes the GHG emission (in MMT CO2e) estimated for 2030 and 2050 from the implementation of the MS.1 scenario under the three different grid cases, and Table 14 shows the estimated GHG emissions reduced in comparison the baseline forecast for each year. Under the reference case grid and compared to baseline emissions, the MS.1 scenario strategies are estimated to reduce on-road transportation emissions (including those from tailpipe/evaporative and electricity) by about 6% in 2030 and by about 9% in 2050, as the impacts of land use strategies, transit enhancements, and transit price reductions increases.

Table 13. GHG Emissions Estimated for 2030 and 2050 under the MS.1 Scenario Compared to 2005

GHG Emissions Results	2030			2050		
	Ref. Grid	Mod. Grid	Clean Grid	Ref. Grid	Mod. Grid	Clean Grid
On-Road Mobile (tailpipe) GHG Emissions ($MMTCO_2e$)	16.46			16.19		
Electricity GHG Emissions from On-Road Vehicles (MMT CO2e)	0.21	0.19	0.04	0.18	0.11	0
Total On-Road Related GHG Emissions (MMT CO_2e)	16.67	16.65	16.50	16.37	16.30	16.19
% Reduction (tailpipe) from 2005	-21%			-22%		
% Reduction total from 2005	-20%	-20%	-20%	-21%	-21%	-22%

Table 14. GHG Emissions Estimated for 2030 and 2050 under the MS.1 Scenario Compared to Baseline Forecast

Comparison to Baseline Forecast	2030			2050		
	Ref. Grid	Mod. Grid	Clean Grid	Ref. Grid	Mod. Grid	Clean Grid
Baseline On-Road Related GHG Emissions (MMT CO_2e)	17.77			17.93		
GHG Change Compared to Baseline (MMT CO_2e)	-1.10	-1.12	-1.27	-1.56	-1.64	-1.75
% Change from Baseline Forecast	-6%	-6%	-7%	-9%	-9%	-10%

Note: The change in % Change from Baseline Forecast across grids occurs due to the baseline EV fleet penetration share and the progressively improving grid emissions rates, and not due to changes in the strategy's effectiveness. This analysis did not account for the GHG benefits of improvements in traffic flow, which could result in a modest additional benefit.

Note that in addition to reducing travel-related emissions, this scenario may have implications – positive or negative – on emissions from other sectors. Specifically, the addition of new households to the region may increase residential energy consumption, although the per household residential energy consumption of multi-family is typically reduced compared to single-family homes. The shift to remote work may allow some organizations to maintain smaller office spaces or completely eliminate offices, reducing building-related emissions. It is worth noting, however, that shifts to teleworking may increase energy consumption at home offices, as office buildings often maintain a similar level of heating/cooling even when capacity is significantly reduced.[48] There also may be secondary effects, such as some shifts of jobs between different parts of the region, particularly in reducing restaurant, retail, or other jobs in downtown areas that are dependent on worker populations.

Implementation Considerations

The strategies within this scenario are all highly interrelated, as enhancements in land use, transit, and active transportation investments can be integrated into a unified approach. A network-wide approach to enhancing transit, bicycle and pedestrian, and other modal alternatives is often viewed as having synergistic effects.

While land use can be influenced by a variety of regulatory and non-regulatory approaches, including zoning, bonus densities for development in transit-oriented locations, and incentives, market forces play a role, and it would likely take considerable regional coordination to yield the changes in development patterns and increases in housing assumed in the scenario.

[48] O'Brien, William and Fereshteh Yazdani Aliabadi. "Does telecommuting save energy? A critical review of quantitative studies and their research methods." July 2020. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7369595/

Transit enhancements could include a wide variety of efforts including increases in bus rapid transit networks, transit signal priority, Metrorail core capacity, Metrorail or light-rail extensions, increased frequency of transit services, or transit reliability enhancements. Meanwhile, bicycle/pedestrian/micromobility enhancements could include development of additional non-motorized (on-road or off-road) networks, increased deployment of dockless or docked bicycle, e-bikes, or scooters; roadway traffic calming and safety enhancements, additions of sidewalks; and other strategies.

Many of these initiatives particularly related to transit may require considerable investments of resources, not only for development of new infrastructure but also operations of new services. Meanwhile, transit fare reductions would reduce farebox revenue. Consequently, potentially large amounts of additional funding would likely be required to implement components of this scenario. Mandating that employers charge for parking for employees or provide for telework may not be feasible and may need to be implemented through voluntary programs, incentives, or employer trip reduction ordinances.

Scenario MS.2: Mode Shift and Travel Behavior Scenario + Road Pricing

What's Included in the Scenario

This scenario extends upon the same strategies listed above but applies the following road pricing policies:

- VMT Fee: $0.05 per mile in 2030 and $0.10 per mile in 2050
- DC Core Cordon Tax: $10 per entry into downtown 2030 and continuing through 2050

Note that the prices are in relation to "current" year prices for general driving operating costs, parking, etc. and would be expected to be higher in the year of implementation based on inflation and other factors affecting general costs. This analysis of VMT fees focuses on those designed to support a reduction in driving as opposed to replacing existing fuel tax charges; the fees are modeled to implicitly assume these fees are an increase in the cost of driving. If mileage-based usage fees are implemented as a substitute for fuel taxes, these fees would be essentially on top of the fees that are replacing fuel taxes.

Transportation System Impacts

The combination of strategies in the MS.2 scenario is estimated to reduce passenger VMT (in passenger cars and light-duty trucks) by approximately 14% in 2030 and by about 20% in 2050, compared to the baseline forecast, as shown in Table 15 below. The scenario also results in small reduction in commercial truck VMT due to land use modifications only. The analysis assumes no change in vehicle travel by other vehicles classes, such as buses or heavy-duty freight trucks, since the MSTB strategies focus on efforts to encourage people to drive less, largely through mode shifts to transit, ridesharing, bicycling, and walking; through reduced vehicle trip lengths by bringing jobs and housing closer together; and by replacing some vehicle trips through telework.

Table 15. Estimated Change in Passenger VMT from MS.2 Strategies

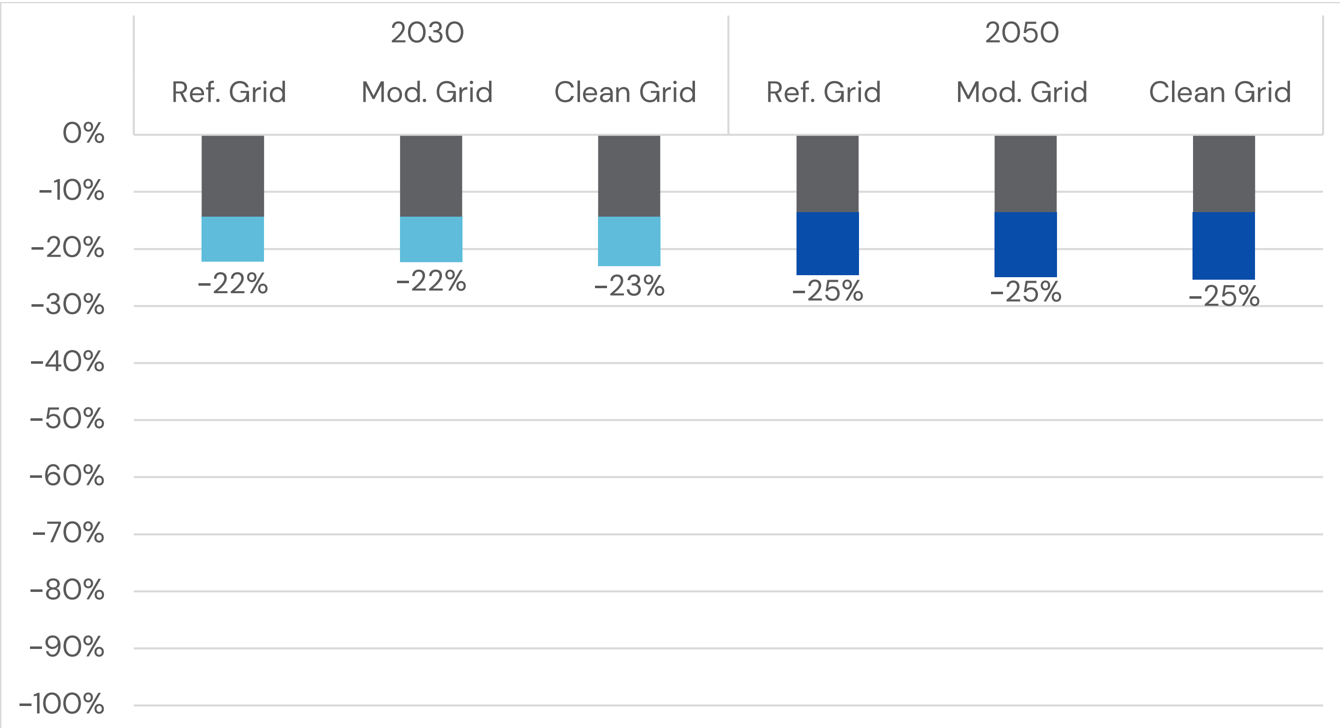
	2005	2018	2030 Baseline Forecast	2030 Under MS.2 Scenario	2050 Baseline Forecast	2050 Under MS.2 Scenario
Passenger car and truck VMT (billions)	35.04	38.11	42.23	36.31	47.01	37.83
% Reduction from baseline forecast				-14%		-20%

It is worth noting that some of the strategies under MS.2 focus on work trips, such as by increasing telework and increasing the application of parking pricing at worksites, while others – such as land use changes, transit fare reductions, transit enhancements, and bicycle/pedestrian/micro-mobility enhancements – have impacts on reducing vehicle travel for both work and non-work trips.

GHG Reductions Estimated

Figure 16 shows the estimated GHG emission reductions for the three different grid scenarios (Reference Case, Modified Reference Case, and Clean Grid Case). This scenario is estimated to result in on-road transportation GHG emissions that are 22-23% below the 2005 level in 2030, and about 25% below the 2005 level in 2050, depending on the grid assumptions. In this case, changes in the electric grid have a relatively small impact on overall emissions, since a small share of vehicles are assumed to be EVs. The level of emissions reduced off the baseline forecast grows over time as strategies such as land use policies have more effect over time.

Figure 16. On-Road Transportation GHG Emission Reductions under Scenario MS.2 Compared to 2005



Note: The grey portion of the bars indicate GHG emissions reductions occurring in the baseline forecast.

Table 16 summarizes the GHG emission (in MMT CO2e) estimated for 2030 and 2050 from the implementation of the MS.2 scenario under the three different grid cases, and Table 17 shows the estimated GHG emissions reduced in comparison the baseline forecast for each year. Under the reference case grid and compared to baseline emissions, the MS.2 scenario strategies are estimated to reduce on-road transportation emissions (including those from tailpipe/evaporative and electricity) by about 9% in 2030 and by about 13% in 2050, as the impacts of land use strategies, transit enhancements, and transit price reductions increases.

Table 16. GHG Emissions Estimated for 2030 and 2050 under the MS.2 Scenario Compared to 2005

GHG Emissions Results	2030			2050		
	Ref. Grid	Mod. Grid	Clean Grid	Ref. Grid	Mod. Grid	Clean Grid
On-Road Mobile (tailpipe) GHG Emissions (MMTCO_2e)	15.94			15.48		
Electricity GHG Emissions from On-Road Vehicles (MMT CO2e)	0.20	0.18	0.04	0.17	0.10	0
Total On-Road Related GHG Emissions (MMT CO_2e)	16.14	16.12	15.98	15.66	15.59	15.48
% Reduction (tailpipe) from 2005	-23%			-25%		
% Reduction total from 2005	-22%	-22%	-23%	-25%	-25%	-25%

Table 17. GHG Emissions Estimated for 2030 and 2050 under the MS.2 Scenario Compared to Baseline Forecast

Comparison to Baseline Forecast	2030			2050		
	Ref. Grid	Mod. Grid	Clean Grid	Ref. Grid	Mod. Grid	Clean Grid
Baseline On-Road Related GHG Emissions (MMT CO_2e)	17.77			17.93		
GHG Change Compared to Baseline (MMT CO_2e)	-1.63	-1.65	-1.79	-2.28	-2.35	-2.45
% Change from Baseline Forecast	-9%	-9%	-10%	-13%	-13%	-14%

Note: The change in % Change from Baseline Forecast across grids occurs due to the baseline EV fleet penetration share and the progressively improving grid emissions rates, and not due to changes in the strategy's effectiveness

Note that in addition to reducing travel-related emissions, this scenario may have implications – positive or negative – on emissions from other sectors. Specifically, the addition of new households to the region may increase residential energy consumption, although the per household residential energy consumption of multi-family is typically reduced compared to single-family homes. The shift to remote work may allow some organizations to maintain smaller office spaces or completely eliminate offices, reducing building-related emissions. It is worth noting, however, that shifts to teleworking may increase energy consumption at home offices, as office buildings often maintain a similar level of heating/cooling even when capacity is significantly reduced.[49] There also may be secondary effects, such as some shifts of jobs between different parts of the region, particularly in reducing restaurant, retail, or other jobs in downtown areas that are dependent on worker populations.

Implementation Considerations

In addition to the considerations in MS.1, a cordon pricing program is implemented for the downtown DC core. This policy affects only a portion of regional VMT.

Concurrently, a VMT fee is introduced which affects all vehicle trips throughout the region. When designing a VMT fee, considerations should include the tax base (which vehicle types would be affected); the fee rate structure (whether the fee would vary based on vehicle specifications, location, and/or time of travel); and implementation methods (odometers, radio-frequency identification readers, or onboard devices).[50] With VMT fees, states must also determine whether all drivers pay or if there are exemptions for electric vehicles. A VMT fee that applies to all vehicle types would not help incentivize a transition to lower-carbon vehicles (compared to a carbon tax or other carbon pricing policies).

[49] O'Brien, William and Fereshteh Yazdani Aliabadi. "Does telecommuting save energy? A critical review of quantitative studies and their research methods." July 2020. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7369595/

[50] Congress of the U.S. Congressional Budget Office. "Issues and Options for a Tax on Vehicle Miles Traveled by Commercial Trucks." 2019. https://www.cbo.gov/system/files/2019-10/55688-CBO-VMT-Tax.pdf

Scenario MS.3: Amplified Mode Shift and Travel Behavior Scenario + Road Pricing

What's Included in the Scenario

This scenario extends the strategies in MS.2 and is more aggressive in application:

- **Free transit**.
- **Travel demand management strategies**: About 40% telework assumption (equates to about 80% telework for "office" employees on an average day, or just coming into office 1 day per week on average under a hybrid work arrangement); all worksite parking in all locations (not just Activity Centers) is priced by 2050.
- **Transit enhancements**: Enhancements generally equating to a reduction of transit travel times by 15% by 2030 and 30% by 2050, reflecting even more extensive implementation of BRT and other transit enhancement strategies.

This scenario maintains the same road charge averaging of $0.05 per mile in 2030 and $0.10 per mile in 2050 (in comparison to current year prices), and an estimated cordon price for downtown DC of $10 per trip by 2030, continuing beyond.

Transportation System Impacts

The combination of strategies in the MS.3 scenario is estimated to reduce passenger VMT (in passenger cars and light-duty trucks) by approximately 20% in 2030 and by about 25% in 2050, compared to the baseline forecast, as shown in Table 12 below. The scenario also results in small reduction in commercial truck VMT due to land use modifications only. The analysis assumes no change in vehicle travel by other vehicles classes, such as buses or heavy-duty freight trucks, since the MSTB strategies focus on efforts to encourage people to drive less, largely through mode shifts to transit, ridesharing, bicycling, and walking; through reduced vehicle trip lengths by bringing jobs and housing closer together; and by replacing some vehicle trips through telework.

Table 18. Estimated Change in Passenger VMT from MS.3 Strategies

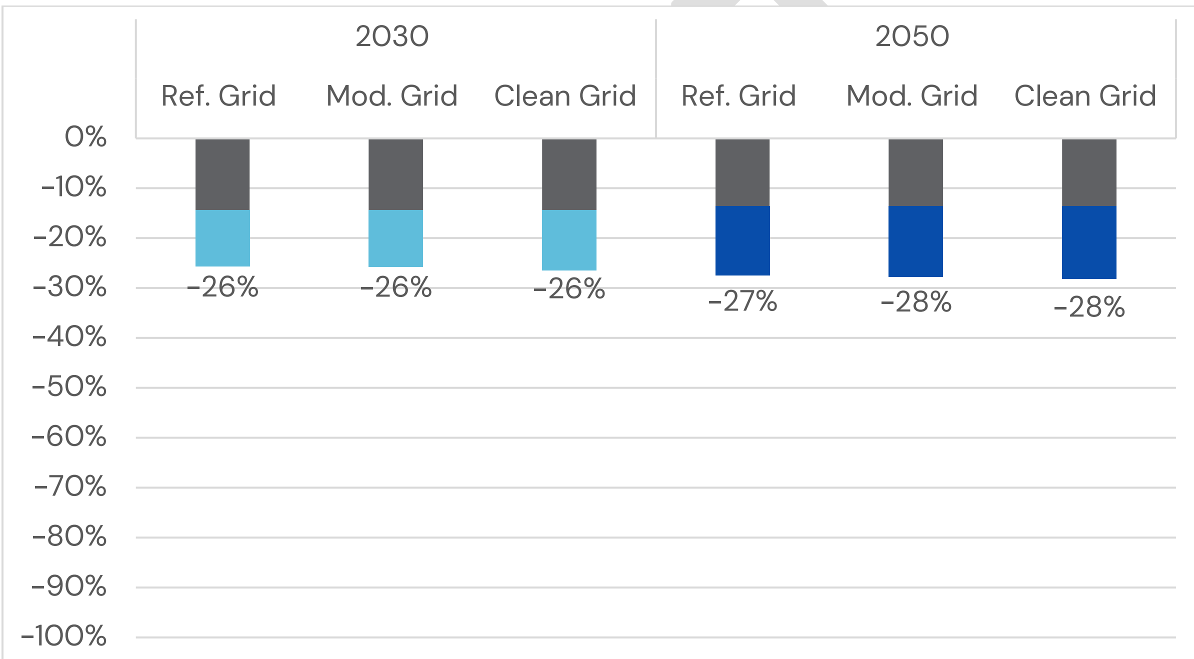
	2005	2018	2030 Baseline Forecast	2030 Under MS.3 Scenario	2050 Baseline Forecast	2050 Under MS.3 Scenario
Passenger car and truck VMT (billions)	35.04	38.11	42.23	33.73	47.01	35.37
% Reduction from baseline forecast				-20%		-25%

It is worth noting that some of the strategies under MS.3 focus on work trips, such as by increasing telework and increasing the application of parking pricing at worksites, while others – such as land use changes, transit fare reductions, transit enhancements, and bicycle/pedestrian/micro-mobility enhancements - have impacts on reducing vehicle travel for both work and non-work trips.

GHG Reductions Estimated

Figure 17 shows the estimated GHG emission reductions for the three different grid scenarios (Reference Case, Modified Reference Case, and Clean Grid Case). This scenario is estimated to result in on-road transportation GHG emissions that are about 26% below the 2005 level in 2030, and 27-28% below the 2005 level in 2050, depending on the grid assumptions. In this case, changes in the electric grid have a relatively small impact on overall emissions, since a small share of vehicles are assumed to be EVs. The level of emissions reduced off the baseline forecast grows over time as strategies such as land use policies have more effect over time.

Figure 17. On-Road Transportation GHG Emission Reductions under Scenario MS.3 Compared to 2005



Note: The grey portion of the bars indicate GHG emissions reductions occurring in the baseline forecast.

Table 19 summarizes the GHG emission (in MMT CO2e) estimated for 2030 and 2050 from the implementation of the MS.3 scenario under the three different grid cases, and Table 19 shows the estimated GHG emissions reduced in comparison the baseline forecast for each year. Under the reference case grid and compared to baseline emissions, the MS.3 scenario strategies are estimated to reduce on-road transportation emissions (including those from tailpipe/evaporative and electricity) by about 13% in 2030 and by about 16% in 2050, as the impacts of land use strategies, transit enhancements, and transit price reductions increases.

Table 19. GHG Emissions Estimated for 2030 and 2050 under the MS.3 Scenario Compared to 2005

GHG Emissions Results	2030			2050		
	Ref. Grid	Mod. Grid	Clean Grid	Ref. Grid	Mod. Grid	Clean Grid
On-Road Mobile (tailpipe) GHG Emissions ($MMTCO_2e$)	15.23			14.90		
Electricity GHG Emissions from On-Road Vehicles (MMT CO2e)	0.19	0.17	0.04	0.16	0.10	0
Total On-Road Related GHG Emissions (MMT CO_2e)	15.42	15.40	15.27	15.06	15.00	14.90
% Reduction (tailpipe) from 2005	-27%			-28%		
% Reduction total from 2005	-26%	-26%	-26%	-27%	-28%	-28%

Table 20. GHG Emissions Estimated for 2030 and 2050 under the MS.3 Scenario Compared to Baseline Forecast

Comparison to Baseline Forecast	2030			2050		
	Ref. Grid	Mod. Grid	Clean Grid	Ref. Grid	Mod. Grid	Clean Grid
Baseline On-Road Related GHG Emissions (MMT CO_2e)	17.77			17.93		
GHG Change Compared to Baseline (MMT CO_2e)	-2.35	-2.37	-2.50	-2.87	-2.94	-3.03
% Change from Baseline Forecast	-13%	-13%	-14%	-16%	-16%	-17%

Note: The change in % Change from Baseline Forecast across grids occurs due to the baseline EV fleet penetration share and the progressively improving grid emissions rates, and not due to changes in the strategy's effectiveness

Note that in addition to reducing travel-related emissions, this scenario may have implications – positive or negative – on emissions from other sectors. Specifically, the addition of new households to the region may increase residential energy consumption, although the per household residential energy consumption of multi-family is typically reduced compared to single-family homes. The shift to remote work may allow some organizations to maintain smaller office spaces or completely eliminate offices, reducing building-related emissions. It is worth noting, however, that shifts to teleworking may increase energy consumption at home offices, as office buildings often maintain a similar level of heating/cooling even when capacity is significantly reduced.[51] There also may be secondary effects, such as some shifts of jobs between different parts of the region, particularly in reducing restaurant, retail, or other jobs in downtown areas that are dependent on worker populations.

Implementation Considerations

Same considerations as MS.2.

[51] O'Brien, William and Fereshteh Yazdani Aliabadi. "Does telecommuting save energy? A critical review of quantitative studies and their research methods." July 2020. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7369595/

Scenario TSMO: Transportation Systems Management and Operations Scenario

What's Included in the Scenario

This scenario assumes extensive Intelligent Transportation Systems (ITS)/incident management deployment to optimize traffic flow. It also incorporates increased connected/automated vehicles (CAVs) in 2050, assumed to generate fuel economy effects similar to ecodriving. Analysis was based on literature showing effects of ITS and ecodriving on emissions profiles for vehicles, reflecting maximum ecodriving efficiencies to account for CAVs.

Transportation System Impacts

TSMO strategies would build on existing deployments in the region to support improved optimization of traffic flow and transportation system performance through implementation of strategies such as enhanced incident management, traffic signal coordination, and integrated corridor management. The literature suggests that the strategies identified in the TSMO scenario exhibit a wide array of impacts in a variety of regional contexts but generally yield small improvements in overall GHG emissions rates for conventional vehicles. The estimates for this study were based on an FHWA study[52] that simulated several ITS improvements, including ramp metering, incident management, active signal control, and active transportation demand management. The combined effects, even with an increase in VMT, were estimated to reduce regional vehicle GHG emissions by 1.647%, due to the more significant reduction in vehicle hours of travel and delay time. The GHG emissions benefits in the proposed in the TSMO scenario were assumed to only apply to ICE vehicles, as EV and PHEV vehicles would see fewer efficiency improvements due to regenerative braking during periods of congestion.

The benefits for CAVs in 2050 are highly uncertain but were estimated based on studies[53,54] showing that ecodriving generally reduces GHG emissions rates per vehicle by about 2% at minimum. This fuel economy improvement was applied across all vehicle types. While some literature suggests that widescale CAV deployment might increase VMT, there are some who believe that wide-scale adoption could also reduce some VMT by encouraging more shared rides. As a result, this study did not assume an offsetting increase in VMT.

GHG Reductions Estimated

Figure 18 shows the estimated GHG emission reductions for the three different grid scenarios (Reference Case, Modified Reference Case, and Clean Grid Case). This scenario is estimated to result in on-road transportation GHG emissions that are 16-17% below the 2005 level in 2030, and between 16-18% below the 2005 level in 2050,

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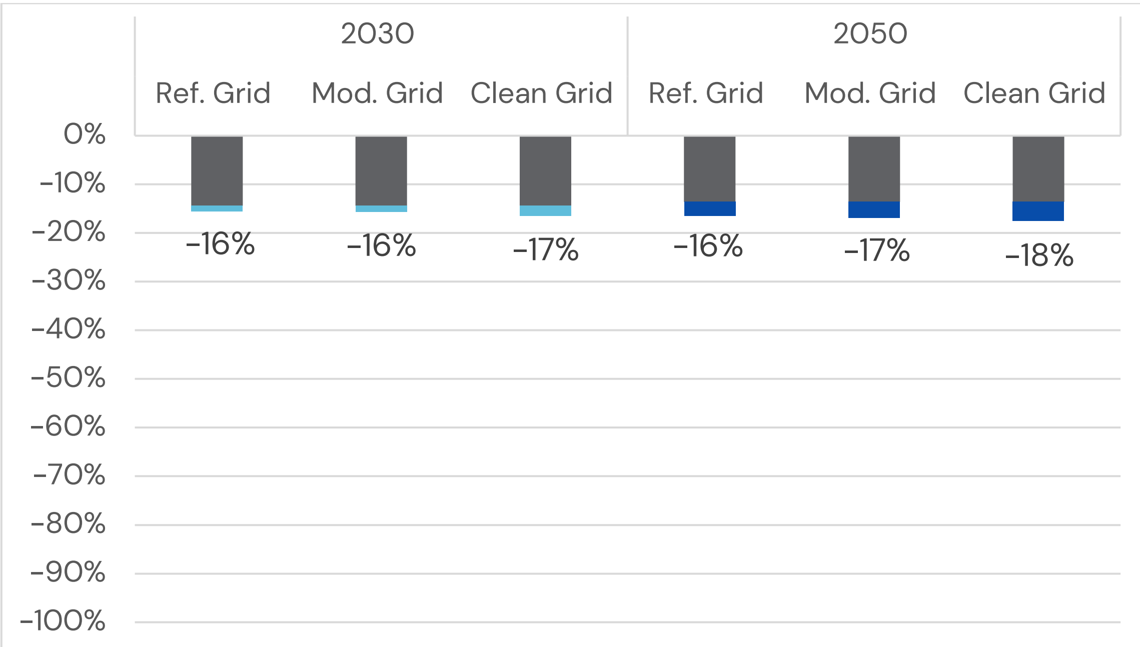
[52] FHWA, "Travel and Emissions Impacts of Highway Operations Strategies," Final Report, dated March 2014, prepared by Cambridge Systematics.

[53] ICF International, "Smart Driving White Paper," prepared for Metropolitan Transportation Commission, October 2014.

[54] Allison, Craig, and Neville Stanton. "Eco-Driving: The Role of Feedback in Reducing Emissions from Everyday Driving Behaviours." Theoretical Issues in Ergonomics Science 20, no. 2 (2019): 85–104. https://doi.org/10.1080/1463922X.2018.1484967.

depending on the grid assumptions. In this case, changes in the electric grid have a relatively small impact on overall emissions, since a small share of vehicles are assumed to be EVs. The level of emissions reduced off the baseline forecast grows slightly over time, as more CAVs with ecodriving behavior come online.

Figure 18. On-Road Transportation GHG Emission Reductions under Scenario TSMO Compared to 2005



Note: The grey portion of the bars indicate GHG emissions reductions occurring in the baseline forecast.

Table 21 summarizes the GHG emission (in MMT CO2e) estimated for 2030 and 2050 from the implementation of the TSMO scenario under the three different grid cases, and Table 22 shows the estimated GHG emissions reduced in comparison the baseline forecast for each year. Under the reference case grid and compared to baseline emissions, the TSMO scenario strategies are estimated to reduce on-road transportation emissions (including those from tailpipe/evaporative and electricity) by about 1% in 2030 and by about 3% in 2050, as the ecodriving benefits of CAVs becomes more pronounced.

Table 21. GHG Emissions Estimated for 2030 and 2050 under the TSMO Scenario Compared to 2005

GHG Emissions Results	2030			2050		
	Ref. Grid	Mod. Grid	Clean Grid	Ref. Grid	Mod. Grid	Clean Grid
Total On-Road Related GHG Emissions (MMT CO_2e)	17.52	17.49	17.33	17.33	17.25	17.12
% Reduction total from 2005	-16%	-16%	-17%	-16%	-17%	-18%

Table 22. GHG Emissions Estimated for 2030 and 2050 under the TSMO Scenario Compared to Baseline Forecast

Comparison to Baseline Forecast	2030			2050		
	Ref. Grid	Mod. Grid	Clean Grid	Ref. Grid	Mod. Grid	Clean Grid
Baseline On-Road Related GHG Emissions (MMT CO_2e)	17.77			17.93		
GHG Change Compared to Baseline (MMT CO_2e)	-0.25	-0.27	-0.44	-0.60	-0.69	-0.81
% Change from Baseline Forecast	-1%	-2%	-2%	-3%	-4%	-5%

Note: The change in % Change from Baseline Forecast across grids occurs due to the baseline EV fleet penetration share and the progressively improving grid emissions rates, and not due to changes in the strategy's effectiveness

Implementation Considerations

The effectiveness of TSMO strategies at reducing GHG reductions could decline over time as the fleet transitions to hybrid and electric powertrains. This is because speed and flow impact hybrid and electric vehicles differently from ICE vehicles. Hybrid and electric vehicles can recapture some energy lost when braking during congested conditions using regenerative braking, whereas ICE vehicles do not have this capability.

COMBO Scenarios (COMBO.1, COMBO.2, COMBO.3, COMBO.4): All Pathways

What's Included in the Scenario

These scenarios combine the strategies from several scenarios, yielding reductions in both emissions rates and VMT. The combinations consist of the following scenario mixes:

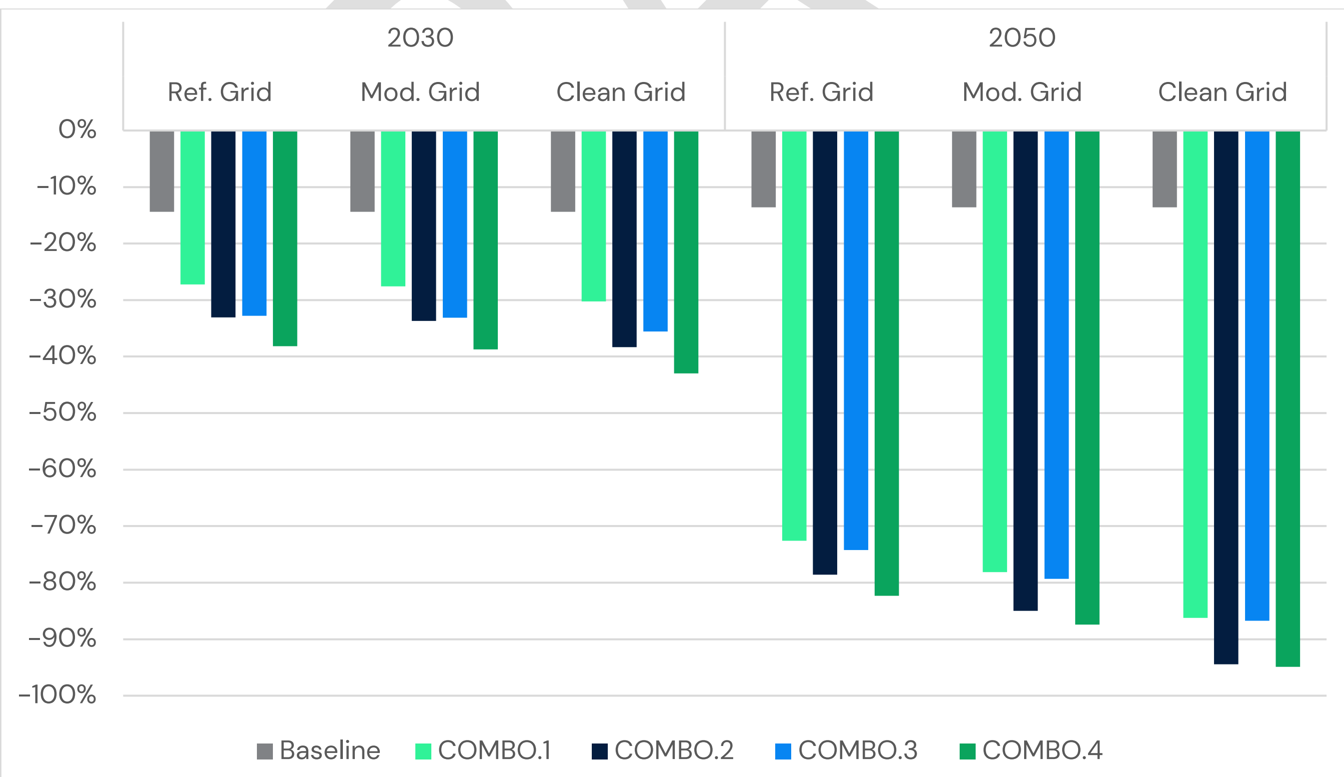
- COMBO.1: All Pathways (VT.1 + MS.1 + TSMO)
- COMBO.2: More Aggressive Technology Emphasis (VT.2 + MS.1 + TSMO)
- COMBO.3: More Aggressive Mode Shift Emphasis (VT.1 + MS.3 + TSMO)
- COMBO.4: Most Aggressive Across All Pathways (VT.2 + MS.3 + TSMO + Shared CAVs)

To simulate a fleet with CAVs, as specified in COMBO.4, all vehicles are assumed to have eco-driving enabled in 2050. Additionally, a share of 2050 SOV vehicle trips and associated VMT are shifted to shared trips, and the affected SOV VMT is reduced proportionally to the projected occupancy rate of these new trips

GHG Reductions Estimated

The emissions reductions benefits of the combination scenarios are shown in Figure 19, and range between a 27-43% reduction in 2030 to a 73-95% reduction in 2050, depending on the electric grid. Combinations provide the largest benefits, particularly in the near-term (2030). By 2050, significant shifts to EVs mean that the power grid is more important in achieving the 80% reduction goal and MSTB strategies become relatively less impactful.

Figure 19. On-Road Transportation GHG Emission Reductions under COMBO Scenarios Compared to 2005



The Table 23 displays the total emissions and the percent reduction compared to 2005 levels. Table 24 displays the difference in emissions and the percent reduction compared to the baseline level.

Table 23. GHG Emissions Estimated for 2030 and 2050 under the COMBO Scenarios Compared to 2005

GHG Emissions Results		2030			2050		
		Ref. Grid	Mod. Grid	Clean Grid	Ref. Grid	Mod. Grid	Clean Grid
COMBO.1	Total On-Road Related GHG Emissions (MMT CO_2e)	15.11	15.03	14.48	5.68	4.54	2.85
	% Reduction total from 2005	-27%	-28%	-30%	-73%	-78%	-86%
COMBO.2	Total On-Road Related GHG Emissions (MMT CO_2e)	13.89	13.76	12.8	4.45	3.11	1.16
	% Reduction total from 2005	-33%	-34%	-38%	-79%	-85%	-94%
COMBO.3	Total On-Road Related GHG Emissions (MMT CO_2e)	13.95	13.88	13.37	5.34	4.3	2.75
	% Reduction total from 2005	-33%	-33%	-36%	-74%	-79%	-87%
COMBO.4	Total On-Road Related GHG Emissions (MMT CO_2e)	12.83	12.71	11.84	3.67	2.61	1.06
	% Reduction total from 2005	-38%	-39%	-43%	-82%	-87%	-95%

Table 24. GHG Emissions Estimated for 2030 and 2050 under the COMBO Scenarios Compared to Baseline Forecast

Comparison to Baseline Forecast		2030			2050		
		Ref. Grid	Mod. Grid	Clean Grid	Ref. Grid	Mod. Grid	Clean Grid
Baseline	Baseline On-Road Related GHG Emissions (MMT CO_2e)	17.77			17.93		
COMBO.1	GHG Change Compared to Baseline (MMT CO_2e)	-2.66	-2.74	-3.29	-12.25	-13.4	-15.08
COMBO.1	% Change from Baseline Forecast	-15%	-15%	-19%	-68%	-75%	-84%
COMBO.2	GHG Change Compared to Baseline (MMT CO_2e)	-3.87	-4.01	-4.96	-13.49	-14.82	-16.78
COMBO.2	% Change from Baseline Forecast	-22%	-23%	-28%	-75%	-83%	-94%
COMBO.3	GHG Change Compared to Baseline (MMT CO_2e)	-3.81	-3.88	-4.39	-12.59	-13.64	-15.18
COMBO.3	% Change from Baseline Forecast	-21%	-22%	-25%	-70%	-76%	-85%
COMBO.4	GHG Change Compared to Baseline (MMT CO_2e)	-4.93	-5.06	-5.93	-14.27	-15.32	-16.88
COMBO.4	% Change from Baseline Forecast	-28%	-28%	-33%	-80%	-85%	-94%

Figure 20 through Figure 23 show the results of the GHG emission reductions performed for the three different grid scenarios (Reference Case, Modified Reference Case, and Clean Grid Case). The grey bars represent the Baseline Forecast where in absence of any actions beyond current plans, GHG emissions are forecast to decrease by about 14% from the 2005 level in both 2030 and 2050.

Figure 20. COMBO.1: GHG Reductions Compared to 2005

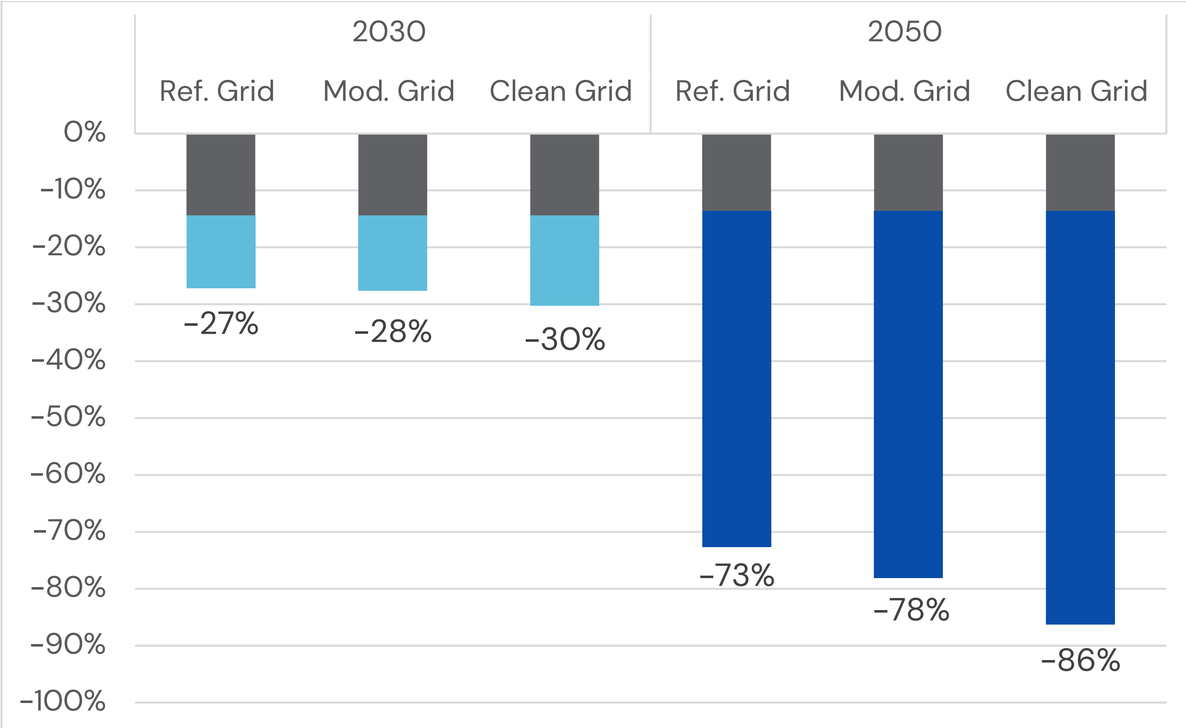


Figure 21. COMBO.2: GHG Reductions Compared to 2005

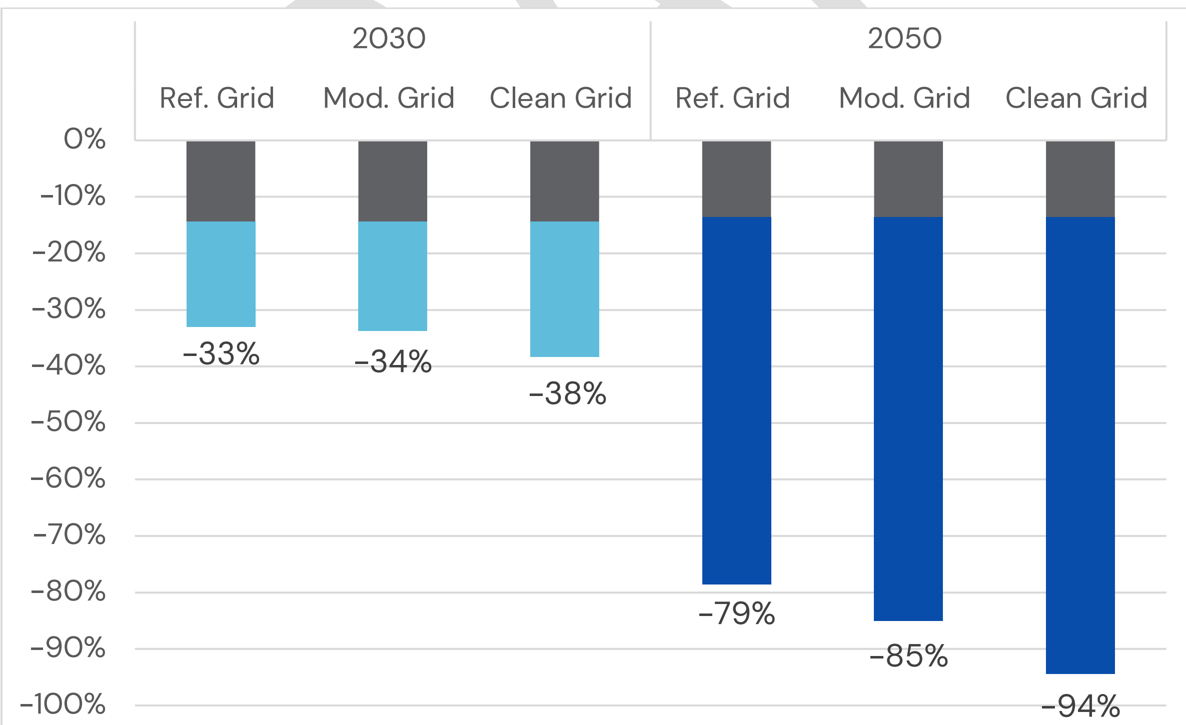


Figure 22. COMBO.3: GHG Reductions Compared to 2005

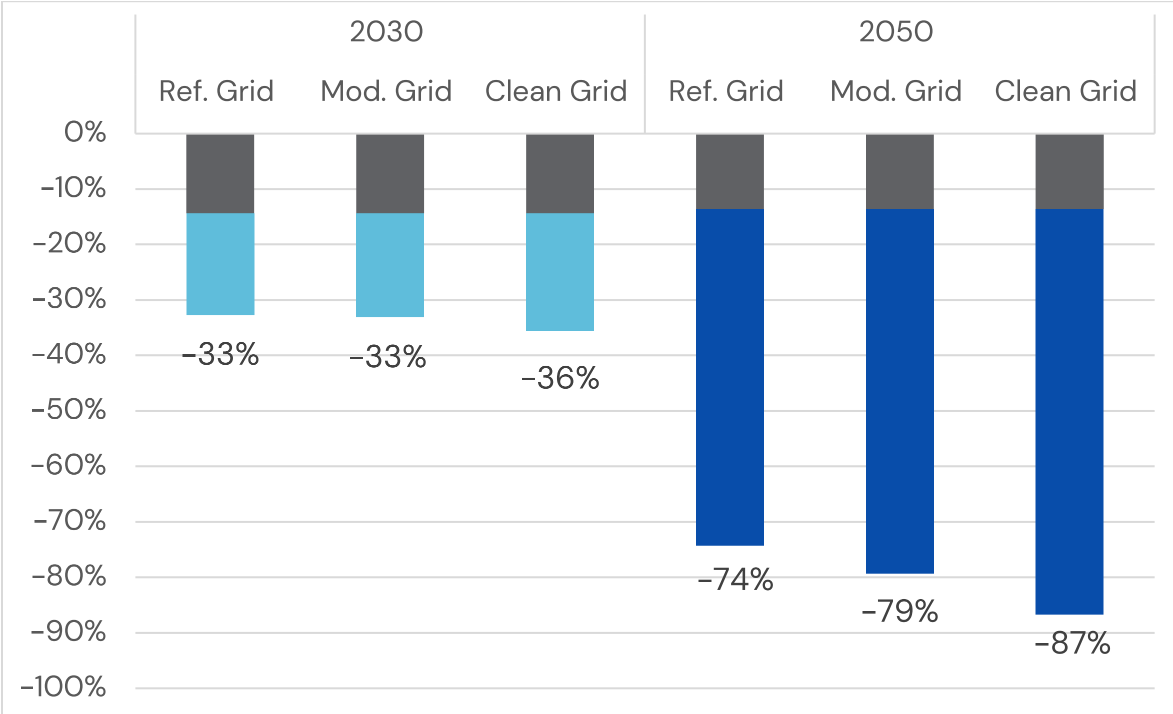
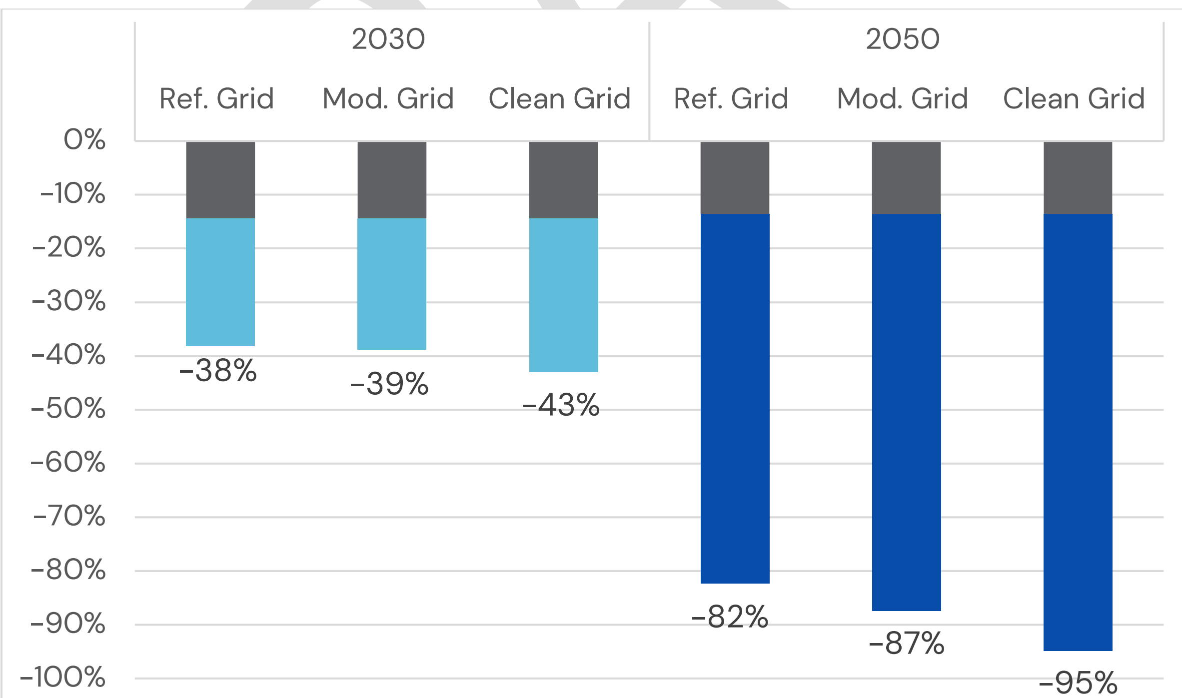


Figure 23. COMBO.4: GHG Reductions Compared to 2005



Implementation Considerations

The COMBO scenarios demonstrate the combined impacts of several GHG reduction scenarios, including Vehicle Technology and Fuels, Mode Shift and Travel Behavior, and Transportation Systems Management and Operations. Implementation considerations of all previous scenario types apply.

5 Implementation Considerations

This section provides a brief description of implementation considerations and outcomes that could be expected from the implementation of the strategies described in the scenarios. The considerations are centered around highlighting the co-benefits and costs of strategies, as well as equity implications.

Co-Benefits and Costs

Air Quality, Public Health and Safety

Any reduction in transportation emissions will generate air quality improvements. In the case of the VT scenarios, low-carbon fuels and EVs yield the largest improvement in local air quality due to the reduction or elimination (in the case of BEVs) of tailpipe criteria pollutants associated with fuel combustion such as nitrogen oxides (NOx), carbon monoxide (CO), particulate matter (PM), and other evaporative emissions such as Volatile Organic Compounds (VOCs), which contribute to the formation of photochemical smog. The strategies modeled under the MSTB scenarios also have air quality co-benefits, through the reduction in VMT and substitution of trips from personal single-occupant vehicles to other forms of transportation. This is especially true for trips that are substituted with non-motorized travel, such as walking and biking. In addition, VMT reduction strategies that rely on enhancing transit can reduce traffic congestion and improve general quality of life, while providing more mobility options and access to services. Further, transit and "active transportation" (e.g., biking and walking) strategies can work together, and when paired with micro-mobility solutions they can also serve as first-and-last-mile solutions for transit. EVs can also be incorporated in other mobility platforms, such as carsharing and ridesharing programs.

Expanding active transportation infrastructure as modeled under the MS scenarios can also make it safer for residents of different abilities to travel on foot or bike. Improved safety of the mobility ecosystem is also a co-benefit of the TSMO strategies, which significantly improves safety by significantly reducing crash rates on roads, and reliability of both roads and transit systems through mechanisms such as, for example, cordon pricing fee structures that regulate traffic flows. On the other hand, the benefits of TSMO strategies on GHGs may be expected to decline as more of the fleet transitions to hybrids and EVs, whose fuel economy does not decrease dramatically at low travel speeds, which can be encountered in situations of traffic congestion and can use technologies such as regenerative braking to improve fuel economy.

Economic

There are several economic co-benefits, as well, associated with each of the scenarios presented in this study. For the VT scenarios, the lower total cost of ownership of EVs would provide a potential incentive for switching, as EVs have notably lower operational and maintenance costs than conventional vehicles (usually 50% less[55]). In addition, , EVs offer the convenience of eliminating trips to the gas station. Widespread vehicle electrification is

[55] Preston, B. EVs Offer Big Savings Over Traditional Gas-Powered Cars. October 2020. https://www.consumerreports.org/hybrids-evs/evs-offer-big-savings-over-traditional-gas-powered-cars/

also poised to generate local workforce development and employment opportunities for the installation and maintenance of private and public EV charging infrastructure.

The strategies included in the MS and TSMO scenarios generate economic co-benefits in the form of increased access to businesses and services through transportation service improvements. When paired with land use strategies and smart development, transit promotes economic activity through the creation of transit-oriented neighborhood, for example, which also generate more opportunity for social interactions within a community. MSTB strategies, such as cordon pricing and VMT fees, can provide steady revenue streams for state and local governments but can also help commuters and freight move more quickly by improving travel time reliability and congestion, with positive impacts on the economy. Finally, teleworking can enhance efficiency and productivity. However, for some stakeholders, the strategies considered here could cause economic losses: for example, reducing transit fares means that there will be some loss of revenue for transit agencies. At the same time, transit enhancements require significant, long-term spending, while the implementation of revenue-generating actions such as cordon pricing and VMT fees requires administrative and enforcement costs. Maintaining active transportation facilities may require new equipment, such as specific snow removal equipment. Finally, while teleworking can save employers and employees time and money, remote workers can generate less economic activity in downtown areas.[56]

Equity

Many of the analyzed strategies and scenarios have potential equity benefits and burdens that would need to be considered and addressed prior to their implementation.

The equity implications of the VT scenarios can be explored at different levels. On one hand, a zero-emission transportation future provides widespread equity benefits to the public, by improving air quality and public health. This is particularly relevant to communities living near freeways, which are typically medium- and low-income, and could especially benefit from zero-emission medium- and heavy-duty vehicles that contribute disproportionately to criteria pollutants associated with adverse health outcomes. However, low-income and minority communities experience financial and logistical barriers that prevent adoption of privately owned EVs, or of private forms of mobility altogether. In these cases, the implementation of both equitable measures in EV adoption (e.g., through low-interest loans, point-of-sale rebates, vouchers, and strategically placed infrastructure to enable EV charging for multifamily residences or for renters) and zero-emission transportation services (e.g., electric transit buses and school buses) is equally critical to offer more options and expand access to clean mobility.

Improved mobility and access to services through enhanced public transit and micromobility options can increase access to jobs, education, healthcare, food, and other key resources for all income levels, but has important equity implications for underserved communities who have less access to safe bike trails and/or private forms of mobility. Thus, enhancing transit while expanding active transportation infrastructure can play

[56] Bloom, N. How Working from Home Works Out. Stanford Institute for Economic Policy Research. June 2020. https://siepr.stanford.edu/sites/default/files/publications/PolicyBrief-June2020.pdf (stanford.edu)

an important role in enhancing mobility for the residents of Equity Emphasis Areas (EEAs).[57] Likewise, teleworking is not an option for all workers. The percentage of people with teleworking-capable jobs varies by race and income level,[58] and lower-paying jobs are typically the ones that require an in-person presence and are best served by a reliable and safe transportation system. Because many low-wage workers have work shifts during off-peak hours that typically feature lower transit service frequencies, cordon pricing and VMT fees can place an extra burden on low-wage workers and might make it more difficult for low-income individuals to access jobs inside the cordon areas.[59] Similarly, VMT fees that are based on vehicle type may be regressive, as low-income drivers are less able to afford newer, more fuel-efficient/alternative fuels vehicles. These equity impacts can be mitigated by designing policies that intentionally apply discounts based on income, such as a means-tested transit fares or other discounted pricing, and by using the revenues to invest in Equity Emphasis Areas. Finally, TSMO strategies that focus on vehicle and/or mobile application-based technology may also present equity challenges. For instance, real-time travel information on mobile apps is not accessible to those without mobile devices. As the region uses more technology to create smart, connected communities, it will be important to make sure not to leave those without access to the same tools behind.[60]

Policy Implementation Issues

Turning GHG emission reduction scenarios into actions will require a combination of policy measures at every level of government, as well as robust long-term planning and strong coordination between public and private stakeholders.

The role of the federal government remains critical for aspects such as setting up grants and incentive programs for EV purchases and EV infrastructure development (relevant for the VT Scenarios) and transit enhancement (relevant for the MS scenarios). While federal clean energy and clean transportation policies can also help spur action at the local level, state and local jurisdictions have a direct key role in the design and implementation of policies and programs that can turn these scenarios into actions. Tools that state and local governments can use include legislative processes to, e.g., set clean power grid requirements or ZEV mandates for new EV sales such

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[57] Equity Emphasis Areas (EEAs) are a regional planning concept adopted in 2021 by the COG Board of Directors to guide future growth and investment decisions. EEAs are approximately 350 of the region's 1,222 total census tracts with high concentrations of low-income individuals and/or racial and ethnic minorities. EEAs were originally developed by the Transportation Planning Board to analyze transportation potential impacts of its long-range plan but will now be applied more broadly across disciplines. See and Sergio Ritacco, "Equity Emphasis Areas for TPB's Enhanced Environmental Justice Analysis - Environmental Justice," Metropolitan Washington Council of Governments, 2020, https://www.mwcog.org/transportation/planning-areas/fairness-and-accessibility/environmental-justice/equity-emphasis-areas/.

[58] Bay Area Council Economic Institute. "Remote Work in the Bay Area: An Initial Evaluation of the Data and Implications for Public Policy." December 2020. http://www.bayareaeconomy.org/wp-content/uploads/2020/12/BACEI_RemoteWork_12.21.20.pdf#page=11

[59] Portland Bureau of Transportation. "Cordon Pricing: Background Memo." January 2020. https://www.portland.gov/sites/default/files/2021/poem_workingdraft_cordonmemo_clean.pdf

[60] Federal Highway Administration. "Transportation Systems Management and Operations (TSMO) in Smart Connected Communities." December 2018. https://transops.s3.amazonaws.com/uploaded_files/fhwahop19004.pdf

as those set by the Advanced Clean Transportation rules, and zoning/land use codes to implement transit and housing development strategies that reduce private driving and maximize sustainable mobility. Municipal codes are also key instruments that local governments have at their disposal to streamline processes that can help advance residential and commercial EV deployments.

While costs are seen as the main barrier to advancing the types of policies that would be required to roll out the programs described in these scenarios, lack of adequate planning, coordination, and agreement between stakeholders is often the largest impediment. As such, a multi-stakeholder approach where the local government facilitates discussions and collects inputs to be incorporated in program design is typically seen as the most successful long-term strategy to implement actions in a way that eliminates possible conflicts (this is particularly relevant for actions that might have real or perceived costs for some stakeholders and benefits for others, such as free transit or parking pricing) even when considering the short-term costs associated with education and awareness programming. The role of the private sector is also key, in both supporting and helping to shape proposed policies and programs. For example, collaboration with developers is key for a smooth implementation of land use policies; likewise, private employers play a key role in the shaping of telework or vanpooling policies.

In moving forward, policy makers will need to consider the costs, revenue implications, benefits, and equity implications of policy actions, and consider how transportation investments can best move toward GHG reduction goals while supporting the region's mobility, safety, economy, and community and other environmental goals.

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