


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

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Executive Summary

Introduction and Purpose

The Metropolitan Washington Council of Governments (COG) 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. Consequently, the National Capital Region Transportation Planning Board (TPB), which is the metropolitan planning organization (MPO) for the metropolitan Washington region, is studying ways to achieve significant reductions of on-road transportation related GHG emissions, commensurate with the overall regional goals.

This document is an initial step in a climate change mitigation study that seeks to identify what kinds of strategies may be effective to achieve reductions of on-road transportation GHG emissions associated with the 50% and 80% reduction goals by 2030 and 2050, respectively. This document summarizes a literature review of climate change mitigation plans and studies conducted within the metropolitan Washington region, in other areas across the country, and around the world, and research on transportation GHG strategies and their effectiveness. The literature review findings provide a basis for identifying possible transportation GHG strategies to include in scenarios and to consider for modeling and analysis. *Note: Citations of studies have been included in the main report but largely have been omitted in the Executive Summary for the sake of brevity.*

Climate Planning in the Region

- ➔ **What are organizations in the region doing to plan for transportation sector GHG emissions reductions?**

State and Local Governments

State and local governments throughout the Washington region have developed or are developing climate action plans to support significant GHG reductions and to ensure sustainable growth, economic opportunities, and better health outcomes for their residents. Transportation actions identified in these plans include a broad array of strategies, including those focused on cleaner **vehicle technologies and fuels** (e.g., increasing electric vehicle [EV] adoption), **mode shift and travel behavior (MSTB)** strategies (e.g., enhancing public transit, active transportation options, land use planning, transportation demand management [TDM], and other strategies to reduce vehicle miles traveled [VMT]), and **transportation systems management and operations (TSMO)** strategies (e.g., incident management, traffic signal coordination, and other strategies to reduce travel delay and improve the operating conditions on the roadway network). In addition, some jurisdictions have noted the potential role of **carbon pricing** including carbon taxes, fuel taxes, or other market-based strategies like cap-and-trade or cap-and-invest programs.

Maryland, Virginia, and the District of Columbia each have developed climate action plans, including economy-wide targets for GHG reduction. Virginia and the District's climate action plans were released in 2008 and 2010, respectively, and both jurisdictions have taken action to develop and/or implement policy and regulatory approaches to reduce GHG emissions. The Maryland Department of the Environment (MDE) published the 2030 Greenhouse Gas Emissions Reduction Act (GGRA) Plan in February 2021, as a continuation of efforts set by the first GGRA becoming law in 2009 and reauthorized in 2016, as well as prior iterations of the GGRA Plan (2013, 2015, and 2019). Table ES-1 summarizes the targets and associated strategies in these plans.[1]

Table ES-1. Summary of State GHG Reduction Targets and Transportation Strategies Identified in Plans

Jurisdiction	GHG Reduction Target	Transportation Target	Vehicle / Fuel Strategies	MSTB Strategies	TSMO Strategies	Carbon / Fuel Pricing
Maryland	Maryland law requires a minimum of 40% below 2005 levels by 2030; the GGRA Plan committed to a more ambitious goal of 50% below by 2030 and net zero by 2045	40% reduction by 2030 goal, and strive to have 535,000 plug-in hybrid electric vehicles and battery electric vehicles registered in MD (without federal action) or 790,000 vehicles (with federal action) by 2030	✓	✓	✓	
Virginia	30% below the business-as-usual projections for 2025	No transportation-specific GHG emissions reduction target	✓	✓	✓	
District of Columbia	50% below 2006 levels by 2032, and 80% by 2050	Goal for all new vehicles registered in DC to be electric by 2045 (except heavy duty)	✓	✓	✓	✓

The three jurisdictions are undertaking various policy actions, including on-going investments in transit, bicycling and walking, and travel demand management programs and policies. Some examples of notable climate initiatives include:

- Adoption of the California Air Resources Board (CARB) Zero-Emission Vehicle (ZEV) Program by Maryland and Virginia; this program requires auto manufacturers to deliver a minimum percentage of passenger cars and light-duty trucks as ZEVs each year.
- A multi-state Memorandum of Understanding (MOU), signed by Maryland and the District of Columbia, as well as 11 other states, striving to make at least 30% of all new medium- and heavy-duty vehicle sales in their respective jurisdictions ZEVs by 2030, and 100% by 2050.

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[1] Some local and international jurisdictions have set targets for carbon neutrality, while others set targets for net zero emissions. These goals both mean that the amount of emissions produced is equivalent to the amount being removed from the atmosphere. Carbon neutrality may imply that some emissions can be offset by funding an equivalent amount of carbon savings in a separate location. For the transportation sector, some agencies may consider only tailpipe emissions, while others may account for the full fuel-cycle, including extraction, transport, and distribution of the energy used in transportation (including emissions associated with electric power for EVs), and others may even consider emissions associated with manufacturing motor vehicles.

- 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.[2]
- Engagement by the District of Columbia, Maryland, and Virginia, along with 11 other states, in the Transportation and Climate Initiative (TCI), a regional collaboration to improve transportation and reduce carbon emissions from the transportation sector. In December 2020, the District of Columbia signed a memorandum of understanding with Massachusetts, Connecticut, and Rhode Island for the Transportation and Climate Initiative Program (TCI-P), a multijurisdictional cap-and-invest program. TCI-P will set a decreasing cap for transportation emissions in the region and generate proceeds that will then be utilized to improve clean transportation in each jurisdiction.

Many of the local jurisdictions in the COG region also have developed climate action plans or are in the process of developing them. Table ES-2 below summarizes key components of several plans that have been completed, are in draft, or are at a point where actions have been identified (others are earlier in the process).

Table ES-2. Sample Local GHG Reduction Targets and Transportation Strategies Identified in Plans

Jurisdiction	2050 GHG Reduction Target	Key Transportation Goals	Vehicle / Fuel Strategies	MSTB Strategies	TSMO Strategies	Carbon / Fuel Pricing
Alexandria, VA	80-100% Reduction (from 2005 baseline)	• By 2023 reduce VMT 1% per year • By 2023 increase transit, walking, and biking by 15% over 2018	✓	✓		
Arlington County, VA	Carbon Neutral	Reduce the amount of carbon produced from transportation to 0.5 $MTCO_2e$/capita/year by 2050	✓	✓		
Fairfax County, VA	Carbon Neutral	N/A	✓	✓	✓	
Montgomery County, MD	Carbon Neutral by 2035	• 100% electrification of transportation options by 2035 • Reduce private vehicle trips from 75% of total trips to 60% by 2027 • Double the proportion of bus, rail, and bicycle trips (from 2018 baseline) by 2035	✓	✓	✓	✓*

*Advocates for carbon tax or gas tax increase but notes that this is outside county authority.

Across the state and local plans that have attempted to meet aggressive GHG reduction goals, the plans highlight the importance of implementing multiple strategies, including vehicle technology and fuels strategies and MSTB strategies, as well as the challenges ahead for achieving deep GHG reductions. For instance, the Maryland Department of Transportation GGRA Plan, which explored strategies for the transportation sector to achieve the original "40 by 30" goal (i.e., 40% reduction by 2030), concluded that achieving this goal will require

[2] 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.

aggressive investment in transportation beyond current levels of projected funding, supportive policies, a shared commitment to advance low-cost and low-carbon technologies, and increasing penetration of EVs in public and private vehicle fleets. The draft Montgomery County Climate Action Plan notes that to meet its carbon neutral goals, 100% of private and public transportation options will need to be electrified or use other zero emissions technologies by 2035; the County's electric supply must be 100% renewable by 2030 to ensure that transportation options powered by electricity produce zero emissions; and private motor vehicle trips will need to be reduced from 75% to 60% of total trips (double the proportion of trips taken by transit and bicycle).[3] The plan sets out transportation-related actions, spanning from electrification incentives and expanding EV infrastructure to expanding public transit and active transportation, congestion pricing, off-road vehicle electrification, and advocating for a carbon tax.

Utilities

As battery electric vehicles have zero tailpipe emissions and shifts to EVs are a primary driver of significant GHG reductions in climate action plans, it is important to recognize the increasing role that electricity will play in transportation-sector GHG emissions, when accounting for transportation across the fuel cycle (not just tailpipe emissions).[4] Carbon reductions from electricity are legislated, with Maryland requiring a 50% renewable portfolio by 2030, the District requiring 100% of electricity be generated by renewable sources by 2032, and Virginia requiring 100% of electricity to be generated by zero carbon sources by 2045. As a result, cleaner energy will help to reduce upstream emissions and help move towards zero emissions on a fuel-cycle basis. Utilities, including Dominion, WGL, PEPCO, and BG&E, also are taking actions that include EV incentives for customers, increasing charging infrastructure, EV education, and support for electric school buses.

Climate Planning in Other Regions of the U.S. and Internationally

- ➔ **How have other places achieved GHG reductions or plan to achieve GHG reductions?**

City and Regional Climate Planning in the U.S.

Many cities and regional planning organizations around the U.S. have committed to significant GHG reduction. At least 1,066 mayors in cities across the U.S. joined the U.S. Conference of Mayors' Climate Protection Agreement, and many cities have developed their own climate action plans. Many regional planning agencies are also working to address GHG reduction goals. Examples of strategies in these plans include:

- Electrification of private vehicles and public-sector fleets (e.g., carbon neutral New York City fleet by 2040, launching an e-cargo delivery pilot in the City of Boston in 2022, ferry electrification in the Puget Sound region and commitment to 100% ZEV transit fleet by King County Metro in the Seattle region)
- Encouraging mode shifts to reduce VMT per capita (e.g., bus lane expansion and enforcement in New York City, targets to reduce VMT per capita by 39% by 2035 and 45% by 2050 in the City of Los Angeles)

[3] The plan explains that mode shifting will reduce the number of private vehicles that will need to be electrified (the plan assumes that 100% of vehicles will be electrified and produce zero tailpipe emissions).
[4] Fuel-cycle emissions account for the upstream emissions associated with extraction, transport, and distribution of the energy used in transportation (including electricity-related emissions for EVs); fuel-cycle emissions do not account for emissions associated with physical infrastructure or production of vehicles or batteries.

- Other types of strategies, such as using sustainable aviation fuels (Seattle region), storing energy captured from trains (Los Angeles Metro), and reducing truck traffic associated with commercial waste collection (New York City)

International Climate Plans and Transportation-Related Initiatives

Across the world, there are also noteworthy emissions reduction plans and strategies that may offer lessons to consider in the U.S.[5] Examples include:

- Paris – The City of Paris has implemented low-emissions zones that limit access to central Paris by higher-polluting vehicles (moving toward a 2024 Zero Diesel target and the 2030 Zero Petrol target); expanded public transportation; supporting active transportation by closing certain areas of the city to motorized traffic during some days, adding bicycle facilities, and reducing speed limits; and planning to eliminate 70,000 parking spots, half of the city's on-street parking.
- London - London is working to meet zero carbon goals through policies such as a congestion charge zone, which charges a fee to drivers entering the zone; a low-emission zone with daily fees for high-polluting commercial vehicles; expanded EV charging and hydrogen fueling infrastructure; and expanded active transportation infrastructure.
- Norway - In 2020, more than half of all new cars sold in Norway were electric, due in part to significant financial incentives, including reduced parking fees and ferry fares, exemption from the 25% value added tax, full or partial exemption from road tolls, and access to bus lanes. The government has also supported fast charging and hydrogen refueling facilities.
- The Netherlands - The Netherlands has the highest bicycle mode share of trips in the world, with 28% of all trips made by bicycle and 16% by walking. The nation has built an extensive, connected network of bicycle Infrastructure, redesigned streets to calm traffic and enhance safety, integrated biking with public transport, and implemented policies that make car travel expensive or inconvenient.

Transportation Strategies and their Effectiveness

➔ **What do literature and past scenario studies tell us about transportation strategies to reduce GHG emissions?**

Approaches to Achieve Transportation GHG Reductions

Transportation GHG emissions can be reduced essentially through three primary pathways:

- **Vehicle technologies and fuels strategies –** Reducing the carbon-intensity of vehicle travel by shifting toward lower carbon fuels (emitting less carbon per unit of energy), increasing the fuel efficiency of vehicles (less energy used per VMT), or shifting to ZEVs (zero emissions from the tailpipe).
- **Mode Shift and Travel Behavior (MSTB) strategies** - Shifting travel to more efficient modes and reducing VMT, often through improving public transit, active transportation options, travel demand management programs, land use planning, and road pricing or other pricing strategies.

[5] It is worth noting that each of these places has significantly higher fuel taxes and costs associated with driving than in the U.S.

- **Transportation Systems Management and Operations (TSMO) strategies** - Reducing vehicle travel delay and/or encouraging more eco-friendly driving patterns, since GHG emissions from conventional vehicles are highest during idling and during stop-and-go congested conditions.

When exploring how to achieve these changes, it is useful to recognize a continuum of implementation approaches, as shown in Figure ES-1.

Figure ES-1. Continuum of Implementation Approaches

These approaches range from education/information (e.g., providing information on vehicle fuel economy or encouraging people to try transit) to investments (e.g., providing EV charging equipment or new transit services), incentives (e.g., subsidies to purchase EVs, free transit, or increasing the price of driving through tolls), and regulation (e.g., fuel economy standards, requiring employers to adopt telework policies). Policies like **fuel taxes or carbon pricing** are generally viewed as particularly effective since they create a financial incentive both for encouraging people to choose more fuel efficient, low-emissions vehicles and encouraging less vehicle travel.

When analyzing the effectiveness of strategies from the literature, it is important to note that it is often difficult to compare studies for a variety of reasons, including:

- **Strategies can vary in their degree of stringency/application** – For instance, a VMT-fee of 10 cents per mile will have a different effect than a fee of 25 cents per mile.
- **The effectiveness of strategies varies over time** – Some strategies have near-term impacts, such as pricing strategies and telework, which may be implemented quickly, while others take more time – for instance, land use policies have impacts as development occurs and vehicle technology strategies require a turn-over of the vehicle fleet.
- **Strategy effectiveness often depends on context** – Particularly for VMT reduction strategies, factors such as land use patterns, existing travel options, and existing transportation pricing (including fuel prices) have important effects on traveler response. Strategies such as transit and bicycle/pedestrian enhancements typically have more effects in urban areas compared to less densely developed areas and have more effects when the cost of driving is high.

Studies that have looked at various pathways to achieve significant GHG reductions from transportation generally find that **vehicle technology and fuel strategies have the largest potential for deep GHG reductions**, with **supporting effects from MSTB strategies,** particularly during the transition to ZEVs**.** While TSMO strategies can contribute to GHG reductions as well, impacts at a regional scale have not as often been explored. A study that explored pathways to reduce transportation petroleum use by half on the West Coast between 2015 and 2030, for instance, estimated that additional shifts to alternative fuels (e.g., EVs) and vehicle efficiency improvements could together achieve about 27% of needed reductions, and initiatives focused on travel demand could achieve about 2% of needed reductions in 2030 (with existing policies and regulations related to vehicles, fuels, and sustainable community development yielding the remainder).[6]

A 2021 study by the National Academy of Sciences on "Accelerating Decarbonization of the U.S. Energy System" (in prepublication release) notes that "Electrification of energy services, in tandem with decarbonization of electricity generation, has emerged as a core element in nearly all deep decarbonization scenarios." The study notes the large near-term potential in the transportation sector, highlighting the importance of increased vehicle fuel economy standards, with light-duty ZEVs ramping to 50% of light-duty vehicle sales and 30% of medium- and heavy-duty sales in 2030; setting a clean energy standard for electricity generation, designed to reach 75% zero-emissions electricity by 2030 and net zero by 2050; and the potential role of carbon pricing. The study also emphasizes the benefits of "no regrets" actions, particularly in the first 10 years, including encouraging MSTB strategies that shift travel from SOVs to multi-occupancy vehicles, public transit, cycling and walking (although it notes that historically, these shifts can be difficult and costly to achieve), as well as shifting on-road trucking to freight rail, improvements in the fuel efficiency of new internal combustion engine (ICE) vehicles, and TSMO strategies.[7]

Vehicle/Fuel Strategies

Hybrid, Plug-in Hybrid, and Electric Vehicles

Replacing gasoline or diesel-fueled internal combustion engine (ICE) powered vehicles of all classes with hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs) has been identified in most climate plans as a primary means of achieving deep GHG reductions from transportation. HEVs, which have been on the market for over a decade, offer average GHG emission reductions of 25% compared to ICE technology. PHEVs, which combine an electric motor and a regular combustion engine, offer on average 50% GHG reduction compared to an ICE vehicle and BEVs offer the greatest direct emissions reduction because they eliminate fuel combustion and tailpipe emissions entirely. Based on the current electrical power generation mix and associated grid emissions in the COG region, switching from an ICE vehicle to BEV is estimated to reduce total (across the fuel cycle) GHG emissions by 73 to 76%. Shifts to renewable fuels in electricity generation will increase these benefits further.

A key factor for achieving near-term GHG reduction is the rate at which vehicle fleets turn over. Given that personal vehicles can be expected to stay in service 10 to 20 years, it is estimated that to achieve a goal of net zero emissions from vehicles by 2050 will require automakers to stop selling new ICE vehicles altogether by around 2035. Some economic research also suggests that if automakers phase out sales of new ICE vehicles, it is possible older gasoline-powered cars might be held onto longer as consumers who cannot afford electric vehicles hold onto cheaper used models.

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[6] ICF, *Half the Oil: Pathways to Reduce Petroleum Use on the West Coast,* January 2016. https://www.ucsusa.org/sites/default/files/attach/2016/01/ICF-Half-the-Oil-CA-WA-OR.pdf.
[7] National Academies of Sciences, Engineering, and Medicine, 2021. *Accelerating Decarbonization of the U.S. Energy System*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25932.

As a result, the effectiveness of vehicle fleet strategies depends on both 1) the types and efficiencies of new vehicles available; and 2) the rate of vehicle turnover. Policies such as electrifying government fleets and ridesharing fleets (which tend to drive more miles), higher-fuel efficiency standards (national policy), and offering rebates to replace older vehicles with more fuel-efficient models (e.g., "Cash for Clunkers") can help to advance these goals. Some of these rebate programs, however, have been criticized for benefiting higher-income groups who are more likely to be purchasing new rather than used vehicles. There are also equity issues associated with charging. It can be difficult for those who live in multi-family dwelling units or other larger housing units to charge their vehicles at home. At the state level, California is leading an effort to incorporate equity into incentive and rebate programs by offering point-of-sale vouchers, and low-income rebates to overcome existing upfront cost barriers for low-income populations. These initiatives have been recently followed by other states that have joined the ZEV Program.

Low-Carbon Fuel Standards

In addition to shifting the fleet of vehicles, changes in the fuels used in ICE vehicles can also reduce GHG emissions. A low-carbon fuel standard (LCFS) is a performance- and market-based regulation that requires fuel producers and suppliers to lower the GHG intensity, or carbon intensity, of transportation fuels. Because the regulation does not set volumetric targets for specific fuels, it is considered a fuel-neutral policy that offers regulated entities greater flexibility.[8]

California, Oregon, and Washington are the only three U.S. states that have implemented a LCFS program to date. LCFS programs have been shown to reduce GHG emissions and increase the share of lower carbon fuels in the transportation sector, while having a smaller cost impact on retail fuel prices relative to other decarbonization policies. In addition, an LCFS program can be designed with cost containment elements to avoid significant cost pressures on fuel producers and consumers. Estimated impacts of LCFS programs in North America show reductions of GHG emissions by an average of 3.6% to 5.5% per year. As a result, these fuel standards can help to support GHG reductions during the period of phase out of ICE vehicles.

Mode Shift and Travel Behavior (MSTB) Strategies

While for individual travelers and trips, substantial GHG reductions can be achieved by shifting from driving alone to ridesharing, transit, bicycling, walking, or telework, most studies suggest that MSTB strategies can achieve meaningful but not deep GHG reductions on their own at a regional scale over a 10- to 30-year period.

Modeling studies, conducted by the U.S. Environmental Protection Agency, the U.S. Department of Transportation, and others have typically estimated a reduction in light-duty transportation GHG emissions of 4% to 24% from MSTB strategies compared to a projected baseline forecast for 2050, based on a range of assumptions. These studies typically show that higher-level reductions require aggressive assumptions associated with raising the cost of travel through VMT fees and/or Pay-as-you-Drive insurance. Across a series of regional scenario studies conducted for the U.S. EPA, for instance, transportation pricing strategies like VMT fees and parking pricing showed the greatest potential impact on regional light-duty VMT, with hypothetical

[8] Examples of fuels include ethanol produced from various sources, soybean-based biodiesel, and waste grease biodiesel.

pricing strategies of $0.05 to $0.10 per mile on their own estimated to result in a 3.8% to 9.6% decrease in regional light-duty VMT compared to the future baseline forecast. Land use and smart growth strategies also showed relatively large effects, depending on amount of development growth anticipated. Transit improvements and bicycle and pedestrian infrastructure generally showed modest effects, around 1% or less in relation to the baseline forecast. These study effects are generally consistent with previous studies conducted for COG, such as work of the Long-Range Plan Task Force, which analyzed various transit, land use, and other strategies.

Constraints generally relate to the fact that many of these strategies are geared toward reducing a subset of trips. For instance, while employer-based trip reduction strategies -- including telework, commuter benefits, and parking cash out strategies -- have notable impacts on reducing vehicle commuting, commuting to and from work accounts for slightly less than one quarter of total vehicle trips and about 29% of VMT by households nationally. Bicycle and pedestrian modes generally are geared toward short trips, and while enhancements to bicycle/pedestrian infrastructure increase activity by these modes, they do not always substitute for vehicle trips; however, they have the potential to reduce longer trips by improving connections to transit. Pricing strategies that are broad-based such as VMT fees affect more travel and create incentives that when combined with investments in transit, bicycling, walking, and other strategies can have more notable effects.

At the regional scale, for nearly a decade, California's 18 MPOs have been required to demonstrate that their long-range transportation plans will achieve GHG reduction targets established by the California Air Resources Board (CARB). Notably, the MPOs cannot take credit for federal or state programs that improve vehicle fuel efficiency or accelerate EV deployment but must rely entirely on VMT reduction through Sustainable Communities Strategies. The CARB targets are expressed as a percentage change in per capita passenger vehicle GHG emissions relative to 2005, with targets for 2035 ranging from a 13% reduction to a maximum 19% reduction per capita. These targets are considered aggressive, and many of the larger MPOs have found it challenging to demonstrate how their long-range transportation plans would hit the targets. Most urbanized areas also are projected to grow in population at higher rates, so even with meeting the targets, total VMT is forecast to increase.[9] A statewide assessment of how well the SB 375 program has been reducing VMT and GHG emissions found that progress is not on track to meet the targeted level of VMT per capita reduction to date.

While showing relatively modest regional effects, MSTB strategies are viewed as important to help to keep VMT from increasing further due to population growth and to combat the potential "rebound effect" of vehicle efficiency policies,[10] which would degrade the benefits of vehicle technology improvements. Bundling MSTB strategies is often cited as important to generate the largest benefit, recognizing that combining MSTB strategies often can yield synergistic effects (a larger emissions reduction benefit than simply summing the effect of strategies on their own). Studies suggest that a mix of "push" and "pull" strategies together are the most effective at stimulating modal shift - for instance, by combining pricing policies that increase the cost or inconvenience of driving with transit investments. It has been noted, for example, that campaigns and infrastructure to support cycling that also affect space and priority for cars are generally regarded as more effective in reducing VMT than

[9] For instance, in the San Francisco Bay Area, population is forecast to increase by about 27% during the period 2005-2035, while the VMT per capita target is a reduction of 19%.
[10] The "rebound effect" occurs when people drive more with more fuel-efficient vehicles since the cost of driving is lower.

those that do not, and the greatest effects can be reached when combined with measures that discourage car traffic, such as vehicle congestion fees, closing streets for car traffic, or removing car parking. On the other hand, some combinations of strategies have diminishing returns. For instance, increasing transit investment and increasing telework together may result in less than the sum of effects of these strategies individually, since some people who shift from driving to transit may be the same people who shift to telework, thereby eliminating a transit trip rather than a vehicle trip when teleworking.

A 2018 scenario study in the Albuquerque, New Mexico region attempted to identify which MSTB strategies it would take to reach a 40-70% reduction in light-duty vehicle GHG emissions from 2012 levels by 2040. The scenario analysis suggested that no strategy alone could reach the 40% mark but a combination of very compact development, transit enhancements, and a $0.25 per mile VMT fee potentially could. According to this analysis, a high VMT fee would have the largest effect, with other strategies playing a smaller role.

Overall, MSTB strategies focusing on land use and multimodal transportation options have significant co-benefits in terms of public health, enhancing access to jobs and other opportunities, and equity. Road pricing and telework strategies raise some equity concerns in relation to impacts on lower-income households and disparities in the ability of typically lower-income jobs in retail, warehousing, service industries, and others to telework. Equity impacts from road pricing may be addressed through strategies to lower transit costs, implement free transit programs, and/or invest fees collected into transit and other options.

Transportation Systems Management & Operations (TSMO) Strategies

ICE vehicles sitting in traffic or moving in stop-and-go conditions consume more fuel and emit more emissions than vehicles traveling at a steady rate between 35 mph and 65 mph. Consequently, there is some potential to reduce GHG emissions by smoothing traffic flow. It is estimated that traffic incidents, weather conditions, special events, and poor traffic signal timing are responsible for about half of the delay on roadways, and so operational strategies that reduce non-recurring delay could also have notable effects on reducing emissions.

Studies on eco-driving strategies that aim to improve fuel economy by smoothing acceleration and deceleration, limiting unnecessary idling, and avoiding excessive speeding have generally demonstrated average fuel savings of 2% to 7%. Eco-driving can be implemented as a behavioral change strategy (education, incentives) or a vehicle design feature (especially for connected and automated vehicles). While offering some promising reductions, a review of eco-driving training studies found that the impact of training deteriorates in a matter of months, even with financial incentives, and effectiveness wanes over time even with in-vehicle feedback. However, connected and autonomous vehicle technology may allow these levels of fuel savings to persist.

Most studies of TSMO strategies show effects on individual corridors or facilities and do not assess impacts at a regional level; moreover, many of these studies do not account for potential induced traffic (i.e., improved traffic flow spurring additional vehicle travel). A simulation modeling study of several operational improvement strategies conducted in the San Francisco Bay Area, sponsored by the Federal Highway Administration, suggested that the impacts of a comprehensive package of strategies in 2015 would result in about a 2.3%

increase in VMT but an overall reduction of vehicle hours of travel of 8.8%. The combined effects, even with an increase in VMT, were estimated to reduce regional vehicle carbon dioxide emissions by about 1.6%, suggesting modest regional emissions reduction potential.

It should be noted that these studies are based on ICE vehicles and that the effects of speeds and traffic flow on hybrid vehicles and EVs will differ. For instance, for hybrid vehicles, energy from braking charges the vehicle's battery, resulting in higher miles per gallon in stop-and-go city driving compared to freeway driving. As a result, the benefits of TSMO and eco-driving strategies on GHGs would be expected to decline as the fleet transitions to hybrids and EVs.

Carbon Pricing

Carbon pricing is a market-based approach that attempts to capture the social costs of GHG emissions (e.g., costs associated with effects of heat waves, droughts, flooding, and other effects of climate change) and tie them to their sources through a price on emissions. Carbon taxes are implemented economy-wide, setting a specific price on carbon emissions and letting the market achieve emissions reductions in response to the price incentive. Motor fuel taxes are similar but with the tax rate typically specified by individual fuel rather than set in relation to the price of carbon. These policies create economic incentives that reduce GHG emissions in multiple ways: by encouraging shifts to purchases of more fuel-efficient/lower-carbon emitting vehicles, encouraging a reduction of VMT, and encouraging use of lower-carbon fuels. Fuel taxes are much lower in the U.S., than in other advanced economies; the average fuel tax rate (combining federal, state, and local taxes) in the U.S. was approximately $0.52 per gallon in 2019, compared to an average rate of $2.24 per gallon among 36 nations.

Studies in several countries including Canada, Sweden, and Ireland have estimated reductions of carbon emissions of from 1.75% to 19%, depending on level of the carbon tax and other factors. The literature tends to show relatively low price-elasticities for drivers consuming fuel, at approximately -0.3 in the short run and -0.7 in the long run. These values suggest that a 10% increase in fuel prices could be expected to reduce consumption by 3% in the first one to two years and 7% within five to ten years. Consequently, large increases in fuel price could yield notable effects on fuel consumption, although price elasticity estimates vary considerably with economic conditions. Alternative supply-side strategies include emissions trading schemes, such as cap-and-trade and cap-and-invest policies, which cap the amount of carbon dioxide that can be produced and let the market determine the price of carbon and the overall set of strategies that will achieve the emissions limit.

There are some equity concerns associated with implementing a carbon tax or significant increases in fuel taxes in the transportation sector, as such a tax could be regressive. However, subsidies may be provided for low- and moderate-income households, and the use of revenues to fund transit, bicycling, walking and other infrastructure or subsidies (e.g., free transit) could help to support equity.

Conclusions and Next Steps

Overall, the review of literature suggests that significant reductions in GHG emissions from on-road transportation are feasible technologically and from a behavioral perspective, but likely will be challenging to achieve without significant policy actions at all levels of government to rapidly advance the adoption of ZEVs and reduce use of ICE vehicles. Mode shifts, vehicle efficiency improvements, and TSMO strategies can play an important role in reducing emissions, particularly in the 10 to 20-year timeframe to meet near-term goals while the vehicle fleet transitions toward ZEVs. The research highlights that the timeframes of achieving reductions in GHG emissions also varies across strategies, with some economic incentives, demand management strategies, and transit and highway operations strategies potentially having near-term effects while others, such as transit investments, land use changes, and large-scale turn-over of the vehicle fleet will take more time. The literature also points to both equity concerns and opportunities to support equity associated with many of the strategies.

This review will help to inform consideration of possible scenarios for analysis of significant GHG emissions reductions from on-road transportation in the metropolitan Washington region. Moving forward to the scenario analysis and final report, this study also will further explore the equity implications of strategies.

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Literature Review

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.[11] 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.

This document is an initial step in a climate change mitigation study that seeks to identify what kinds of projects, programs, and policies (collectively referred to as "strategies") may be effective to achieve significant reductions of on-road transportation GHG emissions (associated with the 50% and 80% reduction goals by 2030 and 2050, respectively). This document provides a literature review and summary of climate change mitigation studies conducted within the metropolitan Washington region, in other areas across the country, and around the world. The focus of the literature review is to summarize findings regarding what transportation GHG reduction strategies are being proposed, planned, and implemented, and what the literature says about the potential effectiveness of strategies to help inform scenarios for analysis in the metropolitan Washington region.

This literature review is organized into the following sections, with a focus on reviewing relevant actions and strategies for achieving on-road transportation GHG reductions:

- A review of climate action plans in the metropolitan Washington region, including those from state and local governments, as well as utilities (since electric utility-related decarbonization strategies affect the overall effectiveness of electric vehicle strategies).
- A review of climate plans from outside the metropolitan Washington region, including from a sample of cities, regions, and states within the U.S. and internationally.
- A summary of national-level policies affecting transportation GHGs that will have important implications on regional goals.
- A review of literature on the effectiveness of various transportation strategies at reducing GHG emissions.

[11] 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/

In this document, transportation actions are grouped into the following three primary categories of strategies reflecting primary pathways to reduce GHG emissions: 1) **Vehicle Technologies and Fuels strategies** (addressing strategies that increase the share of lower carbon fuels or shift the fleet of motor vehicles to more fuel efficient vehicles or electric vehicles); 2) **Mode Shift and Travel Behavior (MSTB) strategies** (which reduce the amount of vehicle travel and/or shift travel to more efficient modes, such as transit, ridesharing, bicycling, and walking), and 3) **Transportation Systems Management and Operations (TSMO) strategies** (which optimize the efficiency of travel by reducing vehicle travel delay and/or encourage more eco-friendly driving patterns). In addition, **carbon pricing**, which involves both demand-side measures such as carbon taxes and supply-side measures such as emissions trading systems, is addressed separately. Such pricing strategies create economic incentives that support both changes in vehicle technologies/fuels and shifts in travel mode and travel behavior.

The literature review findings provide a basis for identifying possible transportation GHG strategies to include in scenarios and to consider for modeling/analysis based on the likely impact and effectiveness.

Summary of Previous COG and TPB Studies on Climate Change

COG has a rich set of past work exploring transportation GHG emissions reduction strategies to pull from and many of the most promising strategies for decarbonized transportation systems have already been studied. The "Climate Change Mitigation Study of 2021- Phase 1 Report" documented previous studies completed by COG and TPB addressing transportation GHG reductions through previous modeling and studies.[12] The Phase 1 report notes that the performance analysis of the region's long-range transportation plan (LRTP), Visualize 2045, predicts a reduction in vehicle miles traveled (VMT) per capita, but that this reduction is more than offset by population growth (an estimated 1.3 million additional people in the region). Assumed vehicle fuel economy improvements, however, yield an overall estimate of on-road GHG emissions that are 23% below 2005 levels in 2045 (p. 2), but this is still far short of the 50% to 80% goals if applied to transportation. The Phase 1 report is focused on the findings from four studies:

- The Final Report of the "What Would it Take?" Scenario Study (WWIT), which was completed by the TPB in 2010 and asked how the region could achieve regional GHG reduction goals in the transportation sector.[13]
- The final Technical Report of the Multi-Sector Working Group (MSWG) study, which identified viable and implementable local, regional, and state strategies for reducing GHG emissions across key sectors - Energy, the Built Environment, Land Use, and Transportation. This effort was a partnership of the TPB with the Metropolitan Washington Air Quality Committee (MWAQC) and COG's Climate, Energy, and Environment Policy Committee (CEEPC). [14]
- The Final Report from the TPB's Long-Range Plan Task Force (LRPTF), which identified projects, programs, and policies to improve the performance outcomes of the region's transportation system and included carbon dioxide emissions as one of the metrics.[15]
- The Metropolitan Washington 2030 Climate and Energy Action Plan (CEAP), which was published in late 2020.[16] Within the CEAP, there are several transportation strategies including MSTB and Zero-Emission Vehicles (ZEVs) that together with actions from other sectors were identified to achieve the 50% below 2005 level goal by 2030. It is worth noting that while the CEAP includes transportation-related

[12] Metropolitan Washington Council of Governments. "TPB Climate Change Mitigation Study of 2021, Phase 1 Report: Greenhouse Gas Emissions Reductions Strategies: Findings from Past Studies." March 2, 2021. https://www.mwcog.org/documents/2021/03/16/tpb-climate-change-mitigation-study/

[13] Metropolitan Washington Council of Governments. "Final Report: What Would It Take? Transportation and Climate Change in the National Capital Region." Washington, D.C. May 18, 2010. https://www.mwcog.org/documents/2010/05/18/what-would-it-take-scenario-land-use-projects/

[14] Metropolitan Washington Council of Governments (submitted by ICF International). "Final Technical Report: Multi-Sector Approach to Reducing Greenhouse Gas Emissions in the Metropolitan Washington Region." January 31, 2016. https://www.mwcog.org/documents/2016/08/01/multi-sector-approach-to-reducing-greenhouse-gas-emissions-in-the-metropolitan-washington-region-finaltechnical-report/

[15] National Capital Region Transportation Planning Board (prepared by ICF International). "An Assessment of Regional Initiatives for the National Capital Region: Technical Report on Phase II of the Long-Range Plan Task Force." December 20, 2017. https://www.mwcog.org/documents/2017/12/20/long-range-plan-task-force-reports-projects-regional-transportation-priorities-plan-scenario-planning-tpb/

[16] 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/

strategies, the bulk of reductions contained within the CEAP occur in other sectors, mainly through Clean Electricity and Zero-Emission Buildings.

Overall, the studies identify pathways to significant GHG reductions in transportation but also highlight some of the challenges. For instance, both the WWIT and the MSWG study explored an array of state, regional, and local strategies and found a significant gap in achieving the 2030 and 2050 goals without new federal measures, such as significantly higher light-duty and heavy-duty vehicle fuel economy standards and/or significant increases in fuel prices, even with aggressive "stretch" strategies. The MSWG study, similar to the more recent CEAP, estimated that the largest regional GHG emissions reductions could come from outside the transportation sector. In the MSWG study, building energy efficiency and the power sector/renewables were estimated to contribute the largest reductions, with on-road transportation strategies responsible for a reduction of 4.2 million metric tons (MMT) of carbon dioxide (CO_2) and land use strategies for a reduction of 2.9 MMT CO_2 in 2050, off a baseline of 80.8 MMT CO_2 from all sectors.

The LRPTF study explored a range of transportation strategies independently – focusing on transportation investments and policies that address mode shift and travel behavior and TSMO strategies (it did not explore vehicle and fuel strategies). The study estimated CO_2 emissions reductions from these strategies in 2040 as compared to the constrained element of the TPB's long-range plan, finding the most significant reductions from amplified employer-based travel demand management, which included parking pricing strategies and transit/vanpool subsidies (7% reduction), followed by regional land use strategies (4% reduction) and then a series of transit investments and policies, including Metrorail core capacity improvements, transit rail extensions, regionwide bus rapid transit and transitways, and transit fare policy changes (each generally 1-2% reduction). Operational improvements regionwide were estimated to reduce emissions by about 1%.

As TPB looks to determine the best and most effective strategies for reducing GHG emissions, most of the ideas outlined in these studies are still relevant today. This literature review highlights both the potential for strategies as well as some of their limitations. At the same time, new and more aggressive scenarios and assumptions about strategies, new applications of strategies, and combinations of strategies will be explored to identify what may be possible. Equity considerations are also noted throughout the report and will be a priority consideration moving forward into new stages of analysis.

Climate Planning in the National Capital Region

Many governments at the state and local levels have recognized the importance of climate action, and its importance to ensure sustainable growth, economic opportunities, and better health outcomes for their residents. This section provides a summary of climate action plans at the state and local levels within the metropolitan Washington region.

State Climate Action Planning

States have the opportunity to address climate change through a variety of policies and actions for the economy as a whole. Nationally, the transportation sector is the largest sector contributing to GHG emissions, responsible for about 29% of U.S. emissions.[17] The majority of these emissions come from on-road sources. Consequently, transportation is an important component of GHG reduction plans. Actions may be specified via state legislation, and include investment and funding strategies, incentives, regulation, and integrating climate and sustainability considerations in the state agencies' planning and operations.

In the last few years, many states have developed or updated climate action plans or implemented legislation that includes a commitment to GHG reduction goals. Examples of state GHG programs around the country adopting statewide Renewable Energy Portfolio Standards, developing electric vehicles (EV) and charging incentive programs, and pursuing investments in transit, bicycling, and walking, and other sustainable modes. Many states also participate in collaborative programs, such as the Regional Greenhouse Gas Initiative (RGGI) program that caps carbon emissions from power generation facilities or the Transportation and Climate Initiative (TCI), which seeks to decarbonize the transportation sector using a "cap-and-invest" program. State action is limited somewhat in scope and capabilities, and states often look, in part, to federal and local government actions to implement complete and comprehensive climate action solutions.

States in the metropolitan Washington region recognize the challenges of climate change and have made commitments to reduce GHG emissions, as summarized below in Table 1. These policies and commitments are briefly described below.

[17] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions Inventory." p. ES-27. 2021. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks. On-road transportation accounts for about 81% of the transportation emissions (p. 2-37).

Table 1. Summary of State Government Greenhouse Gas Reduction Targets, Transportation Sector Targets, and Transportation Strategy Types

Jurisdiction	GHG Reduction Target	Transportation Target	Vehicle/Fuel Strategies	MSTB Strategies	TSMO Strategies	Carbon / Fuel Pricing
Maryland	Maryland law requires a minimum of 40% below 2005 levels by 2030; the GGRA Plan committed to a more ambitious goal of 50% below by 2030 and net zero by 2045	40% reduction by 2030 goal, and strive to have 535,000 plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs) registered in MD (without federal action) or 790,000 vehicles (with federal action) by 2030	✓	✓	✓	
Virginia	30% below the business-as-usual projections for 2025	No transportation-specific GHG emissions reductions target	✓	✓	✓	
District of Columbia.	50% below 2006 levels by 2032, and 80% by 2050; updated to carbon neutral goal by 2050	Goal for all new vehicles registered in DC to be electric by 2050	✓	✓	✓	✓

Maryland

On February 8, 2021, the Maryland Department of the Environment (MDE) published the 2030 Greenhouse Gas Emissions Reduction Act Plan (GGRA Plan).[18] This Plan is a continuation of the efforts set by the first Greenhouse Gas Emissions Reduction Act becoming a law in 2009 (and re-authorized in 2016), and in the various iterations of the GGRA Plan (2013, 2015, and 2019).

Through this Plan, Maryland set ambitious GHG reduction goals of 50% by 2030 compared to 2006 levels. It also calls for net-zero economywide GHG emissions by 2045. The GGRA Plan notes that goals will require a tailored and inclusive approach to climate and justice, and the plan details a set of measures that include investments in energy efficiency and clean/renewable energy solutions, clean transportation, and improved management of forests and carbon sinks. The plan aims for these measures to not only reduce GHG emissions but to also contribute to a stronger state economy by creating Maryland jobs and improving the health of communities. The plan places a special emphasis on incorporating environmental and climate justice into the state's climate approach, including ensuring an equitable distribution of the benefits on disadvantaged and overburdened communities.

The transportation strategy detailed in the GGRA Plan is focused on providing Maryland residents reliable transportation alternatives to single occupancy vehicles, while supporting the deployment of zero-emissions

[18] Maryland Department of the Environment. "2030 Greenhouse Gas Emissions Reduction Act Plan." 2021. https://mde.maryland.gov/programs/Air/ClimateChange/Pages/Greenhouse-Gas-Emissions-Reduction-Act-(GGRA)-Plan.aspx

vehicles. The three strategies highlighted in the plan are 1) deploying zero-emissions vehicles through light-, medium-, and heavy-duty ZEV regulations, tax credit incentives, and electric vehicle supply equipment (EVSE) deployment, 2) leading by example through additional deployment of EVSE and ZEVs in the state motor vehicle fleet, and 3) reducing VMT (compared to baseline forecast trends) through expanding investments in public transit systems and bike and pedestrian infrastructure, travel demand management, and other strategies.[19]

The plan notes that transportation technologies play a critical role in reducing emissions from the transportation sector, with emissions reductions coming from federal standards and supplemental state actions, such as the Maryland Clean Cars Program, which applies California's vehicle emissions standards to vehicles purchased in Maryland. It notes that the pace of adoption of new vehicle technologies is the primary determinant for emissions reductions from the transportation sector by 2030. The plan also identifies contributions from multimodal freight strategies, travel demand management and pricing initiatives, public transportation, and bicycle and pedestrian initiatives. Estimated GHG emissions reductions from "on-the-books" and "emerging and innovative" (unfunded) transportation strategies in 2030, compared to a 2030 business-as-usual scenario are summarized below:

- Transportation technologies (largely vehicle technologies; also including innovative TSMO strategies): 4.11-4.47 Million Metric Tons (MMT) carbon dioxide equivalent (CO_2e) reduction.
- Travel demand management and pricing strategies (largely from expanded telework and dynamic demand management strategies): 0.80-1.99 MMT CO_2e.
- Public transportation strategies (including EV transit bus feel transition): 0.27-0.33 MMT CO_2e.
- Multimodal freight strategies (including freight rail programs, and unfunded programs): 0.12-0.15 MMT CO_2e.
- Bicycle and pedestrian strategies (including existing programs and expanded infrastructure development): 0.06-0.07 MMT CO_2e.

Following the GGRA Plan, Maryland Department of Transportation (MDOT) worked with MDE and other partners to develop and test strategies for the transportation sector to achieve the original "40 by 30" goal (i.e., reduce GHG emissions by 40% from 2006 levels by 2030), through its own MDOT GGRA Plan.[20] This transportation-focused plan included a reference case (including federal vehicle technology and fuel economy standards, federal renewable fuels standards, and the Maryland Clean Cars Program) and an analysis of two policy scenarios: one with "on-the-books" strategies, and one with more aggressive "emerging and innovative" strategies. The analysis estimated that under the reference case, on-road GHG emissions would decrease by 6.35 MMT CO_2e in 2030 compared to 2006 (about a 21% reduction from the 2006 level). On-the-books strategies, which include plans and programs to yield annual VMT growth of 0.6% per year rather than 1.2% per year, as well as various TSMO, demand management, and other strategies, would decrease on-road GHG emissions by another 2.19 MMT CO_2e (additional 7% reduction), falling short of the 40% reduction goal. The aggressive policy scenario included 16 emerging strategies and 6 innovative strategies, some combination of

[19] The Plan includes strategies to reduce the rate of growth of VMT to 0.6% annual growth, plus additional smart growth and transit measures.

[20] Maryland Department of Transportation. "2020 Maryland Department of Transportation GGRA Plan." 2021. https://www.mdot.maryland.gov/OPCP/MDOT_GGRA_Plan.pdf

which would be needed to meet the 40% reduction goal. Examples of currently unfunded strategies with the largest estimated GHG reduction potential evaluated under this scenario included:

- Regional Clean Fuel Standard (estimated $148M cost for a reduction of 0.895 MMT CO_2e).
- EV market share ramp-up of an additional 255,000 vehicles (estimated $140M cost for a reduction of 0.88 MMT CO_2e).
- Extended CAFE Standards (Model years 2026-2030) (no cost, for a reduction of 0.80 MMT CO_2e).
- Autonomous/connected vehicle technologies (estimated $43-$63M cost for a reduction of 0.68-0.73 MMT CO_2e).
- Expanded telework (estimated $100-200M cost for a reduction of 0.300-0.793 MMT CO_2e).
- Expanded dynamic travel demand management strategies (estimated $15-30M cost for a reduction of 0.274-0.972 MMT CO_2e).
- Pay-As-You-Drive Insurance (no cost/private sector implementation for a reduction of 0.123-0.292 MMT CO_2e).
- TSMO/Integrated Corridor Management, Arterial System (estimated $453-680M cost for a reduction of 0.10-0.18 MMT CO_2e).
- TSMO/Integrated Corridor Management, Limited Access System (estimated $108-152M cost for a reduction of 0.08-0.14 MMT CO_2e).
- 50% to 75% EV transit bus fleet (estimated $93M funding for an estimate of 0.081 to 0.103 MMT CO_2e reduction).

While the addition of emerging and innovative strategies was estimated to have the potential to meet the 40% reduction goal in on-road transportation emissions from 2006 levels by 2030, the report concluded that achieving this emissions reduction goal will not be easy and will require aggressive investment in transportation beyond current levels of projected funding, supportive policy and new and additional funding to support the investments, a shared commitment to advance reliable, low-cost and low-carbon technologies, and a best-case scenario for the adoption of EVs in public and private vehicle fleets in Maryland.

Virginia

Virginia's latest Climate Action Plan was released in 2008 and included a GHG emissions reduction goal of 30% below the business-as-usual projections (equivalent to a reduction of 69 MMT of carbon dioxide equivalent), by 2025.[21] The CAP included the following recommendations for the transportation sector: "Reductions of GHG emissions related to VMT through expanded commuter choice, improved transportation system efficiency, and improved community designs."

Since then, in 2020, Governor Northam signed the Bill HB 1164 that directs the Department of Environmental Quality to address climate change by *developing and implementing policy and regulatory approaches to reducing climate pollution and promoting climate resilience in the Commonwealth and by ensuring that climate impacts and climate resilience are taken into account across all programs and permitting processes.*[22]

[21] Governor's Commission on Climate Change. "Final Report: A Climate Change Action Plan." 2008. https://rga.lis.virginia.gov/Published/2009/RD19/PDF
[22] Virginia's Legislative Information System. "House Bill No. 1164." 2020. https://lis.virginia.gov/cgi-bin/legp604.exe?201+ful+HB1164

The transportation sector produces roughly 48% of Virginia's GHG emissions (48 MMT annually). Thus, the Commonwealth is deploying different strategies to mitigate emissions from this key sector.[23] In recent years, Virginia has made significant changes to support transportation decarbonization, including becoming the 13th state to join the California Zero-Emission Vehicle (ZEV) Regulation.[24]

Virginia's Transportation Plan (VTrans) is an ongoing effort from the Commonwealth of Virginia that aims to deploy a transportation system that will be "good for business, good for communities and good to go."[25] Amongst the objectives set by VTrans, there are sustainable transportation communities' goals, including:

- Reducing per-capita VMT.
- Reducing transportation-related nitrogen oxides (NOx), volatile organic compounds (VOC), particulate matter (PM) and carbon monoxide (CO) emissions.
- Increasing the number of trips traveled by active transportation (bicycling and walking).

In March 2021, VTrans released a Policy guide for the identification and prioritization of the VTrans mid-term needs, based on the VTrans guiding principles, and objectives.[26] This policy guide included recommendations that aim to increase the transportation system's sustainability and its equitable access, including:

- Transit access to equity emphasis areas.
- Pedestrian and bicycle access to activity centers.
- Transportation demand management solutions based on roadway facility type and VTrans travel market.

The Virginia EV Incentive Working Group -- a highly collaborative group composed of State agencies, private partners, and non-governmental organizations (NGOs) -- has finalized a Feasibility Report in November 2020 that highlights the need for Virginia to put in place strong incentives for clean vehicle technologies and to accelerate the transition of Virginia's on-road vehicles towards zero-emission vehicles.[27] This report suggests that Virginia should aim for an EV deployment target of 10-20% of market share by 2027 and recommends additional policies including, EV-Ready building code ordinances, toll cost reduction, and the adoption of a Low-Carbon Fuel Standard, to achieve this goal.

District of Columbia

The District of Columbia's first Climate Action Plan, Climate of Opportunity, was released in 2010 and committed the District to GHG emissions reduction targets of 50% below 2006 levels by 2032, and of 80% below by

[23] Virginia Electric Vehicle Incentive Working Group. "Electric Vehicle Incentive Working Group Feasibility Report." 2020. https://www.virginiaev.org/wp-content/uploads/2020/11/FINAL-EV-Rebate-Report-11.18.pdf

[24] Conner Smith. "Virginia Becomes 13th State to Join the ZEV Program." 2021. https://www.atlasevhub.com/news/virginia-becomes-13th-state-to-join-the-zev-program

[25] Commonwealth of Virginia. "Virginia's Transportation Plan." https://www.vtrans.org/

[26] Office of Intermodal Planning and Investment for the Commonwealth Transportation Board. "Policy Guide for the Identification and prioritization of the VTrans mid-term needs." March 2021. https://icfbiometrics.blob.core.windows.net/vtrans/assets/docs/Policy_Guide_for_Identification_and_Prioritization_of_VTrans_Mid-term_Needs.pdf

[27] Virginia Electric Vehicle Incentive Working Group. "Electric Vehicle Incentive Working Group Feasibility Report." 2020. https://www.virginiaev.org/wp-content/uploads/2020/11/FINAL-EV-Rebate-Report-11.18.pdf

2050.[28] [29] At the inaugural North America Climate Summit in 2017, Mayor Muriel Bowser committed the District to the more ambitious goal to achieve carbon neutrality by 2050. Carbon Free DC summarizes this commitment and the steps required to achieve this goal.[30] This plan states that the biggest driver of emissions in the District is currently the energy used to heat, cool, and power buildings (73% of total GHG emissions), and that emissions from cars, trucks, and buses (including the electricity used to power the Metrorail trains, DC streetcar, and the Circulator buses) account for 22% of all GHG emissions. Waste disposal and wastewater treatment make up the remaining 5% of total GHG emissions. Carbon Free DC emphasizes that achieving carbon neutrality will require building on existing policies and programs but will also require innovative thinking and shifts in the way people move around the city.

The District of Columbia's Climate and Energy Action Plan, called Clean Energy DC, was completed in August 2018 and lays out a set of 55 actions for the District government, local businesses, and residents to dramatically reduce GHG emissions.[31] For the transportation sector, actions are dedicated to encouraging the use of EVs, and noted that these actions work with tandem with MoveDC, the District's comprehensive transportation plan. MoveDC was last updated in 2014 and built on the SustainableDC 2032 transportation goal of increasing the share of public transit, biking, and walking to 75% of all work trips within the District. A 2021 update of MoveDC is underway and includes a focus on mapping mobility networks for bicycles, transit and freight to achieve mode shift goals; addressing how recent, emerging and future mobility trends and innovations will shape the transportation system; ensuring equity is a key consideration in making transportation decisions; and engaging with the community to develop a plan that reflects current values and meets federal requirements.[32]

To reduce transportation GHG emissions, Carbon Free DC and Clean Energy DC rely upon the mode shifts from MoveDC, estimating that these shifts from passenger cars to transit, biking, and walking can help the District avoid 3.6% of total GHG emissions (from all sources) in 2032 compared to business-as-usual trends, and would reduce GHG emissions by more than 1 MMT CO_2e by 2050. The plans note that policies that enable mixed-use development and high-density affordable housing are important to support and implement these goals. The Clean Energy DC plan estimates that federal fuel economy standards can help the District avoid 7.1% of total GHG emissions in 2032, transit bus fleet electrification would avoid 2.6% of emissions, and that EV adoption would avoid an additional 0.9% of total GHG emissions in 2032.[33] One of the major milestones highlighted in Carbon Free DC is the need to ensure that all new vehicles registered in DC by 2050 are electric. To accelerate

[28] Government of the District of Columbia. "Climate of Opportunity." September 2010. https://doee.dc.gov/sites/default/files/dc/sites/ddoe/publication/attachments/ClimateOfOpportunity_web.pdf

[29] District of Columbia Department of Energy & Environment. "Climate Action Planning." https://doee.dc.gov/service/climate-action-planning

[30] District of Columbia Department of Energy & Environment. "Carbon Free DC." https://storymaps.arcgis.com/stories/034104405ef9462f8e02a49f2bd84fd9

[31] Government of the District of Columbia. "Clean Energy DC: The District of Columbia Climate and Energy Action Plan." August 2018. https://doee.dc.gov/sites/default/files/dc/sites/ddoe/page_content/attachments/Clean%20Energy%20DC%20-%20Full%20Report_0.pdf

[32] District Department of Transportation. "Move DC." https://movedc-dcgis.hub.arcgis.com/

[33] The analysis assumes the District will achieve its 2032 mode share target. The GHG reductions from EV strategies were calculated after assuming significantly reduced VMT due to the mode share changes, and the GHG reductions from the transit bus fleet electrification strategy assumes increased use of buses due to mode share change.

the transition to EVs, Clean Energy DC identifies strategies for EV readiness (e.g., adopt an EV-ready building code and EV-ready parking lot requirement), EV adoption (e.g., provide EV purchase incentives, implement an EV bulk buy program, establish an EV showcase and purchase center, pursue an EV-only carsharing fleet), shifting to zero emission transit vehicles, and anticipating electric autonomous ridehailing vehicles in the future.

Other State Policy Efforts

In concert with the climate action plans, some of the notable policy actions that the three state-jurisdictions are implementing are noted below. Other actions related to transportation, such as investments in transit, bicycling and walking, and travel demand management programs and policies are also on-going.

ZEV Regulations

Fourteen states have adopted the California Air Resources Board (CARB) Zero-Emission Vehicle (ZEV) Program which requires auto manufacturers to deliver a minimum percentage of passenger cars and light-duty trucks as ZEVs each year.[34] ZEVs are defined as vehicles that produce zero exhaust emissions, excluding emissions from air conditioning systems, and include full battery-electric, hydrogen fuel cell, and plug-in hybrid-electric vehicles. The ZEV regulation is part of the broader Advanced Clean Cars package of regulations that California has developed to limit smog-forming and GHG emissions from tailpipes of light-duty vehicles. Maryland and Virginia have adopted the CARB ZEV regulation.

Multi-State MOU on Medium- and Heavy-Duty Vehicle Sales

Thirteen states/jurisdictions, including Maryland, and the District of Columbia have signed a Memorandum of Understanding (MOU) committing them to strive to make at least 30% of all new medium-and heavy-duty vehicle sales (in their respective jurisdictions) zero-emission vehicles by 2030, and 100% by 2050.[35]

Vehicle and Charging Station Incentive Programs

Jurisdictions are offering grants and rebates for the purchase or lease of zero-emission vehicles and charging stations. Maryland currently offers an excise tax credit up to $3,000 for EVs and plug-in hybrids, and a rebate of 40% of the cost of electric vehicle charging equipment and installation through the Electric Vehicle Supply Equipment (EVSE) Rebate Program.[36] The District of Columbia offers a tax exemption for EVs and high efficiency vehicles (median excise tax per vehicle in 2019 was $680) and a tax credit for alternate fuel infrastructure (including EVSE).[37] Virginia has not implemented statewide EV and EVSE incentives at this time, however the Virginia EV Incentive Working Group has finalized a Feasibility Report in November 2020 that highlights the need

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[34] California Air Resources Board. "Current Zero-Emission Vehicle Regulation." https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/zev-program/current-zero-emission-vehicle-regulation

[35] NESCAUM. "Multi-State Medium and Heavy-Duty Zero Emission Vehicle Memorandum of Understanding." https://www.nescaum.org/documents/multistate-truck-zev-governors-mou-20200714.pdf

[36] Maryland Department of the Environment. "Zero Emission Vehicles." 2021. https://mde.maryland.gov/programs/Air/MobileSources/Pages/ZEV.aspx#:~:text=Incentives%20for%20EV%20Purchases&text=Maryland%20offers%20a%20rebate%20of,%245%2C000%20for%20retail%20service%20stations

[37] DC Department of Energy & Environment. "Electric Vehicles Resources." https://doee.dc.gov/service/electric-vehicles-resources

for Virginia to put in place strong incentives for clean vehicle technologies, to accelerate the transition of Virginia's on-road vehicles towards zero-emission vehicles.[38]

Additional incentives, like Maryland's HOV lanes access incentives for EV drivers, are being offered by states to promote adoption of cleaner vehicle technologies. In addition to voluntary programs, many states are working on marketing campaigns, such as the *Drive Change Drive Electric campaign*, where states are participating in a public-private partnership between auto manufacturers and U.S. Northeast states to advance consumer awareness, understanding, consideration and adoption of electric cars, including battery electric, plug-in hybrid electric, and fuel cell electric vehicles.[39] The Alternative Fuel Data Center keeps an up to date record of all federal and state laws for each state, as well as all the available incentives, including from private utilities.[40]

Transportation and Climate Initiative

The Transportation and Climate Initiative (TCI) is a regional collaboration composed of 13 states and the District of Columbia that aims to reduce carbon emissions from the transportation sector and improve the region's transportation systems.[41]

Since early 2019, Virginia, Maryland and the District of Columbia, along with 11 other states, have been engaged in TCI to design a regional cap-and-invest program that would set a decreasing cap for transportation emissions in the region, and generate proceeds that will then be utilized to improve clean transportation in each jurisdiction. This cap-and-invest program, now called the TCI Program (TCI-P), aims to set a threshold for carbon emissions from gasoline and on-road diesel fuels sold in the participating jurisdictions and will do that by requiring fuel suppliers to hold allowances for the emissions that result from the combustion of the covered fuels. The number of allowances available (and auctioned in regional auctions) will decline over time, which translates into emissions reductions in the transportation sector. The proceeds generated from the allowance auctions will be distributed to the participating jurisdictions, to be invested into equitable, cleaner and more resilient transportation projects and programs that further emissions reductions and provide more sustainable transportation choices. A draft model rule detailing the regulatory framework under which the covered fuel suppliers would operate was released in March 2021.[42]

On December 21, 2020, the District of Columbia, Massachusetts, Connecticut, and Rhode Island signed a Memorandum of Understanding (MOU) to become the first jurisdictions to participate in the TCI-P. Since the announcement of the TCI-P development, many public and private stakeholders (including the American Lung Association, the Natural Resources Defense Council [NRDC], the Union of Concerned Scientists, and Toyota) have publicly stated their support for a policy that addresses GHG emissions from the transportation sector in

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[38] Virginia Electric Vehicle Incentive Working Group. "Electric Vehicle Incentive Working Group Feasibility Report." 2020. https://www.virginiaev.org/wp-content/uploads/2020/11/FINAL-EV-Rebate-Report-11.18.pdf
[39] Drive Change. Drive Electric Campaign. "What's stopping you from going electric?" https://driveelectricus.com/
[40] U.S. Department of Energy. "Alternative Fuels Data Center." 2021. https://afdc.energy.gov/laws
[41] Transportation and Climate Initiative. https://www.transportationandclimate.org/
[42] Transportation and Climate Initiative Program. "Draft Model Rule." March 2021. https://www.transportationandclimate.org/sites/default/files/TCI-P-Draft-Model-Rule-March-2021.pdf

the jurisdictions that participated in the program design.[43] To address concerns about potential impacts to low-income and other disadvantaged populations, the TCI-P is being designed and implemented with equity as a central organizing focus, with each MOU signatory jurisdiction committing to work with its own Equity Advisory Body and the public to inform implementation of equity commitments.[44] To date, Virginia and Maryland have not signed on to the TCI-P, which will start with a "reporting year" in 2022 and a regulated year in 2023.

Local Government Climate Action Planning

Many of the local jurisdictions in the metropolitan Washington region have developed climate action plans or are in the process of developing them. Table 2 below summarizes key components of a sample of plans that have been completed, are in draft, or are at a point where actions have been identified (others are earlier in the process of development). This section provides an overview of some of the actions being taken by local governments, rather than a comprehensive list of plans in the region.

Table 1. Sample of Local Government Greenhouse Gas Reduction Targets, Transportation Sector Targets, and Transportation Strategy Types

Jurisdiction	2050 GHG Reduction Target	Transportation Goals	Vehicle/ Fuel Strategies	Vehicle Travel Demand	Mgmt. & Operations Strategies	Carbon Pricing / Fuel Pricing
Alexandria, VA	80-100% Reduction (from 2005 baseline)	• By 2023 reduce VMT 1% per year • By 2023 increase transit, walking, and biking by 15% over 2018	✓	✓		
Arlington County, VA	Carbon Neutral	Reduce the amount of carbon produced from transportation to 0.5 $MTCO_2e$/capita/year by 2050.	✓	✓		
Fairfax County, VA	Carbon Neutral	N/A	✓	✓	✓	
Montgomery County, MD	Carbon Neutral by 2035	• 100% electrification of transportation options by 2035. • Reduce private vehicle trips from 75% of total trips to 60% by 2027. • Double the proportion of bus, rail, and bicycle trips (from 2018 baseline) by 2035.	✓	✓	✓	✓ Advocate for carbon tax / gas tax (notes outside county authority)

[43] Transportation and Climate Initiative. "Statements of Support for Regional Low-Carbon Transportation Policy Development Announcement." https://www.transportationandclimate.org/statements-support-regional-low-carbon-transportation-policy-development-announcement
[44] Transportation and Climate Initiative. TCI-P FAQs. https://www.transportationandclimate.org/TCIP-FAQ

City of Alexandria

The City of Alexandria has taken aggressive action to implement strategies to increase transit ridership and reduce VMT. Alexandria's VMT declined by 12.5% from 2010-2016, and the City identified that actions that helped lead to the reduction in VMT included increased frequency of transit service, dedicated transit lanes, and limited stops for faster service, as well as the implementation of "Complete Streets Guidelines" (which supports safe access to all transportation modes), an expanded bicycle and pedestrian network, and a bikeshare program.

Alexandria adopted an Environmental Action Plan in 2019, which set the following GHG reduction and transportation targets:[45]

- 2030 – Reduce emissions 50% below 2005 baseline
- 2050 – Reduce emissions 80-100% below 2005 baseline
- 2023 – Reduce VMT 1% per year
- 2023 – Increase transit, walking, and biking by 15% over 2018
- 2030 – Double dedicated bus lanes to 1.5 miles

In addition to these goals, the Environmental Action Plan outlines goals and actions for mitigating climate change and sets corresponding targets. The City of Alexandria will prioritize low-carbon mobility options, work to reduce automobile dependency, and improve, expand and integrate public transit systems. Finally, the city will encourage adoption of electric vehicles. The following targets and goals related to electric vehicle adoption are outlined in the plan:

- By 2021, initiate electric passenger vehicle pilot programs for the Alexandria Transit Company (DASH: Driving Alexandria Safely Home), Alexandria City Public Schools, and the City vehicle fleet to evaluate costs, benefits, technical feasibility, and implementation opportunities to transition city fleet vehicles to electric vehicle technology, and install vehicle charging infrastructure at city facilities.
- By 2024, implement electrification of, at minimum, 25%of applicable nonelectric passenger city fleet vehicles consistent with Fleet Replacement Plan criteria and scheduled replacement.
- By 2028, implement electrification of all city non-electricity energy use (city facilities, operations, and vehicles).
- By 2029, implement and support the implementation of a publicly accessible electric vehicle charging infrastructure that is supported by renewable energy supply.
- By 2040, implement electrification of all city non-electricity energy use (city facilities, operations, and vehicles).

As part of the City of Alexandria's preparation for a transition to electric vehicles, the city developed an Electric Vehicle Charging Infrastructure Readiness Strategy (EVRS) which recommends actions for the city to support EV infrastructure and support goals outlined in the Environmental Action Plan. The EVRS sets out 31 recommendations addressing the following areas:[46]

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[45] City of Alexandria. "Environmental Action Plan 2040." July 2019. https://www.alexandriava.gov/tes/eco-city/info/default.aspx?id=112252

[46] City of Alexandria. "Electric Vehicles in Alexandria." April 2021. https://www.alexandriava.gov/tes/eco-city/info/default.aspx?id=109894

- Meeting Charging Demand: actions that remove charging availability as a barrier for segments of the population like vehicle owners without private parking.
- Enhancing Communications and Awareness: actions that inform and build capacity among the general population.
- Strengthening Zoning, Building Codes, and Permitting: actions that remove barriers to installing new charging infrastructure.
- Advocating in State Government or with Dominion Energy: actions for which city staff can advocate at the state level or with Dominion Energy that will strengthen the region's electric vehicle ecosystem.
- Building Successful Business Models for Chargers: actions that improve the business case for publicly accessible charging stations.
- Establishing an Inter-departmental Implementation Working Group: a single action to form a group that oversees the implementation of the EVRS's recommendations.[47]

In addition to the EVRS, the 2019 Environmental Action Plan directed the city to develop an update of the 2011 Energy and Climate Action Plan. The updated plan is currently under development.[48]

Arlington County, VA

Arlington County adopted an updated Community Energy Plan in 2019, which addresses opportunities to achieve the County's goal of carbon neutrality by 2050.[49]

Arlington County has been working to reduce GHG emissions since 2007 and achieved a 13% reduction in energy consumption in transportation from 2007-2016. As of 2016, 39% of Arlington County's energy use was associated with the transportation sector. The 2019 Community Energy Plan provides a pathway to meeting its goal of carbon neutrality, with 32% of the GHG emissions reductions coming from sustainable transportation strategies.

The Community Energy Plan sets a target of reducing Arlington's transportation-related carbon emissions from 3.7 to 0.5 MT CO_2e per capita per year by 2050, which equates to an 88% decrease in transportation emissions. The Plan acknowledges that this is an ambitious target, and notes that if vehicles drove 8% less, were 75% more fuel efficient, and were predominantly EVs (using mostly renewable energy) by 2050, Arlington would meet the transportation component of targeted emissions reductions for 2050. The following milestones will help the County track progress (compared to a baseline of 3.7 MT 2007):

- 2020: 2.7 MT CO_2e per capita
- 2030: 1.7 MT CO_2e per capita
- 2040: 0.8 MT CO_2e per capita[50]

[47] City of Alexandria. "Electric Vehicles in Alexandria." April 2021. https://www.alexandriava.gov/tes/eco-city/info/default.aspx?id=109894#EVChargingStrategy
[48] City of Alexandria. "Energy and Climate Change Action Plan." May 2021. https://www.alexandriava.gov/tes/eco-city/info/default.aspx?id=118548#ECCAP
[49] Arlington County. "Community Energy Plan." September 2019. https://arlingtonva.s3.amazonaws.com/wp-content/uploads/sites/13/2019/10/Final-CEP-CLEAN-003.pdf
[50] Arlington County. "Community Energy Plan." September 2019. https://arlingtonva.s3.amazonaws.com/wp-content/uploads/sites/13/2019/10/Final-CEP-CLEAN-003.pdf

The Community Energy Plan identifies a substantial uptake in rates of use of transit, bicycling, and walking, substantive reduction in VMT per capita, improved fuel economy, saturation of vehicle market by EVs, and supra-regional EV market (drive-through) as key factors for reducing GHGs in the transportation sector and achieving the above milestones. Part of achieving this will be reducing VMT and increasing multimodal travel, as well as promoting and encouraging electric vehicles in the private and commercial sectors. Finally, the Community Energy Plan directs the County to develop a comprehensive plan for transitioning government fleet to carbon-neutral transportation by 2050. The comprehensive plan is to be completed by 2022.

Fairfax County, VA

Fairfax County is currently developing its first GHG emissions reduction plan, the Community-wide Energy and Climate Action Plan (CECAP). The draft CECAP will be publicly available spring or summer 2021. The CECAP is guided by input from a Working Group composed of community members from each district in the county. The Working Group has selected a long-term target of carbon neutrality by 2050, with direct emissions reductions of at least 87% from a 2005 baseline (the remaining reductions could come from carbon offsets or emerging technologies). Additional sector-based goals may be selected in future meetings. Transportation strategies in the CECAP will focus on increasing electric vehicle (EV) adoption, supporting efficient land use, active transportation, public transportation, and transportation demand management (TDM) to reduce VMT, and increasing fuel economy and use of low carbon fuels for transportation.

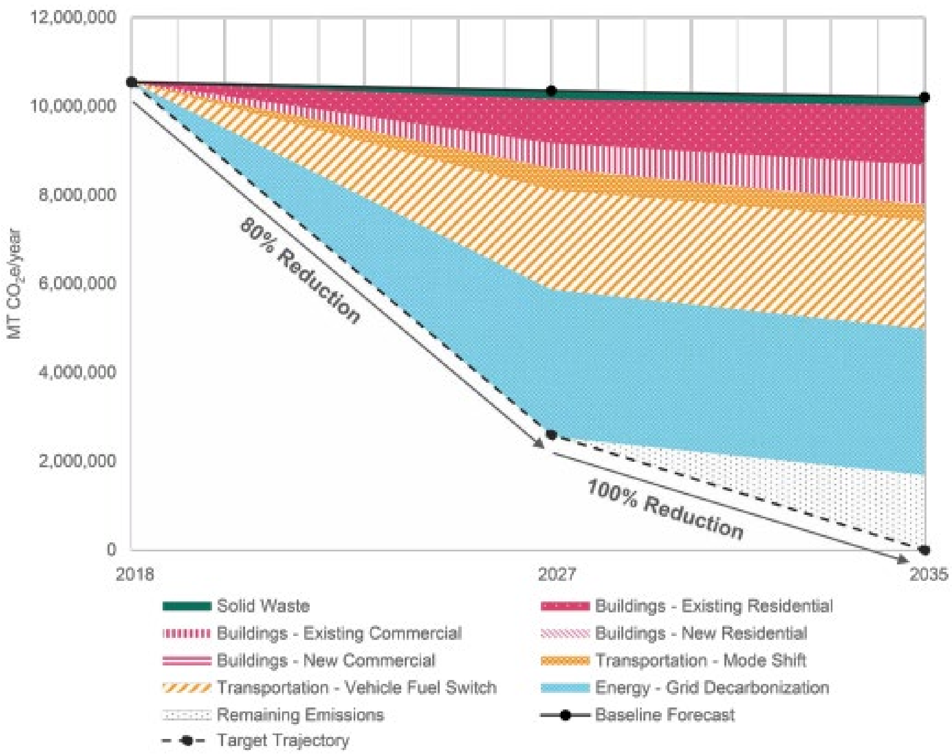
Montgomery County, MD

Montgomery County has developed a Draft Climate Action Plan, and the final Climate Action Plan is expected to be finalized in 2021.[51] The County has set ambitious GHG reduction goals and aims to reach carbon neutrality by 2035. By 2027, Montgomery County plans to cut GHG emissions by 80% from 2005 levels. The Draft Climate Action Plan provides a potential emissions reduction pathway across primary sectors, showing that the largest reductions will come from the energy sector/grid decarbonization, followed by transportation actions. In 2018, the transportation sector (on-road transportation, aviation, rail, and off-road vehicles) accounted for 42% of the County's GHG emissions. Of those emissions, on-road transportation was the primary contributor (36% of total emissions).

The Draft Climate Action Plan states that, in order to sufficiently reduce transportation sector emissions, 100% of public and private transportation will have to transition to zero emissions power sources or be electrified by 2035, and private vehicle use will need to be significantly reduced through mode shifting. These transitions will be supported through County programs and resources (e.g., educational campaigns and financing tools) and the development of a comprehensive EV infrastructure network. The Draft Plan provides a transportation emissions reduction pathway, which anticipates that vehicle fuel switching will play the largest role in transportation sector emissions reductions through 2035 (87% of reductions, with the remaining 13% from mode shift). The emissions reduction pathway below (Figure 1) shows how transportation emissions reductions can contribute to the total emissions reduction targets, with overall GHG emissions reaching the 2027 goal of 80% below 2005 levels and moving toward carbon neutral by 2035.

[51] Montgomery County Government. "Montgomery County Climate Action Plan." https://www.montgomerycountymd.gov/green/Resources/Files/climate/draft-climate-action-plan.pdf

Figure 1. Montgomery County GHG Emissions Reduction Pathway[52]



Three transportation-sector targets in the Draft Climate Action Plan include:

- 100% electrification of transportation options, including all private and public transportation options by 2035. This aligns with the county's goal of 100% renewable electricity supply by 2030.
- Reduce private vehicle trips from 75% of total trips (the 2018 base level) to 60% by 2027.
- Double the proportion of bus, rail, and bicycle trips over the 2018 base levels of total trips by 2035. [53]

The Draft Climate Action Plan sets out 13 transportation-related actions to meet the above targets, including expanding public transit, expanding active transportation, private vehicle electrification incentives, congestion pricing, electrification of buses and public fleets, expanding EV infrastructure, transportation demand management and telework strategies, traffic management systems, EV car share program for low-income communities, off-road vehicle electrification, and advocating for a vehicle carbon gas tax and rail alternative fuels. For each strategy, the Draft Climate Action Plan provides specific actions to implement, as well as descriptions of level of potential emissions reductions, potential co-benefits (such as public health, racial equity and social justice, and environmental stewardship) and level of investment required. The transportation strategies all individually fall into the GHG reduction potential category of medium or low, but collectively have the potential to make a significant impact.

[52] Montgomery County Government. "Montgomery County Climate Action Plan." Public Draft. https://www.montgomerycountymd.gov/green/Resources/Files/climate/draft-climate-action-plan.pdf

[53] The plan explains that mode shifting will reduce the number of private vehicles that will need to be electrified (the plan assumes that 100% of vehicles will be electrified and produce zero emissions), and the doubling in transit and bicycle trips is needed to fill the transportation needs created by the reduction in private vehicle use.

Prince George's County, MD

Prince George's County passed a resolution in 2020 mandating the development of a Climate Action Plan for the county by September 2021. The Climate Action Plan is currently under development and will help the County move towards its goal of an 80% reduction in GHG emissions by 2050 from a 2008 baseline.[54]

City of Rockville

The City of Rockville is currently in the process of developing a climate action plan that will focus primarily on mitigating GHG emissions from energy used by the transportation and buildings sectors.[55] The Draft Plan is expected to be published in the spring or summer of 2021.

Utilities

The metropolitan Washington region is provided with energy services from several different local utilities. As fuel sources switch from liquid fuels to alternatives such as natural gas and electricity, the integration of transportation policy is increasingly impacted by utility energy procurement strategies, the programs of local utilities, and the carbon intensity of their fuels. Moreover, as battery electric vehicles have zero tailpipe emissions and shifts to EVs are a primary driver of significant GHG reductions in climate action plans, it is important to recognize the increasing role that electricity will play in transportation sector GHG emissions, when accounting for transportation across the fuel cycle (not just tailpipe emissions).[56]

This section describes the climate strategies of major utilities in the region (this is not a comprehensive list of all utilities in the region). These utilities have clean energy and climate initiatives that integrate with their fuel supply, many of which are governed and influenced by state policy. States have been active in developing and revising Renewable Portfolio Standards (RPSs), which require that a specified percentage of the electricity that utilities sell comes from renewable resources. Under existing law, Maryland requires a 50% renewable portfolio by 2030, the District requires 100% of electricity be generated by renewable sources by 2032, and Virginia requires 100% of electricity to be generated by zero carbon sources by 2045 (for Dominion, covering Northern Virginia).[57]

In addition to their own decarbonization plans and state policy, in Maryland and the District of Columbia individual customers can choose their own electricity and natural gas suppliers and influence the carbon intensity of their electricity or natural gas. Virginia provides supplier choice options for larger customers, and individual households can pay an extra fee to ensure that the funds go to a green source of electricity generation. These additional options may allow for accelerated carbon reductions by select customers with significant transportation fleets such as transit providers or local governments.

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[54] Prince George's County. "Climate Change." https://www.princegeorgescountymd.gov/3748/Climate-Change
[55] City of Rockville. "Climate Action Plan." https://www.rockvillemd.gov/2329/Climate-Action-Plan
[56] Fuel-cycle emissions account for the upstream emissions associated with extraction, transport, and distribution of the energy used in transportation (including electricity-related emissions for EVs); fuel-cycle emissions do not account for emissions associated with physical infrastructure or production of vehicles or batteries.
[57] National Conference of State Legislatures, State Renewable Portfolio Standards and Goals. https://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx

Dominion

Dominion Energy recently set goals to reduce emissions from all electricity and natural gas facilities by 50% in 2030 and to achieve net zero emissions by 2050. These goals are coupled with a targeted goal on methane emissions reductions of 65%by 2030 and 80%by 2050. A major goal of Dominion's clean energy strategy is to change the fuel mix used to generate electricity, investing in expanded renewable energy efforts, particularly with regards to offshore wind production, where they are constructing the Virginia Beach offshore wind project set to be completed in 2026 which will provide 8.8 million MW of electricity annually. Dominion is also expanding solar production and maintaining a nuclear generation fleet to increase the share of electric fuels with low emissions. Retiring high emissions generation facilities, mainly using coal and oil will similarly reduce the overall emissions from electric generation.[58]

A special focus of the Dominion Clean Energy plan is to reduce emissions from the use of natural gas, which is being used to replace coal and oil as a base load fuel with lower emissions. Emissions from natural gas systems will be reduced by replacing targeted infrastructure and equipment (mainly cast iron and bare steel pipelines) with new and lower emissions equipment, reducing or eliminating gas venting during planned construction and maintenance, expanding leak detection and repair programs, and investments and partnerships to generate renewable natural gas from decomposing organic material on farms or landfills.[59]

Dominion has several initiatives related to reducing emissions in the transportation sector. In 2019 Dominion launched an ambitious electric school bus program,[60] covering the additional costs with replacing old diesel busses with electric busses and providing the charging infrastructure. Along with GHG emissions reductions, this plan will also improve air quality for bus riders and provide savings for school districts as electric busses have 60%lower operations and maintenance costs. The battery systems associated with this program will be used to support intermittent renewable energy generation. 50 busses in 16 localities were operational by the end of 2020 with further expansions to the program planned, including an autonomous electric shuttle in Fairfax County and additional charging infrastructure for the Charleston area regional bus depot.[61]

Dominion also has programs supporting adoption of EVs more broadly with an online education tool to help customers make the transition to electric vehicles, approval of the smart charging infrastructure pilot program. Dominion similarly is encouraging its own employees to transition to EVs with the goal of installing EV charging stations in all North Carolina and Virginia offices by 2021, offering incentives for employees to purchase electric vehicles, and converting 25% of the light-duty fleet to EVs or plug-in-hybrids (PHEVs) by 2025.

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[58] Dominion Energy. "Delivering Clean Energy." https://www.dominionenergy.com/our-promise/clean-energy
[59] Dominion Energy. "Methane Emissions Reduction." https://sustainability.dominionenergy.com/cleaner-air/methane-emissions-reduction/
[60] Dominion Energy. "Dominion Energy Proposes Largest Electric School Bus Initiative in the Country." August 2019. https://news.dominionenergy.com/2019-08-29-Dominion-Energy-Proposes-Largest-Electric-School-Bus-Initiative-in-the-Country#:~:text=Dominion%20Energy%20Proposes%20Largest%20Electric%20School%20Bus%20Initiative%20in%20the%20Country,-%2D%20Zero%2Demissions%20electric&text=RICHMOND%2C%20Va.%2C%20Aug.,districts%20and%20enhance%20grid%20reliability.
[61] Dominion Energy. "Beyond Net Zero." https://sustainability.dominionenergy.com/cleaner-air/beyond-net-zero/

Alternative fuel vehicles are another priority area for the reduction of GHG emissions for Dominion with a focus on hydrogen and renewable natural gas. Dominion is planning on using existing natural gas distribution infrastructure to deliver hydrogen to fueling stations, with hydrogen being both a fuel and a carrier that can be used to store and transport energy. In Utah, Dominion has a contract with Fleet Saver, an industrial fleet fueling company to distribute renewable natural gas (RNG) to customers from compressed natural gas stations. Additionally, RNG has been delivered as a transportation fuel to customers since 2019.

WGL[62]

WGL has developed a climate business plan specific to the metropolitan Washington region. WGL's parent company AltaGas engaged in extensive research and collaboration with ICF to assess strategies for developing this climate business plan. The overall goal of the plan is to reduce GHG emissions associated with the use of natural gas by 50% by 2032 and achieve carbon neutrality from emissions associated with the use of natural gas by 2050.

WGL has determined that a fuel-neutral decarbonization strategy is the correct approach to decarbonization as provides the desired GHG emissions reductions, similar to what a full electrification approach would achieve, while only costing 59% of what a full electrification strategy would cost. Another important consideration would be energy reliability with the use of multiple fuels preserving customer choice, securing energy reliability, and increasing resiliency from increasing climate-related weather variability. Some forward-looking fuels that will contribute to this strategy would be green hydrogen and biogas.

The plan is built around three key areas: end use energy efficiency, reduced fugitive emissions from transmission and distribution, and sourcing gases with lower emissions to use as part of the natural gas mix. Initiatives relevant to reducing emissions from the transportation sector for WGL come mainly from the reductions of emissions from supply and sourcing of the natural gas used for both the generation of electricity and natural gas used directly as transportation fuels. These reductions will be achieved by the introduction of cleaner gases to the natural gas mix including renewable natural gas derived from biomass and green hydrogen, purchasing certified natural gas from companies following best practices to reduce emissions, and utilizing power to gas storage as a solution to storing excess power generated from renewables long-term.

Pepco

Pepco provides electricity to all of the District of Columbia and parts of Montgomery and Prince George's Counties. In the District, Pepco has set a target in alignment with the District's standard offer service (SOS) requirements to have 100%of the electricity distributed by Pepco be generated from renewable sources by 2032. To help achieve this goal, Pepco will enter into contract(s) for the purchase of renewable electricity directly from renewable energy project developers. Similarly, in Maryland, Pepco has electricity supply

[62] Washington Gas. "Natural Gas and its Contribution to a Low Carbon Future: Climate Business Plan for Washington D.C." March 2020. https://sustainability.wglholdings.com/wp-content/uploads/Climate-Business-Plan-March-16-2020.pdf

requirements to align with Maryland's 50% renewable portfolio standard (RPS) for electricity by 2030.[63] Additional goals to reduce the operationally driven GHG footprint of Pepco include the electrification of the company fleet (30% of passenger fleet to EVs and 30% of medium- and heavy-duty trucks to plug-in hybrids by 2025, increasing both to 50% in 2030), improved energy efficiency in buildings, the transition to 100% clean and renewable energy use at Pepco facilities, reductions in the leakage of sulfur hexafluoride (SF6) associated with electric distribution, and employee engagement to encourage environmental stewardship and environmentally conscious behavior shifts.[64]

Pepco has several electric vehicle programs including a residential incentive program, a commercial incentive program in their Maryland service territory and residential time of use rates for their customers in the District. Pepco provides a public charging network through all their service territory. These programs are enabled and regulated by Maryland and the District which are part of Pepco's service territory. In addition to their existing program, Pepco is working with District of Columbia agencies to provide electric vehicle infrastructure for buses, taxis, and ride-share vehicles.[65] [66]

Pepco efforts specific to the reduction of emissions from the transportation sector include: an analysis of the investments and grid system design changes needed to support electrification in alignment with the Carbon-Free DC roadmap, installation of electric vehicle chargers to support fleet charging as well as workplace charging needs, special rate offers to customers to charge EVs during off-peak energy usage periods, a reintroduction of an ell-electric rate to support building and broader electrification, support for conversion of food trucks to electric auxiliary power to reduce diesel and gasoline fumes from idling trucks, and development of charging infrastructure for electric taxis, rideshare vehicles, buses, and other vehicles in the District.[67]

BGE

PEPCO and BGE are both Exelon owned utilities companies and have similar climate goals and statements on their work. BGE provides electricity and natural gas services to parts of Maryland including portions of the metropolitan Washington region. BGE is a member of the voluntary EPA SF6 emission reduction partnership for electric power systems program and proactively works to prevent SF6 leaks in equipment. Through Exelon, BGE is committed to building one of the country's largest alternative-fuel and energy efficient hybrid vehicle fleets. BGE has also been working on creating a less emission intensive fuel portfolio for their electric generation and is currently aligned with Maryland's 50% RPS by 2030.

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[63] National Conference of State Legislatures. "State Renewable Portfolio Standards and Goals." April 2021. https://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx
[64] PEPCO. "Reducing Our GHG Footprint, Building Resilience, and Preparing for the Future." https://www.pepco.com/SafetyCommunity/Environment/Pages/ClimateActionCompany.aspx
[65] PEPCO. "EVsmart Maryland." https://www.pepco.com/SmartEnergy/InnovationTechnology/Pages/ElectricVehicleProgramMD.aspx
[66] PEPCO. "EVsmart Washington DC." https://www.pepco.com/SmartEnergy/InnovationTechnology/Pages/ElectricVehicleProgramMD.aspx
[67] PEPCO. "Powering a Cleaner and Brighter Future for Our Customers and Communities." https://www.pepco.com/SafetyCommunity/Environment/Pages/PepcoClimateAction.aspx

Climate Planning in Other Regions of the U.S. and Internationally

City and Regional Climate Planning in the U.S.

Many cities and regional planning organizations around the U.S. have made a commitment to significant GHG reduction. At least 1,066 mayors in cities across the U.S. joined the U.S. Conference of Mayors' Climate Protection Agreement, and many cities have developed their own climate action plans.[68] Below, a sample of city and regional plans are highlighted.

New York City

New York City released OneNYC 2050, a plan for the city that includes a "just transition" to carbon neutral by 2050.[69] OneNYC 2050 is city-wide plan that covers many different sectors and topic areas, including transportation. The 2050 target includes transitioning to 100%clean energy. OneNYC also sets the target of having a carbon-neutral city vehicle fleet by 2040 and commits to implementing congestion pricing to reduce traffic and generate funds for subway repairs and enhancements, expanding bus lanes and bus lane enforcement, and making signal improvements to prioritize buses, ultimately aiming to improve bus speeds by 25 percent.[70] MTA New York City Transit has begun deploying all-electric articulated buses as part of the 2020-2024 Capital Plan, which accelerates the transition to a fleet composed fully of zero-emissions electric buses.[71] By 2028, the MTA plans to purchase only electric buses.[72]

OneNYC's chapter on Efficient Mobility and Modern Infrastructure provides a detailed vision for developing a sustainable, low-emissions transportation network.[73] The plan commits to developing a citywide network of EV charging infrastructure, reforming the city's municipal fleet, incentivizing commercial and fleet vehicles (through dedicated curb space for ZEVs, clean truck programs, and leveraging funding from the Volkswagen settlement), and establishing commercial waste zones to reduce truck traffic associated with commercial waste collection by over 50 percent.

Los Angeles

As part of the L.A. Green New Deal, the City of Los Angeles has set a number of climate mitigation targets including 100% electrification by 2030, 100% renewable energy by 2045, and net zero emissions by 2050.[74] The following goals related to mobility and public transit and zero emissions vehicles are part of L.A.'s Green New Deal:

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[68] The United States Conference of Mayors. "Mayors Climate Protection Center." https://www.usmayors.org/programs/mayors-climate-protection-center/

[69] City of New York. "OneNYC 2050." http://onenyc.cityofnewyork.us/#main-content

[70] City of New York. "OneNYC 2050." http://onenyc.cityofnewyork.us/#main-content

[71] MTA. "MTA Deploys First All-Electric Articulated Bus Fleet to 14th Street Busway." 2019. https://www.mta.info/press-release/nyc-transit/mta-deploys-first-all-electric-articulated-bus-fleet-14th-street-busway#:~:text=MTA%20New%20York%20City%20Transit,deliver%20environmental%20benefits%20for%20all

[72] Clayton Guse. "MTA plans to only buy electric buses come 2028 as officials map greener future for NYC Transit." April 2021. https://www.nydailynews.com/new-york/ny-mta-electric-buses-biden-emissions-plan-20210425-dhmcbiltcra2pmvo2pneqkrtn4-story.html

[73] City of New York. "OneNYC Efficient Mobility." http://onenyc.cityofnewyork.us/stories/efficient-mobility/#more-resources

[74] L.A.'s Green New Deal. "L.A.'s Green New Deal." https://plan.lamayor.org/

- Increase the percentage of all trips made by walking, biking, micro-mobility / matched rides or transit to at least 35% by 2025; 50% by 2035; and maintain at least 50% by 2050 (from a baseline of 14% of all trips in 2015).
- Reduce VMT per capita by at least 13% by 2025, 39% by 2035, and 45% by 2050 (from a baseline of 15 VMT per capita per day).
- Ensure Los Angeles is prepared for autonomous vehicles by the 2028 Olympic and Paralympic Games.
- Increase the percentage of zero-emission vehicles in the city to 25% by 2025, 80% by 2035, and 100% by 2050 (from a baseline of 1.4% of vehicles in 2018).
- Electrify 100% of Metro and LADOT buses by 2030 (LA Metro deployed its first 60-foot zero-emission electric bus in July 2020).[75]
- Reduce port-related GHG emissions by 80% by 2050 (from a baseline of 1.5 million metric tons of CO_2e).

The L.A. Green New Deal also sets targets for environmental justice aimed at improving the raw scores of CalEnviroScreen indicators of communities in the top 10% and reducing the number of annual asthma-related emergency room visits in L.A.'s most contaminated neighborhoods.[76] Overall with regard to the transportation sector, the L.A. Green New Deal Sustainability Plan focuses on improving mobility and public transit, reducing VMT, and investing in autonomous and electric vehicles.[77]

In addition to the city-wide plan, the Los Angeles County Metropolitan Transportation Authority (LA Metro) released a 2019 Climate Action and Adaptation Plan, which identifies key strategies for meeting its goal of a climate-resilient and zero-emissions system by 2050. LA Metro also set a target of reducing GHG emissions by 79% relative to 2017 levels by 2030. The following 13 strategies are identified as essential for achieving zero emissions by 2050:

- Switch directly operated buses to battery-powered technologies.
- Deploy battery-powered buses in the contracted fleet.
- Switch vanpool vehicles to battery-powered vehicles.
- Replace non-revenue vehicles with battery-powered vehicles.
- Install systems to store energy captured from trains.
- Buy 100% renewable energy.
- Install photovoltaic systems.
- Install water-saving fixtures.
- Install non-potable recycled water systems.
- Install LED lights at facilities.
- Install electric heating systems.
- Replace facility appliances with more efficient electric appliances.

[75] L.A. Metro. "L.A. Metro deploys first 60-foot zero-emission electric bus for revenue service on the G Line." July 2020. https://www.masstransitmag.com/bus/vehicles/hybrid-hydrogen-electric-vehicles/press-release/21147916/los-angeles-county-metropolitan-transportation-authority-metro-la-metro-deploys-first-60foot-zeroemission-electric-bus-for-revenue-service-on-the-g-line
[76] L.A.'s Green New Deal. "Targets." https://plan.lamayor.org/targets/targets_plan.html
[77] L.A.'s Green New Deal. "Sustainability Plan 2019." 2019. https://plan.lamayor.org/sites/default/files/pLAn_2019_final.pdf

- Install electric vehicle charging at Metro facilities and implement an employee electric vehicle outreach plan.[78]

In addition to the LA Metro climate plan, the City of Los Angeles has set a number of climate mitigation targets including 100% electrification by 2030, 100% renewable energy by 2045, and net zero by 2050 as part of the L.A. Green New Deal sustainability plan. The following goals related to mobility and public transit and zero emissions vehicles are part of L.A.'s Green New Deal:

- Increase the percentage of all trips made by walking, biking, micro-mobility / matched rides or transit to at least 35% by 2025; 50% by 2035; and maintain at least 50% by 2050.
- Reduce VMT per capita by at least 13% by 2025, 39% by 2035, and 45% by 2050.
- Ensure Los Angeles is prepared for autonomous vehicles by the 2028 Olympic and Paralympic Games.
- Increase the percentage of zero-emission vehicles in the city to 25% by 2025, 80% by 2035, and 100% by 2050.
- Electrify 100% of Metro and LADOT buses by 2030 (LA Metro deployed its first 60-foot zero-emission electric bus in July 2020).
- Reduce port-related GHG emissions by 80% by 2050.

The L.A. Green New Deal also sets targets for environmental justice aimed at improving the raw scores of CalEnviroScreen indicators of communities in the top 10% and reducing the number of annual asthma-related emergency room visits in L.A.'s most contaminated neighborhoods. Overall, with regard to the transportation sector, the L.A. Green New Deal Sustainability Plan focuses on improving mobility and public transit, reducing VMT, and investing in autonomous and electric vehicles.

Boston

The City of Boston updated its city-wide Climate Action Plan in 2019, focusing on new strategies to reduce GHG emissions from buildings and transportation.[79] Key focus areas include advocating for priority transit projects in regional plans, improving and expanding active transportation infrastructure, encouraging mode shift, supporting city-wide, zero-emission vehicle deployment, and accelerating the municipal fleet transition to zero- and low-emission vehicles.

Go Boston 2030, the City of Boston's comprehensive transportation plan, sets out the following desired outcomes:

- Traffic fatalities and severe injuries in Boston will be eliminated by 2030.
- Every Bostonian will be within a 10-minute walk of transit, bikeshare, and carshare by 2030.
- Bostonians' average commute to work time will decrease by 10% by 2030.
- Drive alone to work rates will decrease by 50% and transit use will increase by 33% by 2030.
- Carbon neutrality will be achieved by 2050.

[78] L.A. Metro. Metro Climate Action and Adaptation Plan. 2019. https://media.metro.net/projects_studies/sustainability/images/Climate_Action_Plan.pdf

[79] City of Boston. "Boston Climate Action Plan." 2019. https://www.boston.gov/departments/environment/boston-climate-action

- The transportation cost burden for low-income households will decrease from 33% of income spent on transportation in 2015 to 13% by 2030.[80]

As part of this plan, Boston's transportation department launched a New Mobility Team. Working in partnership with New Urban Mechanics, the New Mobility Team is working to expand the Drive Boston program to provide over 150 new locations for car-share in Boston neighborhoods, install electric-vehicle charging stations in municipal parking lots, monitor an ongoing pilot of pickup and drop-off zones for rideshare companies to minimize traffic disruptions, and develop a Shared Mile Playbook of principles for navigating the new technology-driven and on-demand landscape.[81] The transportation department also established a Transit Team, which is working to advance regional rail projects and installing transit interventions such as rapid bus lanes, transit signal priority and real-time information displays, and infrastructure upgrades including new trains.[82] Additionally, the City of Boston is working to launch an e-cargo delivery pilot in 2022 to make parcel delivery service more sustainable and support the city's goal of carbon neutrality.[83]

Puget Sound (Seattle) Region

The Puget Sound Regional Council, the metropolitan planning organization (MPO) for the Seattle region, adopted the following GHG emissions reductions targets for the region:

- By 2030, reduce overall GHG emissions in the region to 50% below 1990 levels.
- By 2050, reduce overall GHG emissions in the region to 80% below 1990 levels.[84]
- King County adopted its own targets, aiming to reduce GHG emissions 25% by 2020, 50% by 2030, and 80% by 2050, from a 2007 baseline.[85]

The Council's VISION 2050 plan provides multicounty planning policies that can act as a guide as counties update local comprehensive plans. The plan lays out a four-pronged GHG emissions reduction strategy: land use, user fees, transportation choices, and technology. Land use policies include concentrating new development around transit stations, changes to development patterns at the local level to create compact and walkable environments and encouraging location of new construction close to services and amenities to reduce VMT. User fees include implementing selected facility tolls and a road usage charge system, a per-mile charge based on how much drivers use Washington's road system.[86] The transportation choices portion of the strategy includes investing in multimodal transportation system improvements to support all modes of travel and ensure equitable access to goods, services, and amenities. Finally, the technology prong of the approach acknowledges the role that technological improvements to vehicles and fuels will play in reducing emissions and encourages

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[80] City of Boston. "Go Boston 2030." https://www.boston.gov/departments/transportation/go-boston-2030
[81] City of Boston. "Smart Streets." 2019. https://www.boston.gov/smart-streets
[82] City of Boston. "Improving Local and Regional Transit Services." 2020. https://www.boston.gov/improving-local-and-regional-transit-services
[83] Christian McNeil. "Boston Aims to Launch E-Cargo Bike Delivery Pilot in 2022." April 2021. https://mass.streetsblog.org/2021/04/13/boston-aims-to-launch-e-cargo-bike-delivery-pilot-in-2022/
[84] Puget Sound Regional Council. "VISION 2050." October 2020. https://www.psrc.org/sites/default/files/vision-2050-plan.pdf
[85] Puget Sound Regional Council. "VISION 2050." October 2020. https://www.psrc.org/sites/default/files/vision-2050-plan.pdf
[86] WA Road Usage Charge. "FAQs." 2021. https://waroadusagecharge.org/faqs/

strategies to prepare for implementation of new technologies (such as electric vehicle infrastructure). The region is already leading in some areas in implementing new technologies. For example, Washington State Ferries (WSDOT) is electrifying several ferries operating within the Puget Sound region, and the Port of Seattle has set an aggressive target for sustainable aviation fuels.[87] Additionally, Kings County Metro is an early adopter of electric buses and has committed to move to a 100% zero-emissions fleet powered by renewable energy no later than 2040.[88]

An analysis of the above four-pronged approach was conducted in 2018 that showed potential emissions reductions between 24% to 75% below 2006 base year levels.[89] The range of potential emissions reductions demonstrates the varying degrees of effort that could be taken within each category. The lower end of the range represents the 2008 VISION 2040 growth strategy and the investments and policies in the 2018 Regional Transportation Plan. The higher end represents potential emissions reductions with aggressive electrification of the transportation system in addition to implementing the strategies outlined in the VISION 2050 plan. Much of the electricity in the Puget Sound region is derived from renewables including hydro-electric power, which means that there is large potential for reducing transportation emissions through electrification.

At the local level, the City of Seattle recently released a Transportation Electrification Blueprint[90] which sets bold goals for 2030, including the following:

- 100%of Shared Mobility will be Zero Emission: As shared mobility services like bikes, scooters, taxis, Uber, Lyft, carshare services and others continue to expand in Seattle, the city will ensure those options will be electric and emissions free.
- 90%of All Personal Trips are Zero Emission: By 2030, nine out of 10 trips will be walking, biking, electric transit or in an electric vehicle (or avoided all together).
- 30%of Goods Delivery is Zero Emission: The city will spur the transition of private fleets to EVs and support market transformation in freight and goods delivery over the next 10 years.
- 100%of City Fleet is fossil-fuel free (Executive Order 2018-02): Seattle will operate a large municipal fleet with zero fossil fuels by 2030.[91]

[87] Puget Sound Regional Council. "VISION 2050." October 2020. https://www.psrc.org/sites/default/files/vision-2050-plan.pdf
[88] King County Metro. "Transitioning to a zero-emissions bus fleet." https://kingcounty.gov/depts/transportation/metro/programs-projects/innovation-technology/zero-emission-fleet.aspx#:~:text=Transitioning%20to%20a%20zero%2Demissions,a%20battery%2Delectric%20bus%20fleet.&text=Metro%20has%20committed%20to%20move,energy%20no%20later%20than%202040
[89] Puget Sound Regional Council. "VISION 2050." October 2020. https://www.psrc.org/sites/default/files/vision-2050-plan.pdf
[90] City of Seattle. "Seattle's Clean Transportation Electrification Blueprint." March 2020. https://www.seattle.gov/Documents/Departments/OSE/ClimateDocs/TE/TE%20Blueprint%20-%20FINAL%20-%20March%202020.pdf
[91] City of Seattle. "Seattle's Clean Transportation Electrification Blueprint." March 2020. https://www.seattle.gov/Documents/Departments/OSE/ClimateDocs/TE/TE%20Blueprint%20-%20FINAL%20-%20March%202020.pdf

San Francisco Bay Area

The San Francisco Bay Area has made significant investments in regional transportation planning efforts through the Metropolitan Transportation Commission's (MTC) Climate Initiatives Program.[92] The Climate Initiatives Program aims to address GHG emissions from transportation, which makes up 40%of the Bay Area's overall GHG emissions. MTC launched this program in 2009 and has continued to invest in and expand the program ever since. The 2040 Bay Area Plan directs $526 million to the regional Climate Initiatives Program.[93] [94] Initiatives under the program include car sharing, climate innovation grants, commuter benefits programs, electric vehicle activities, increasing safe walking and biking routes to schools, smart-driving pilot studies, vanpooling, car sharing, targeted transportation alternatives campaigns, trip caps (ordinances focused on reducing vehicle trips to and from workplaces), and EV infrastructure and incentives.

As with all MPOs in California, the MTC develops a Sustainable Communities Strategy, with a focus on reducing GHG emission through a reduction in VMT. The current Sustainable Communities Strategy (the 2040 Bay Area Plan) is centered on "focused growth," which encompasses the following strategies:[95]

- Assign higher densities than currently allowed by cities to select Priority Development Areas (PDAs).
- Keep current urban growth boundaries in place.
- Preserve and incorporate office space caps in job-rich cities.
- Assume that all for-profit housing developments in cities with PDAs will make 10%of units deed-restricted in perpetuity. Deed restrictions regulate the use of land and can be used to preserve the long-term affordability of housing.
- Reduce the cost of building in PDAs and Transit Priority Areas (TPAs) through eased parking minimums and streamlined environmental clearance.
- Assume subsidies stimulate housing and commercial development within PDAs.
- Assess commercial development fee based on VMT to improve jobs-housing ratio and to fund affordable housing in PDAs.[96]

International Climate Plans and Transportation-Related Initiatives

Paris

At the United Nations Paris Climate Conference (COP21) in 2015, the City of Paris committed to several ambitious climate goals, including reaching carbon neutrality and 100% renewable energy by 2050. The city also set interim goals for 2030 from 2004 levels, including reducing local GHG emissions by 50%, reducing energy consumption by 35%, consuming 45% renewable energy (including 10% locally produced), and becoming a zero-

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[92] MTC. "Climate Initiatives Program." April 2019. https://mtc.ca.gov/our-work/plans-projects/climate-change-programs/climate-initiatives-program
[93] MTC. "Plan Bay Area 2040." http://2040.planbayarea.org/
[94] MTC. "Climate Initiatives Program." April 2019. https://mtc.ca.gov/our-work/plans-projects/climate-change-programs/climate-initiatives-program
[95] MTC. "Plan Bay Area 2040 Final." July 2017. http://2040.planbayarea.org/files/2020-02/Final_Plan_Bay_Area_2040.pdf
[96] MTC. "Plan Bay Area 2040 Final." July 2017. http://2040.planbayarea.org/files/2020-02/Final_Plan_Bay_Area_2040.pdf

fossil fuel area. Paris also has transportation-specific goals, including transportation sector carbon neutrality and "phasing out diesel-powered mobility by 2024 and petrol-powered mobility by 2030."[97]

To meet these goals, the City Council of Paris approved an ambitious Climate Action Plan in 2018. In the Paris metropolitan area, 24% of GHG emissions come from the transportation sector; therefore, the plan includes several strategies focused on reducing transportation related GHG emissions.

For instance, noteworthy strategies include:

- **Low-Emissions Zones –** With a categorization system that authorizes vehicles based on age and emissions, higher-polluting vehicles have limited access to central Paris. Since 2017, Paris has been gradually phasing in stricter authorization policies, moving toward the 2024 Zero Diesel target and the 2030 Zero Petrol target. The City of Paris is working to extend the zone into the broader metropolitan area. Paris is also considering automated monitoring and penalty schemes to improve enforcement.
- **Expansion of Active Transportation** – The Paris Pedestrian Strategy, adopted in 2017, aims to improve walking conditions, add more continuous footpaths, and facilitate access to public transport. One especially noteworthy strategy has been "Paris Respire" (Paris Breathes), which involves closing certain quartiers to motorized traffic on Sundays and public holidays. Paris is also working to implement more green streets and quiet streets. Additionally, Paris is working to make the city 100% cycle-friendly and achieve 15% bicycle mode share. Strategies include developing new bicycle facilities, reducing speed limits, expanding bike share systems, and supporting educational programming on biking and bike maintenance.[98]
- **Public Transportation** – Public transportation is another major feature of Paris's transportation emission reduction efforts. Major expansion projects, including the Grand-Paris Express build-out and rapid transit line extensions, will help the city shift away from private vehicles.
- **Cleaner Municipal Fleet** - Paris is working to reduce the footprint of the municipal vehicle fleet by eliminating diesel-powered vehicles, replacing light petrol-powered vehicles with clean vehicles, and working with manufacturers to find cleaner options for pavement-cleaning machines and other similar vehicles.
- **Freight Logistics Coordination** – The city is working with several other agencies in the region to establish an urban logistics governance system for the area. Paris is also building out several multimodal logistics hubs; campaigning for a distance-based tax on heavy goods vehicles; and encouraging clean modes for last-mile freight.[99]

Paris is taking a holistic approach to climate planning, viewing individuals, businesses, government agencies, and other parties as key components of long-term solutions. Therefore, the city has placed an emphasis on policies

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[97] Mairie de Paris. "Paris Climate Action Plan." 2018. https://cdn.locomotive.works/sites/5ab410c8a2f42204838f797e/content_entry5ab410faa2f42204838f7990/5ab41171a2f422048d8f5a9c/files/Paris_Climate_Action_Plan.pdf?1562248411

[98] Mairie de Paris. "Paris Climate Action Plan." 2018. https://cdn.locomotive.works/sites/5ab410c8a2f42204838f797e/content_entry5ab410faa2f42204838f7990/5ab41171a2f422048d8f5a9c/files/Paris_Climate_Action_Plan.pdf?1562248411

[99] Mairie de Paris. "Paris Climate Action Plan." 2018. https://cdn.locomotive.works/sites/5ab410c8a2f42204838f797e/content_entry5ab410faa2f42204838f7990/5ab41171a2f422048d8f5a9c/files/Paris_Climate_Action_Plan.pdf?1562248411

that encourage individual members of society to shift away from private vehicle ownership and towards cleaner options. The city has implemented incentives programs that make it easier for households to stop using older vehicles and shift towards alternative modes. Additionally, Paris plans to eliminate 70,000 parking spots – half of the city's on-street parking – and to provide cheaper parking for EVs.[100]

London

London has dramatically reduced vehicle-based emissions through congestion pricing, vehicle emissions policies, and investments in cleaner modes including transit and bicycling. In fact, London significantly reduced VMT even as population rose by nearly 15%; between 2003 and 2014, annual VMT fell by 11%, transit ridership grew 39%, and bicycle ridership doubled in the Greater London region; the largest declines in VMT took place in Inner London, but Outer boroughs also saw a decline..[101] In Great Britain as a whole, annual VMT rose throughout most of that time period, with a three-year dip in the late 2000s during the global financial crisis.[102]

London is working to meet the goals established in Zero Carbon London, London's climate action plan. Following the UK's 2015 commitment to the Paris Agreement, Mayor Sadiq Khan released this plan in 2018, which outlines a series of actions for making London a zero-carbon city by 2050.[103] Transportation actions are laid out in greater detail in the 2018 Mayor's Transport Strategy.[104] The driving goal behind this plan is the target of 80%of transportation mode share being public transportation and active transportation by 2041. Currently, 63% of trips are made by walking, cycling, and public transportation. Other goals include reducing freight traffic during peak morning periods in central London by 10%by 2026 and reducing total London traffic by 10-15%by 2041. The Mayor also set goals to make all new buses zero emission by 2025, all new cars and vans by 2030, and all other vehicles by 2040.

Much of London's VMT and emissions reductions can be attributed to tolling, vehicle emissions policies, and electrification efforts:

- **Congestion Charge Zone** – In 2003, London introduced a Congestion Charge zone, which charges a flat fee to drivers entering the zone during weekdays from 7 am to 6 pm. When the charge was introduced, the city expanded the bus system, allowing many people to transition away from private cars, and built on an already extensive bus priority network. The number of cars entering the zone fell by 39% between 2002 and 2014.[105]

[100] Natalie Marchant. "Paris halves street parking and asks residents what they want to do with the space." 2020. https://www.weforum.org/agenda/2020/12/paris-parking-spaces-greenery-cities/
[101] Andrea Broaddus. "Longer-term Impacts of the London Congestion Charge." http://www.ucconnect.berkeley.edu/longer-term-impacts-london-congestion-charge; "The Adaptable City: The Use of Transit Investment and Congestion Pricing to Influence Travel and Location Decision in London." 2015. https://escholarship.org/uc/item/0px3f6gk
[102] Department for Transport. "Road Traffic Estimates: Great Britain 2019." 2020. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/916749/road-traffic-estimates-in-great-britain-2019.pdf
[103] Mayor of London. "Zero carbon London: A 1.5°C compatible plan." 2018. https://www.london.gov.uk/sites/default/files/1.5_action_plan_amended.pdf
[104] Mayor of London. "Mayor's Transport Strategy." 2018. https://www.london.gov.uk/sites/default/files/mayors-transport-strategy-2018.pdf
[105] Nicole Badstuber. "London congestion charge: what worked, what didn't what next." 2018. https://theconversation.com/london-congestion-charge-what-worked-what-didnt-what-next-92478

- **Low Emission Zone –** The focus shifted to emissions in 2008 when London launched a Low Emission Zone (LEZ). The LEZ is a charging scheme with daily fees for high polluting commercial vehicles, such as buses with diesel engines. Mayor Khan took these strategies a step further when he launched an Ultra-Low Emission Zone (ULEZ) in 2019 in central London. In this zone, most vehicles need to meet to certain emissions standards or pay a daily charge. The ULEZ has helped reduce carbon emissions by over 12,000 tonnes in the central zone.[106] In October 2021, London will expand the ULEZ to 18 times its current size.[107]
- **Fleet electrification** – London has one of the largest electric bus fleets in Europe, second only to Moscow.[108] The Department for Business Energy and Industrial Strategy and Office for Zero Emission Vehicles is working with SSE Enterprise on a project called Bus2Grid, which uses vehicle-to-grid technology to charge and export energy from 28 electric buses.[109] Additionally, the transportation network company Uber has committed to be fully electric in London. In March 2021, Uber started giving riders in London's Zone 1 the option to request an electric vehicle.[110]
- **Comprehensive approach** – In London, over half of the main air pollutants come from road transport.[111] London is placing an emphasis on public transportation - making riding a more pleasant experience and increasing connectivity. Other action steps include expanding EV charging and hydrogen fueling infrastructure, reducing freight emissions, and expanding active transportation infrastructure.

Norway

At a national level, Norway has demonstrated that significant GHG emissions reductions can be achieved through EV policies and programs. Overall carbon emissions have been declining in Norway; in 2019, carbon emissions hit a 27-year low.[112] Diesel and gasoline sales have also been declining steadily. Between 2017 and 2019, diesel and gasoline sales fell more than during the 1974 oil crisis, 1988 stock market crash, and 2008 financial crisis combined.[113] Much of that decline can be attributed to the significant rise in EVs. There are more than 330,000 battery electric vehicles registered in Norway.[114] In 2020, more than half of all new cars sold in Norway were electric.[115]

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[106] Mayor of London. "Air Quality in London 2016-2020." 2020. https://www.london.gov.uk/what-we-do/environment/pollution-and-air-quality/air-quality-london-2016-2020
[107] Mayor of London. "The Mayor's Ultra Low Emission Zone for London." 2021. https://www.london.gov.uk/what-we-do/environment/pollution-and-air-quality/mayors-ultra-low-emission-zone-london
[108] Charles Morris. "Europe's largest electric bus fleet adds its 500th vehicle." 2020. Charged. https://chargedevs.com/newswire/europes-largest-electric-bus-fleet-adds-its-500th-vehicle/#:~:text=Moscow's%20electric%20fleet%20is%20thus,the%20streets%20in%20autumn%202018
[109] SSE Enterprise. "Bus2Grid." https://www.sseutilitysolutions.co.uk/products/bus2grid-2/
[110] Steve Dent. "Uber adds all-electric vehicles to its list of ride options in London." 2021. https://www.engadget.com/uber-london-electric-vehicle-ride-choice-070800561.html
[111] Mayor of London. "Mayor's Transport Strategy." 2018. https://www.london.gov.uk/sites/default/files/mayors-transport-strategy-2018.pdf
[112] Steve Hanley. "Norway May Achieve Emissions Reduction Goals This Year, Thanks To More EVs & Higher Public Transportation Usage." 2020. https://cleantechnica.com/2020/06/23/norway-may-achieve-emissions-reduction-goals-this-year-thanks-to-more-evs-higher-public-transportation-usage/
[113] Joshua Hill. "Thanks to electric cars, Norway will reach climate target in 2020." 2020. The Driven. https://thedriven.io/2020/06/25/thanks-to-electric-cars-norway-will-reach-climate-target-in-2020/
[114] Norsk Elbilforening. "Norwegian EV policy." https://elbil.no/english/norwegian-ev-policy/
[115] VOA News. "Norway Says More Than 50% of New Cars Are Electric." 2021. https://www.voanews.com/europe/norway-says-more-50-new-cars-are-electric

Since the 1990s, when Norway abolished an EV import tax, Norway has taken steps to promote EVs. Many policies have focused on financial incentives, including reducing parking fees, ferry fares, and company car tax rates for EVs. Other EV incentives include access to bus lanes and exemption from the 25% value added tax (VAT) on purchases.[116] In total, there are 14 fiscal incentives focused on vehicles, fuel, or road use that differentiate, in some way, based on carbon emissions.[117] Fridstrøm (2021) notes that most of the policies are effectively taxes on internal combustion engine vehicles, rather than subsidies on EVs. For example, passenger vehicles are charged a one-off registration tax; zero- emission vehicles (ZEVs) are fully exempt. ZEVs are fully or partially exempt from road tolls. Therefore, these policies capture some of the social cost of carbon. In fact, Fridstrøm estimated the implied cost Norway has applied to carbon, based on the set of policies, taxes, and subsidies for each vehicle type: approximately 780 euros (~$937 USD) per ton of CO_2 for passenger vehicles (combining the one-off registration tax, tolling, ownership tax, etc.). The government has also supported fast charging and hydrogen refueling facilities and does provide some subsidies for certain low-emission vehicles.[118]

Electrification is a particularly effective emissions reductions strategy for Norway because its energy sources are largely renewable and low carbon. Over 65% of Norway's energy comes from low-carbon sources, including hydropower, solar, wind, and geothermal. Hydropower is the primary source of energy in Norway.[119] According to one estimate, Norway's EV policies are ultimately contributing to 400 million tonnes of carbon emissions reductions between 2010 and 2050.[120]

Netherlands

The Netherlands is a global example of a strong focus on active transportation policies and programming. The Netherlands has the largest bicycle modal share of trips in the world.[121] There was an average of 1.3 bicycles per inhabitant in 2018. In 2019, 28% of all trips were made by bicycle and 16% by walking, while 47% of trips were made by car. Bicycle trips were most common for short trips, especially for education-related trips and for work commutes within 5 kilometers (3.1 miles). Bicycle mode share is highest among women and young people ages 18 and under. It is important to note that cycling mode share is highest in urbanized areas. Even in the Netherlands, some have noted there is potential for greater cycling mode share; 47% of all car trips were shorter than 7.5 km in the 2019 study.[122]

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[116] Jake Richardson. "The Incentives Stimulating Norway's Electric Vehicle Success." 2020. https://cleantechnica.com/2020/01/28/the-incentives-stimulating-norways-electric-vehicle-success/

[117] Lasse Fridstrøm. "The Norwegian Vehicle Electrification Policy and Its Implicit Price of Carbon." 2021. https://doi.org/10.3390/su13031346

[118] Lasse Fridstrøm. "The Norwegian Vehicle Electrification Policy and Its Implicit Price of Carbon." 2021. https://doi.org/10.3390/su13031346

[119] Hannah Ritchie and Max Roser. "Norway: Energy Country Profile." 2021. https://ourworldindata.org/energy/country/norway

[120] Sverre Alvik and Bent Erik Bakken. "How Norway's EVs have cut emissions globally." 2021. https://www.dnv.com/energy-transition/how-norway-evs-have-cut-emissions-globally.html

[121] Mathijs de Haas and Marije Hamersma. "Cycling facts: new insights." 2020. https://english.kimnet.nl/binaries/kimnet-english/documents/publications/2020/11/03/cycling-facts-new-insights/KiM+e-book+Cycling+facts-ENG.def.pdf

[122] Mathijs de Haas and Marije Hamersma. "Cycling facts: new insights." 2020. https://english.kimnet.nl/binaries/kimnet-english/documents/publications/2020/11/03/cycling-facts-new-insights/KiM+e-book+Cycling+facts-ENG.def.pdf

The Dutch have achieved this high bicycle mode share by building extensive, connected, safe networks of bicycle infrastructure. The impetus for this effort emerged from a rise in traffic deaths in the 1970s, especially among children, as well as the 1973 oil crisis.[123] Through the Sustainable Safety framework, the Dutch have not only created safe bike lanes, but have also redesigned streets in order to calm traffic and enhance safety. Bike parking, integration with public transport, and policies that make car travel expensive or inconvenient have also helped encourage this shift.[124] Political commitment, public support, and stakeholder engagement and alignment have all been key to achieving over 22,000 miles of bike paths.[125]

Other strategies include:

- **Expansion of e-bike programs –** In line with global trends, there has also been a recent rise in e-bike use in the Netherlands. For example, in North-Brabant, Netherlands, an e-cycling incentive program was designed to encourage e-bike commuting. This program gave commuters the chance to earn financial incentives by using e-bikes. After just one month of the program, the e-bike share of bicycle commute trips increased from 0 to 68%. Approximately half of the e-bike trips came from car trips and the other half came from conventional bike trips. In this program, adoption of e-bikes was influenced by age, gender, car ownership, physical condition, and household composition.[126]
- **Public transit –** Public transit is also a key component of Dutch efforts to reduce emissions and move away from car travel. The Netherlands central government formed a partnership with regional authorities, transit operators, and other relevant stakeholders to develop a cohesive strategy for public transportation. This partnership laid out several goals in the "Public Transport in 2040" plan (2019), including growing ridership at the rate of growth of demand for transport and making the entire public transportation sector "practically" emission-free.[127] Other goals including cutting the public transportation sector's use of primary resources by 50% by 2030 and becoming fully circular (eliminating the use of primary resources) by 2050. Strategies include strengthening connections between cities; integrating development and transportation planning; expanding rapid transit networks; and developing multimodal interchange hubs.
- **Speed limit reduction** – In 2019, in order to cut emissions and air pollution – particularly nitrogen dioxide, NO2 - the government mandated a daytime speed limit maximum of 100 kilometers per hour (km/h), which is approximately 62 miles per hour. Cars travel 25% more efficiently at 100 km/h than at 130 km/h, which will lead to reduced GHG emissions. The added travel time will also encourage a slight reduction in VMT.[128] However, research on the effectiveness of this strategy presents mixed outcomes. It

[123] BBC News. "Why is cycling so popular in the Netherlands?" 2013. https://www.bbc.com/news/magazine-23587916#

[124] John Pucher and Ralph Buehler. "Making Cycling Irresistible: Lessons from the Netherlands, Denmark, and Germany." 2008. http://www.cycle-helmets.com/irresistible.pdf

[125] Centre for Public Impact. "The rise of cycling in the urban areas of The Netherlands." 2016. https://www.centreforpublicimpact.org/case-study/focusing-bicycles-transport-urban-netherlands

[126] Joost de Kruijf, Dick Ettema, Carlijn B.M. Kamphuis, Martin Dijst. "Evaluation of an incentive program to stimulate the shift from car commuting to e-cycling in the Netherlands." 2018. Journal of Transport & Health, Volume 10. https://doi.org/10.1016/j.jth.2018.06.003

[127] Government of the Netherlands. "Public Transport in 2040: Outlines of a vision for the future." 2019. https://www.government.nl/binaries/government/documents/publications/2019/06/13/public-transport-in-2040-outlines-of-a-vision-for-the-future/Public+Transport+in+2040.pdf

[128] TU Delft. "Motorway speed limits of 100 km/h largely advantageous." https://www.tudelft.nl/en/tpm/research/stories-of-science/motorway-speed-limits-of-100-kmh-largely-advantageous

is too soon to evaluate the effectiveness of this strategy in the Netherlands, but a study of speed limit reductions in Oslo, Norway found no evidence of reduced air pollution.[129]

- **Renewable energy share –** The Dutch National Energy and Climate Plan (2019) also included plans to increase the use of renewable energy in transportation. In 2018, renewable energy made up 9.5% of energy consumption for mobility.[130] By 2050, one-third of mobility-related energy consumption will be renewable, according to the plan. To achieve this goal, the government is working to promote the use of biofuels in the transportation sector.[131]

Several Dutch cities are also participating in a European effort to deploy eHUBs. eHUBs are hubs of shared and electric mobility, including e-bikes, e-cargo bikes, e-scooters, and/or e-cars. These on-street hubs vary in size, location (both residential and urban areas), and mobility offerings.[132]

[129] Ingrid Kristine Folgerø, Torfinn Harding, Benjamin S. Westby. "Going fast or going green? Evidence from environmental speed limits in Norway." 2020. Transportation Research Part D: Transport and Environment, Volume 82. https://doi.org/10.1016/j.trd.2020.102261

[130] The Netherlands Ministry of Economic Affairs and Climate Policy. "Integrated National Energy and Climate Plan." 2019. https://ec.europa.eu/energy/sites/default/files/documents/nl_final_necp_main_en.pdf

[131] The Netherlands Ministry of Economic Affairs and Climate Policy. "Integrated National Energy and Climate Plan." 2019. https://ec.europa.eu/energy/sites/default/files/documents/nl_final_necp_main_en.pdf

[132] Interreg North-West Europe. "eHUBs – Smart Shared Green Mobility Hubs." https://www.nweurope.eu/projects/project-search/ehubs-smart-shared-green-mobility-hubs/#tab-6

National Policies

National policies play a key role in influencing transportation GHG emissions. In the United States, policies have varied as the priorities and political breakdown of the legislatures and administrations change. This section highlights areas of federal policy with significant impacts on carbon emissions from the transportation sector.

Fuel Efficiency Standards and GHG Standards

Fuel Efficiency Standards were first set in 1975, through the Energy Policy and Conservation Act (EPCA) of 1975, and are regulated by the National Highway Traffic Safety Administration (NHTSA) as part of the United States Department of Transportation (USDOT).[133] Standards are fleet-wide averages that must be achieved by an automaker for its light-duty vehicle (LDV) fleet (i.e., passenger cars and trucks) each year. The standards are known as Corporate Average Fuel Efficiency (CAFE) standards. Regulatory authority is now shared with the United States Environmental Protection Agency (EPA), which began working on GHG emissions standards under the authority of the Clean Air Act. The NHTSA and EPA now issue joint Final Rules for CAFE and GHG regulations.[134]

In 2020, under the Trump administration, the CAFE standards were adjusted by the Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule. This rule required a smaller year-over-year reduction in GHG emissions when compared to the previous CAFE standards finalized in 2012, beginning with the 2021 model year. In addition to the United States standards, the EPA in 2013 granted the state of California the unique authority to set its own GHG emissions standards under the Clean Air Act. Many states, while not allowed to set their own standards (as the Clean Air Act generally preempts state regulations of motor vehicles), have opted to follow California's motor vehicle emissions regulations. In the metropolitan Washington region, currently, Maryland, Virginia, and the District of Columbia have all elected to do so.[135] In 2019, the Trump administration revoked California's waiver, which had allowed California to create its own GHG standards, but the EPA is currently considering reinstating the waiver.[136]

Alternative Fuel Vehicle Incentive

Alternative-fuel vehicles have the potential for deep emissions reductions and federal policies have been put in place to incentivize zero-emission vehicles such as electric and hydrogen fuel cell vehicles. Federal policy currently provides a federal income tax credit for plug-in hybrid and electric vehicles up to $7,500 for each

[133] USDOT. "Corporate Average Fuel Economy (CAFE) Standards." https://www.transportation.gov/mission/sustainability/corporate-average-fuel-economy-cafe-standards

[134] EPA. "EPA and NHTSA Set Standards to Reduce Greenhouse Gases and Improve Fuel Economy for Model Years 2017-2025 Cars and Light Trucks." 2012. https://nepis.epa.gov/Exe/ZyPDF.cgi/P100EZ7C.PDF?Dockey=P100EZ7C.PDF

[135] American Council for an Energy-Efficient Economy. "Tailpipe Emission Standards." 2020. https://database.aceee.org/state/tailpipe-emission-standards

[136] EPA. "Notice of Reconsideration of a Previous Withdrawal of a Waiver for California's Advanced Clean Car Program (Light-Duty Vehicle Greenhouse Gas Emission Standards and Zero Emission Vehicle Requirements)." 2021. https://www.epa.gov/regulations-emissions-vehicles-and-engines/notice-reconsideration-previous-withdrawal-waiver

eligible vehicle.[137] This program has been in place since 2010 but the credit's total value has been slowly phasing out based on vehicle sales.[138]

In the past, the federal government has created programs such as Car Allowance Rebate Systems (CARS), an economic incentive program for fuel efficient vehicles (commonly called "Cash for Clunkers"), as part of the 2009 post-recession stimulus.[139] This program is no longer active as all $3 billion in funding was used with eligible trade-in rebates of $3,500 and $4,500. The Biden Administration has indicated interest in their Infrastructure Plan to include a "Cash for Clunkers" program for domestically made electric vehicles upon the trade in of older gasoline vehicles. Some researchers have found that the program benefited consumers and yielded the intended effect of getting consumers to purchase newer vehicles faster.[140] However, the Brookings Institute found that the program had a high cost per ton of carbon dioxide reduced compared to carbon taxes, cap-and-trade, or other more cost-effective policies. [141]

Renewable Fuel Standards

The United States Renewable Fuel Standards (RFS) was created under the Energy Policy Act of 2005 and amended by the Energy Independence and Security Act of 2007 to expand the RFS program. The program is implemented by EPA in consultation with U.S. Department of Agriculture (USDA) and the Department of Energy (DOE). The RFS program requires a certain volume of renewable fuel to replace or reduce the quantity of petroleum-based transportation fuel, heating oil or jet fuel throughout the United States. The 2007 changes increased the size of the program, by boosting the long-term goals of renewable fuel and extending the program out to 2022.

Fuels qualify as a renewable fuel under the RFS program through a set of statutes and regulations, and among them are requirements that fuels must achieve a reduction in carbon emissions as compared to a 2005 petroleum baseline. The EPA has a variety of different pathways for fuels to qualify and those with higher GHG reduction from the fuel is one of the ways for a higher value to be placed through the RFS program.[142]

The RFS program obligations are applied to all refiners or importers of gasoline or diesel fuel and contribute to the costs of the fuels used.

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[137] IRS. "Plug-In Electric Drive Vehicle Credit." 2021. https://www.irs.gov/businesses/plug-in-electric-vehicle-credit-irc-30-and-irc-30d
[138] U.S. EPA. "Federal Tax Credits for New All-Electric and Plug-in Hybrid Vehicles. https://www.fueleconomy.gov/feg/taxevb.shtml
[139] Alternative Fuels Data Center. "Car Allowance Rebate System." https://afdc.energy.gov/laws/423
[140] Busse, Meghan R., Christopher R. Knittel, Jorge Silva-Risso, and Florian Zettelmeyer. "Did 'Cash for Clunkers' Deliver? The Consumer Effects of the Car Allowance Rebate System." November 2012. http://ceepr.mit.edu/files/papers/2013-009.pdf
[141] Ted Gayer and Emily Parker. "Cash for Clunkers: An Evaluation of the Car Allowance Rebate System." 2013. https://www.brookings.edu/wp-content/uploads/2016/06/cash_for_clunkers_evaluation_paper_gayer.pdf
[142] U.S. EPA. "Overview for Renewable Fuel Standard." https://www.epa.gov/renewable-fuel-standard-program/overview-renewable-fuel-standard

Biden Administration Climate Plans and Implementation

As candidate for President, Joe Biden included a broad agenda focused on climate within his campaign, promising to have the United States achieve a 100% clean energy economy and net-zero emissions no later than 2050. President Biden aims to achieve this work through a series of executive orders that go beyond previous administration's work, by establishing enforcement mechanisms that include milestone targets, by making large investments in clean energy and climate research, and by creating incentives for the rapid deployment of clean energy, especially in areas most impacted by climate change.[143]

Since entering office, the Biden Administration has begun to implement its policies led by a few major initiatives. The American Rescue Plan, passed in March 2021, includes $30.5 billion in federal funding to support the nation's public transportation systems as they continue to respond to the COVID-19 pandemic.[144] Additionally, the administration has begun work on the repeal of the SAFE Vehicles Rule that preempted states from regulating GHG emissions from new vehicles, and announced steps to accelerate deployment of EVs and chargers.[145]

The Biden Administration has also proposed an infrastructure bill, which includes repair and modernization of highways, roads, transit infrastructure (stations, vehicle electrification) and expansion of transit and rail into new communities; clean energy investments to accelerate the decarbonization of the electricity grid and achieve 100% carbon-pollution-free power by 2035; and EV incentives and investments for manufacturers and potentially for customers. The Biden Administration has also shown support for setting a price on carbon, either through a tax or a cap-and-trade program, although no specific plans have been announced.[146]

[143] Joe Biden Campaign. "The Biden Plan for a Clean Energy Revolution and Environmental Justice." https://joebiden.com/climate/
[144] Federal Transit Administration. "American Rescue Plan Act of 2021." 2021. https://www.transit.dot.gov/funding/american-rescue-plan-act-2021
[145] Tyson Fisher. "Biden administration moves on stricter emissions standards." 2021. https://landline.media/biden-administration-moves-on-stricter-emissions-standards/
[146] MIT Technology Review. "How Biden's climate plan stacks up to Bernie's." https://www.technologyreview.com/2020/03/04/905507/joe-biden-bernie-sanders-climate-plan-comparison-democratic-primaries/

Transportation Strategies and their Effectiveness

Governments across the world are working to reduce GHG emissions through targeted transportation actions, and various studies have attempted to examine the potential effectiveness of transportation GHG reduction strategies. This section summarizes some of the common strategies observed in climate action plans, transportation plans, and literature that analyzes their effectiveness at reducing GHGs. For purposes of this literature review, strategies are grouped into the following categories, based on the primary ways by which they reduce GHG emissions:

- **Vehicle Technologies and Fuels strategies**, which seek to reduce the carbon-intensity of vehicle travel by shifting toward lower carbon fuels (less carbon emitted per unit of energy) – including shifts to zero emissions (from the tailpipe) vehicles such as electric vehicles – and/or increase the fuel efficiency of vehicles (less energy used per vehicle mile traveled).
- **Mode Shift and Travel Behavior (MSTB) strategies**, which seek to shift travel to more efficient modes and overall reduce the total amount of vehicle miles traveled (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,** which seek to reduce vehicle travel delay and/or encourage more eco-friendly driving patterns, recognizing that GHG emissions from conventional vehicles are highest during idling and during stop-and-go congested conditions.
- **Carbon pricing,** which includes carbon taxes and fuel pricing strategies, as well as cap-and-trade and cap-and-invest approaches that seek to create economic incentives that support GHG reduction, including changes in vehicle technologies/fuels and VMT reduction.

Many of these strategies are complementary and may be implemented in conjunction with other actions. For example, road pricing policies can be introduced alongside transit system expansions to accelerate desired mode shifts. Governments and agencies implement these strategies in several ways, and different levels of government can undertake different types of strategies. When exploring strategies, it is useful to consider the ways in which strategies are implemented:

- **Education/Information** – For instance, providing information on vehicle fuel economy and the benefits of ZEVs, or encouraging people to try transit.
- **Investments** – For instance, providing EV charging equipment, or increasing the provision of transit services.
- **Incentives/Disincentives** – For instance, providing financial incentives to purchase ZEVs, providing free transit, or increasing the price of driving through tolling, fees, or other pricing mechanisms, such as carbon pricing.
- **Regulation** – For instance, requiring that vehicles meet a certain fuel economy standard, requiring employers to adopt telework policies, or requiring developers to limit parking supply.

Implementation methods may vary based on public support, funding opportunities, and legislative contexts, and would be expected to have important effects on overall GHG reduction potential.

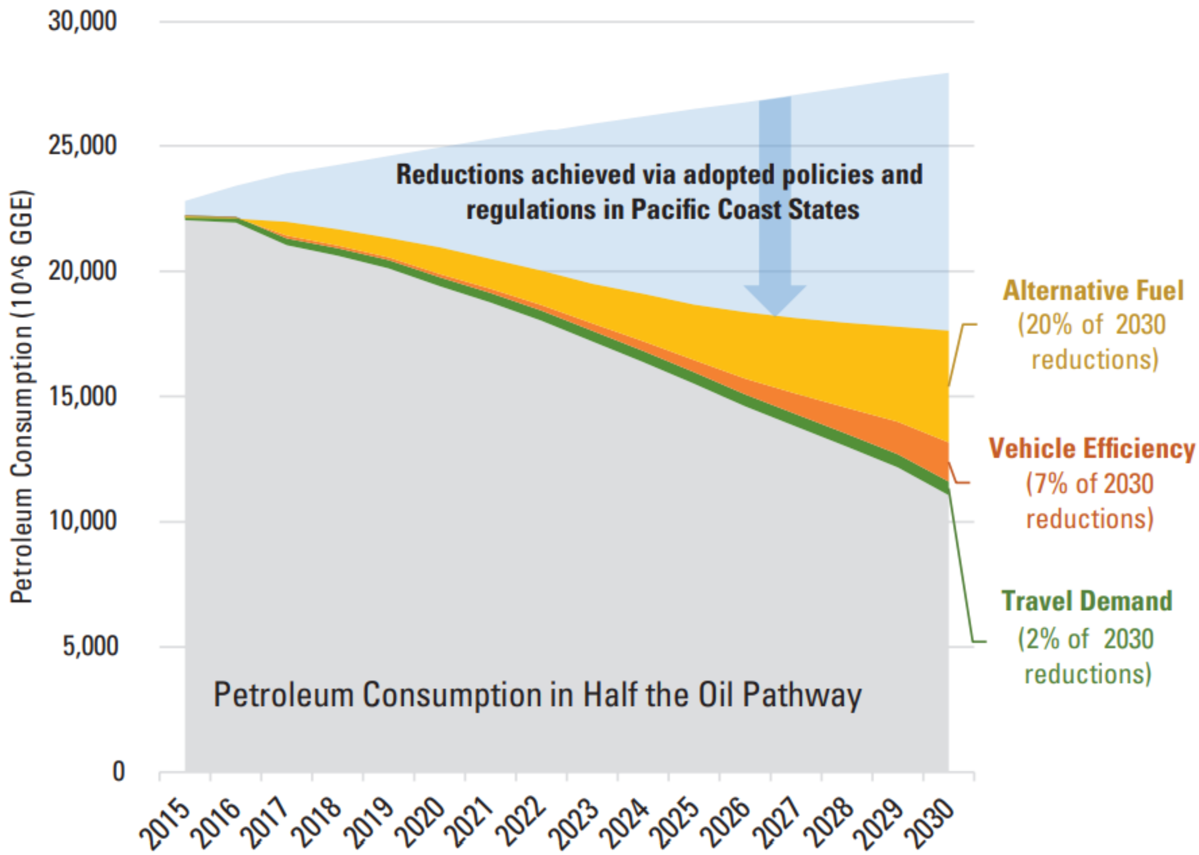
When analyzing the effectiveness of strategies from the literature, it is important to note that it is often difficult to compare studies for a variety of reasons, including:

- **Strategies can vary in their degree of stringency/application** – For instance, a VMT-fee of 10 cents per mile will have a different effect than a fee of $0.25 per mile; therefore, one must be careful to conclude whether a strategy has a large or small effect, based, in part, on how aggressive the implementation is.
- **The effectiveness of strategies varies over time** – Some strategies have near-term impacts, such as pricing strategies, telework, or other strategies that may be implemented quickly. Others take more time to show benefits – for instance, land use policies take time as development occurs, and vehicle technology strategies require a turn-over of the vehicle fleet.
- **Strategy effectiveness often depends on context** – Particularly for VMT reduction strategies, factors such as land use patterns, existing travel options, and existing transportation pricing (including parking pricing and fuel prices) have an important effect of traveler response. Some strategies such as transit and bicycle/pedestrian enhancements often have more effects in urban areas where land uses are conducive to short trips compared to application of similar strategies in more suburban or exurban areas. Some examples of very effective strategy adoption, such as bicycling in some European cities, is within a context of significantly higher fuel prices than in the U.S., and the high price of driving is expected to result in different effects than when the price of driving is low.

Consequently, it is important to consider each of these factors when examining the effects of strategies. Moreover, some studies make comparisons looking at a subset of trips (e.g., work trips) rather than all trips, or make comparisons between different types of conditions but do not necessarily address the potential for overall reductions at a regional scale (e.g., comparing VMT or GHGs for compact, transit-oriented development vs. more traditional suburban development, but not addressing the amount of development that could be affected at a regional scale over a period of time). Many studies report GHG emissions reductions in comparison to a “business as usual” (BAU) case, which can represent either a "do nothing" case or "baseline forecast" accounting for existing policies ("on the books") for future years such as 2030 or 2050. In either case, it is important not to confuse percent GHG reductions compared to the BAU level or baseline forecast with reductions compared to a base year level, such as 2005. Particularly for studies focusing on VMT reduction, many report reductions compared to a BAU scenario or reduction in VMT per capita, which may show notable reductions, but, in some cases, do not reflect VMT reductions compared to a base year due to population growth over time.

A few studies have looked a various pathways to achieve significant GHG reductions from transportation. These studies have generally suggested that vehicle technology and fuel strategies have the largest potential for GHG reductions, with smaller but notable effects from MSTB strategies; TSMO strategies often are not directly explored. The “Half the Oil” study, which explored pathways to reduce petroleum use in transportation by half on the West Coast, for instance, estimated reductions from shifts to alternative fuels, increased vehicle efficiency, and travel demand (i.e., MSTB) strategies, as shown in Figure 2.

Figure 2. Estimated Pathways to Half the Oil in Pacific Coast States



Source: ICF, "Half the Oil: Pathways to Reduce Petroleum Use on the West Coast," January 2016.

A 2021 study by the National Academy of Sciences on "Accelerating Decarbonization of the U.S. Energy System" (in prepublication release) notes that "Electrification of energy services, in tandem with decarbonization of electricity generation, has emerged as a core element in nearly all deep decarbonization scenarios." The study notes the large near-term potential in the transportation sector, highlighting the importance of increased vehicle fuel economy standards, with light-duty ZEVs ramping to 50% of light-duty vehicle sales and 30% of medium- and heavy-duty sales in 2030; setting a clean energy standard for electricity generation, designed to reach 75% zero-emissions electricity by 2030 and net zero by 2050; and the potential role of carbon pricing. The study also emphasizes the benefits of "no regrets" actions, particularly in the first 10 years, including encouraging MSTB strategies that shift travel from SOVs to multi-occupancy vehicles, public transit, cycling and walking; as well as shifting on-road trucking to freight rail, improvements in the fuel efficiency of new internal combustion engine (ICE) vehicles, and TSMO strategies. However, it notes that historically, mode shifts can be difficult and costly to achieve. [147]

[147] National Academies of Sciences, Engineering, and Medicine 2021. *Accelerating Decarbonization of the U.S. Energy System*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25932.

Another recent study by the Rocky Mountain Institute acknowledges that different sectors have different near-term potentials to reduce GHG emissions, informed by currently available technologies. It defines a scenario to limit cumulative GHG emissions compatible with 1.5-degree Celsius warming, which the study equates to reducing U.S. net GHG emissions to about 57% below 2005 levels by 2030, on the way to nearly eliminating net emissions by 2040. This trajectory includes industrial emissions decreasing by 37%, transportation and building sector emissions decreasing by 45%, and electricity emissions decreasing by 83%, respectively, from 2005 levels in 2030. It notes that renewables, electrification, and efficiency are three keystones to reduce the bulk of emissions, especially through 2030. Regarding transportation, the study notes that to meet the ambitious goal of a 45% reduction in transportation emissions by 2030, nearly all new passenger vehicles purchased would need to be electric or otherwise zero-emissions by 2030 (with about one in four cars on the road electric in 2030), about 70% of new medium- and heavy-duty freight vehicles would need to be zero-emissions vehicles, and passenger VMT per capita would need to decline by 20% below 2019 levels.[148]

Vehicle/Fuel Strategies

A variety of strategies exist to reduce the carbon intensity of transportation vehicles and fuels through near- and long-term policy actions.

Hybrid, Plug-in Hybrid and Electric Vehicles

Replacing gasoline or diesel-fueled internal combustion engine (ICE) powered vehicles of all classes with hybrid vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs) has been identified in many climate plans a primary means of achieving significant GHG reductions from transportation due to the significantly lower emissions profiles of these vehicles.

HEVs, which have been on the market for over a decade, offer average GHG emission reductions of over 25% compared to ICE technology. PHEVs, which combine an electric motor and a regular combustion engine, offer on average 50% GHG reduction compared to an ICE vehicle (depending on driving habits), and can be a viable solution especially in regions that have limited access to charging. BEVs offer the greatest direct emissions reduction because they eliminate fuel combustion and tailpipe emissions entirely. However, energy is still required to power the electric motor, and therefore a BEV is still responsible for emissions associated with electrical power generation. Emissions for each stage of the fuel cycle, including production, processing, and final combustion, are typically referred to as fuel-cycle emissions.[149] Despite the fact that electricity in the U.S. is mainly generated by fossil fuels, a BEV charged anywhere in the U.S. still reduces fuel-cycle emissions by at least 65% on average compared to a regular ICE vehicle, primarily due to the greater efficiency of the electric motor

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[148] Teplin, Chaz, Leia Guccione, Lena Hansen, Krutarth Jhaveri, Katie Mulvaney, Jon Rea, and Zack Subin. "Scaling U.S. Climate Ambitions to Meet the Science and Arithmetic of 1.5°C Warming." Rocky Mountain Institute (RMI), April 2021. https://rmi.org/insight/scaling-us-climate-ambitions/

[149] Fuel-cycle emissions account for the upstream emissions associated with extraction, transport, and distribution of the energy used in transportation (including electricity-related emissions for EVs); fuel-cycle emissions do not account for emissions associated with physical infrastructure or production of vehicles or batteries.

(3-4 times more efficient than the ICE technology).[150] Further shifts to renewable fuels in electricity generation will increase these benefits further.

A meta-analysis of 51 studies of the emissions impacts of electric vehicles found that BEVs are associated with substantial reductions in CO_2 emissions.[151] Another literature review, conducted by the Congressional Research Service (CRS), found a wide variability of GHG benefits across studies. This variability is due to the range of assumptions within individual studies including the impact of upstream supply chains, though carbon intensity of the electricity mix was found to explain 70% of this variation. To quantify the overall emissions impacts, CRS chose to highlight one study showing that the lifecycle emissions of BEVs (where lifecycle includes vehicle and battery manufacturing) ranged between 120 and 190 g CO_2e/km. ICE vehicle life cycle emissions amounted to about 280 g CO_2e/km.[152] In other words, even when considering upstream impacts associated with battery manufacturing (which are not counted in fuel-cycle emissions analyses alone), a BEV still reduces emissions by at least 50% compared to ICE technology over the vehicle lifetime.

Hydrogen fuel cell electric vehicles (FCEVs) offer an alternative energy source and reduce demand for lithium batteries; however, hydrogen production and fueling infrastructure is not currently widely available due to high costs. Additionally, hydrogen production is an energy intensive process that currently relies heavily on natural gas or fossil fuel-powered electrolysis. Due to these upstream inefficiencies, FCEVs tend to be more carbon intensive than BEVs on a life-cycle basis.[153] 'Green hydrogen' technologies that rely on clean renewables for hydrogen production are being explored, but applications exist only in small scale pilots, and are not economically viable at scale. Currently, just over 10,000 FCEVs have been sold and leased in the US, and 48 fuel cell buses are in operation in California.[154]

Using up to date information of the power generation mix and associated grid emissions, the U.S. Department of Energy provides estimates for the fuel cycle equivalent annual emissions of BEVs and ICE vehicles for individual states. The results for Maryland, Virginia, and the District of Columbia are provided in Table 3. In Maryland, for instance, the average emissions per BEV are 2,700 lbs. CO_2e per year. Per-vehicle CO_2e emissions for BEVs in Maryland are, on average, 76% less than per-vehicle emissions for ICE vehicles. The variation in BEV emissions per vehicle in Maryland, Virginia, and the District of Columbia can be attributed to differences in the power generation mix. Table 3 shows the average emissions per BEV and per ICE vehicle in each location and the percentage of GHG emissions reductions associated with driving a BEV rather than an ICE vehicle in each location.

[150] Alternative Fuels Data Center. "Emissions from Hybrid and Plug-In Electric Vehicles." https://afdc.energy.gov/vehicles/electric_emissions.html
[151] Requia, Weeberb J., Moataz Mohamed, Christopher D. Higgins, Altaf Arain, and Mark Ferguson. "How Clean Are Electric Vehicles? Evidence-Based Review of the Effects of Electric Mobility on Air Pollutants, Greenhouse Gas Emissions and Human Health." 2018. Atmospheric Environment 185. https://doi.org/10.1016/j.atmosenv.2018.04.040.
[152] Lattanzio, Richard K, Linda Tsang, and Bill Canis. "Vehicle Fuel Economy and Greenhouse Gas Standards: Frequently Asked Questions." 2019. https://crsreports.congress.gov/product/pdf/R/R45204
[153] International Transport Forum (ITF). "Good to Go? Assessing the Environmental Performance of New Mobility." 2020. https://www.itf-oecd.org/good-go-assessing-environmental-performance-new-mobility.
[154] California Fuel Cell Partnership. "FCEV Sales, FCEB, & Hydrogen Station Data." 2021. https://cafcp.org/by_the_numbers

Table 2. Estimated per-vehicle annual GHG emissions reductions in Maryland, Virginia, and the District of Columbia[155]

State/District	BEV emissions per vehicle (lbs. CO_2e / year)	ICE emissions per vehicle (lbs. CO_2e / year)	Percentage of GHG emissions reduction from ICE to BEV
District of Columbia	2,944	11,435	74%
Maryland	2,700	11,435	76%
Virginia	3,137	11,435	73%

Even though BEVs can substantially reduce fuel-cycle GHG emissions in the metropolitan Washington region, a large-scale fleet conversion would require additional investment in renewable energy production infrastructure to make the ICE to BEV conversions sustainable in the long-term. At the national level, one study estimated that to close the U.S. carbon reduction gap consistent with keeping global warming within a 2°C target, solely through the implementation of EVs by 2050, 90% of the national vehicle fleet would need to be electrified, meaning that total electricity generation would need to increase by 50% and excessive demands would be placed on raw material production. The study notes that improving average fuel consumption of conventional vehicles via hybrid technology and weight control would reduce the requirement for electricity but is unlikely to bridge the gap, suggesting the need for policies to reduce vehicle usage as well.[156]

A key factor to consider for achieving near-term GHG reduction is the rate at which vehicle fleets turn over. The average light-duty vehicle operating in the U.S. today is 12 years old, according to IHS Markit.[157] Given the long life of personal vehicles, which can be expected to stay in service 10 to 20 years, it has been estimated that to achieve a goal of net zero emissions from vehicles by 2050 will require automakers to stop selling new ICE vehicles altogether by around 2035 to account for the lag in turnover.[158] Some economic research also suggests that if automakers phase out sales of new ICE vehicles, it is possible older gasoline-powered cars might be held onto longer as consumers who cannot afford electric vehicles hold onto cheaper used models, and this effect could exceed the importance of the mileage "rebound effect," which occurs when fuel-efficient vehicles result in people driving more due to the lower cost per mile.[159]

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155 Alternative Fuels Data Center. "Emissions from Hybrid and Plug-In Electric Vehicles." https://afdc.energy.gov/vehicles/electric_emissions.html
156 Milovanoff, Alexandre, I. Daniel Posen, and Heather L. MacLean. "Electrification of Light-Duty Vehicle Fleet Alone Will Not Meet Mitigation Targets." Nature Climate Change 10. 2020. https://doi.org/10.1038/s41558-020-00921-7.
157 HIS Markit. "News Release: Average Age of Cars and Light Trucks in the U.S. Approaches 12 Years, According to IHS Markit." 2020. https://news.ihsmarkit.com/prviewer/release_only/slug/bizwire-2020-7-28-average-age-of-cars-and-light-trucks-in-the-us-approaches-12-years-according-to-ihs-markit
158 Plumer, Brad, Nadja Popovich, and Blacki Migliozzi. "Electric Cars are Coming. How Long Until They Rule the Road?" The New York Times, March 10, 2021. https://www.nytimes.com/interactive/2021/03/10/climate/electric-vehicle-fleet-turnover.html
159 Jacobsen, Mark R., and Arthur A. van Benthem. "Vehicle Scrappage and Gasoline Policy." 2015. American Economic Review, 105 (3): 1312-38. https://www.aeaweb.org/articles?id=10.1257/aer.20130935

As a result, the effectiveness of vehicle strategies to yield near-term GHG reductions depends on: 1) the extent to which new vehicles are electric and/or more fuel-efficient, and 2) speeding up the rate of vehicle turnover. Policies such as electrifying government fleets and ridesharing fleets (which tend to drive more miles), higher-fuel efficiency standards (national policy), as well as offering rebates to turn in older vehicles for newer, more fuel-efficient models ("Cash for Clunkers") may help to advance these goals. Some of these rebate programs, however, have been criticized for benefiting higher-income groups who are more likely to be purchasing new rather than used vehicles.

At the state level, California is leading an effort to incorporate equity into incentive and rebate programs for alternative fuel vehicles by offering point-of-sale vouchers, and low-income rebates to overcome existing upfront cost barriers for low-income populations. These initiatives have been recently followed by other states that have joined the ZEV Program. For instance, Maine[160] is expanding its EV program with rebates for low-income residents, selected non-profits and tribal governments, while Connecticut[161] is revising its Electric Vehicle Roadmap to add EV incentives for low-income and other disadvantaged communities, and for the purchase of used EVs. Finally, Vermont Credit Union VSECU designed the Green Vehicle Loan to offer lower rates and extended terms to help make financing easy for alternative fuel vehicles. VSECU also works with dealers and electric utilities to simplify loan applications and maximize consumer savings.[162]

Low-Carbon Fuel Standards

A low-carbon fuel standard (LCFS) is a performance- and market-based regulation that requires fuel producers and suppliers to lower the GHG intensity, or carbon intensity (CI), of transportation fuels. Because the regulation does not set volumetric targets for specific fuels – such as the U.S. Renewable Fuel Standard (RFS) and the UK Renewable Transport Fuel Obligation – it is considered a fuel-neutral policy that offers regulated entities greater flexibility relative to an RFS-type program. Low-carbon fuel standards are attractive to policy makers because they send a clear policy signal to investors that long-term solutions are needed for lower-carbon and cost-competitive transportation fuels, while simultaneously incentivizing near-term reductions in emissions through fuel substitution and incremental improvements in existing fuels.

California, Oregon, and Washington are the only three U.S. states that have implemented a LCFS program to date (Washington state adopted a LCRS in April 2021). At a high-level, an LCFS sets a carbon-intensity standard for transportation fuels, which declines over time, typically by year (see Figure 3 below). The predictable nature of the declining standard sends a clear policy signal to the market which, once set, allows entities to be strategic on how to meet the future CI standards at lowest cost. Adding to the flexibility of the program is a credit trading system (the market-based component of the program) that allows regulated parties the freedom to choose how to meet their obligation to meet the CI target:

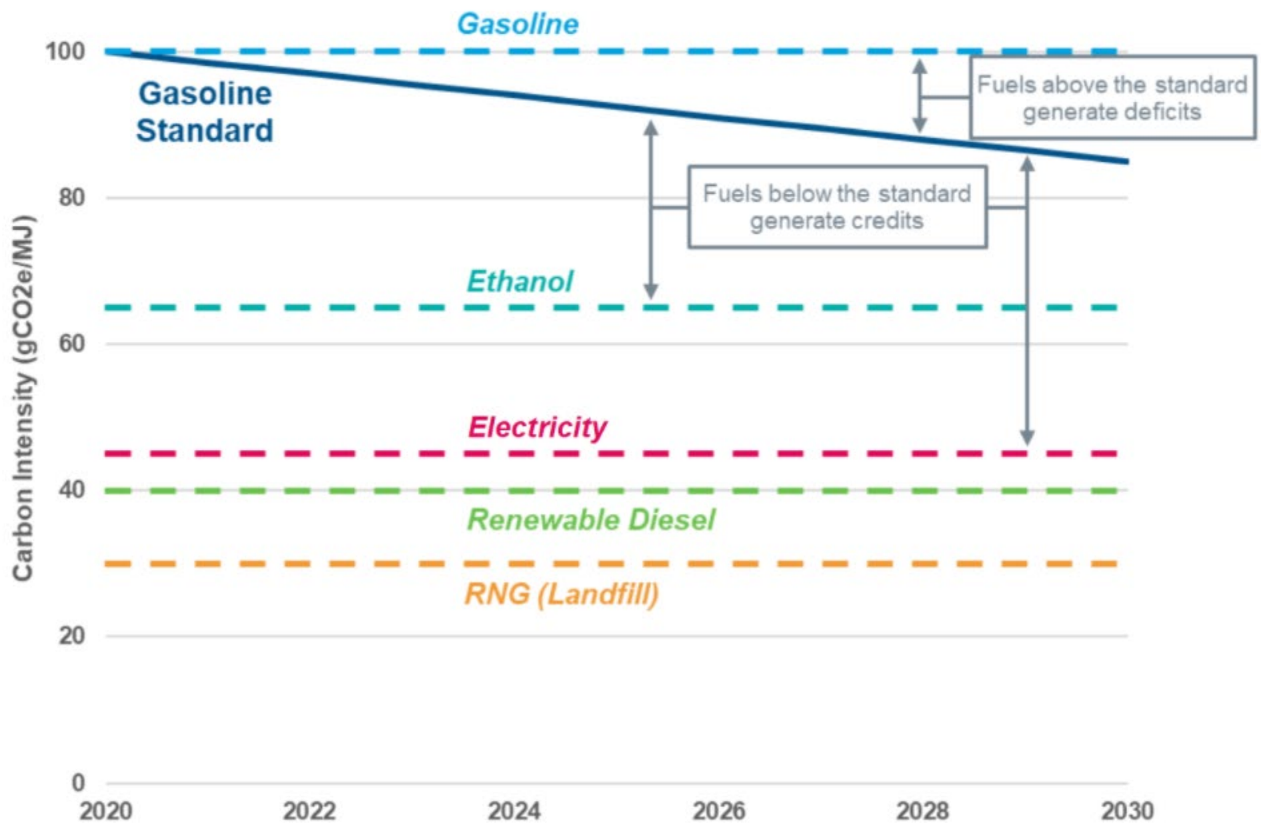
- Reducing the CI of their fuel

[160] Efficiency Maine. "Electric Vehicle Rebates." https://www.efficiencymaine.com/evehicles/electric-vehicle-rebates/
[161] Bengt Halvorson. "Connecticut aiming to revise EV incentive for low-income households." 2019. https://www.greencarreports.com/news/1126325_connecticut-aiming-to-revise-ev-incentive-for-low-income-households
[162] VSECU. "Green Vehicle Loans." https://www.vsecu.com/financial/clean-energy-loans/auto

- Procuring credits on the open market
- Generating credits from fuels or other emission-reducing activity

Within this framework, all fuels that have a CI greater than the standard generate deficits—based on how much greater the fuel's CI is relative to the standard. Alternatively, a fuel that has a CI lower than the standard generates credits, which can be sold on the market to entities with deficits.

Figure 3. Generic Gasoline Standard Relative to Illustrative Low Carbon Fuels[163] [164]



As shown in the figure above, an LCFS sets a carbon intensity standard for transportation fuels, which declines over time, typically by year. The predictable nature of the declining standard sends a policy signal to the market, which allows entities to be strategic on how to meet future standards at lowest cost. LCFS programs have been shown to be a cost-effective mechanism to reduce GHG emissions and increase the share of lower carbon fuels in the transportation sector, while having a smaller cost impact on retail fuel prices relative to other decarbonization policies. In addition, an LCFS program can be designed with cost containment elements to avoid significant cost pressures on fuel producers and consumers.

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[163] Note: the low carbon fuel carbon intensities are illustrative only and reflect individual fuel pathways, not the entire low carbon fuel category.
[164] This graphic comes from a low carbon fuel standard feasibility study completed by ICF in 2020.

As an example of the effectiveness of a LCFS, a review of California's LCFS found that from 2011 to 2017, the share of alternative fuels in the transportation sector increased by 28%.[165] Estimated impacts of LCFS programs in North America show notable reductions in GHG emissions:

- **California** is projected to reduce its GHG emissions by an average of 3.6% of its 2018 transportation emissions per year due to its LCFS program alone.[166]
- **Oregon** is currently reducing its GHG emissions by approximately 4.7% of its 2018 transportation emissions per year.[167]
- **British Columbia** has saved 5.5% of their 2009 transportation emissions per year on average between 2010-2018. [168,169]

Mode Shift and Travel Behavior (MSTB) Strategies

GHG emissions from transportation can be reduced by reducing vehicle travel. Reduced vehicle travel occurs by shifting travel from less-efficient, single-occupant vehicle trips to more-efficient or low/zero-emission modes, such as transit, bicycling, walking, or ridesharing, as well as by reducing the number of vehicle trips (VT) taken and/or trip distances, which equates to reducing vehicle miles of travel (VMT). A wide variety of strategies can be applied to support VMT reduction, including pricing strategies, land use planning, transit improvements, active transportation (bicycle, pedestrian and micromobility), and other travel demand management (TDM) strategies, such as efforts to encourage telework and ridesharing.

This section discusses the potential of MSTB strategies, first summarizing research that broadly addresses VMT reduction, followed by more specific information on individual strategies.

Overall Potential of VMT Reduction Strategies

There is significant compelling evidence that the built environment, including land use and investments in transit, bicycling, and walking, have a significant impact on GHG emissions. For well over the past 10-20 years, seminal studies – including EPA's work on *Our Built and Natural Environments: A Technical Review of the Interactions Between Land Use, Transportation, and Environmental Quality*[170], the *Moving Cooler* study (*Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions*)[171], and the *Growing Cooler* study

[165] Julie Witcover. "Comparison matrix of low carbon fuel programs." 2018. https://policyinstitute.ucdavis.edu/wp-content/uploads/LCFS-Program-Comparison-Matrix-6-2018_UCD_short.pdf
[166] California Air Resources Board. "GHG Emission Inventory Graphs." https://ww2.arb.ca.gov/ghg-inventory-data
[167] State of Oregon. "AQ Programs - Oregon Greenhouse Gas Sector-Based Inventory Data." 2019. https://www.oregon.gov/deq/aq/programs/Pages/GHG-Inventory.aspx
[168] B.C. Ministry of Energy. "Renewable and Low Carbon Fuel Requirements Regulation Summary: 2010-2017." 2017. https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/electricity-alternative-energy/transportation/renewable-low-carbon-fuels/rlcf007_-_2017_summary_2010-17v2.pdf
[169] Province of British Columbia. "Provincial greenhouse gas emissions inventory." 2020. https://www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-inventory
[170] U.S. EPA. "Our Built and Natural Environments: A Technical Review of the Interactions Among Land Use, Transportation, and Environmental Quality." 2013. https://www.epa.gov/smartgrowth/our-built-and-natural-environments
[171] Cambridge Systematics, Inc. "Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions." 2009. https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/MovingCoolerExecSummaryULI.pdf

(*Growing Cooler: The Evidence on Urban Development and Climate Change*)[172] – have clearly identified the important role that land use and transportation investments and policies play on VMT and GHG emissions. Moreover, strategies that support "smart" land use and multimodal transportation options have significant co-benefits in terms of public health, enhancing access to jobs and other opportunities, and equity.

Just as switching from an ICE vehicle to an EV results in dramatically lower emissions, shifting from driving alone to ridesharing, transit, bicycling, walking, or telework results in dramatically lower emissions for the individual traveler. FTA has estimated that if one driver per household switches from commuting alone by car to existing public transit for a commute of 10 miles each way, this would save approximately 8.1% in the annual carbon footprint of a typical American household.[173] Bicycling and walking are zero emissions modes of travel, and a study estimated that if one in five urban residents permanently switched from driving to cycling for just one trip per day, this could cut emissions from all car travel in Europe by about 8%.[174] Transit, bicycling, and walking also require less carbon intensive infrastructure and vehicles.

When looking at the potential for MSTB strategies to have effects over a 10- to 30-year period, most studies suggest that these strategies can achieve meaningful GHG reductions (see discussion below), but are not likely to achieve deep GHG reductions on their own, although effectiveness can be boosted if the policy mix includes stringent road pricing.[175] [176] [177] Still, MSTB strategies are often viewed as quite important to help to work against the rebound effect of vehicle efficiency policies (since these tend to cause people to drive more), as well as to counteract the fact that VMT tends to grow over time in areas with growing populations. These strategies also provide a range of co-benefits. Unfortunately, MSTB strategies become less effective in reducing GHG emissions per mile as vehicle technology and efficiency improve over time.

Although over ten years old, the *Moving Cooler* study is widely referenced as it explored an array of VMT-reduction strategies (as well as ecodriving and operational strategies) and estimated these strategies could achieve annual GHG emissions reductions ranging from less than 4% to 18% under aggressive assumptions and as high as 24% (Maximum Effort Deployment) compared to projected baseline on-road GHGs levels in 2050 (assuming start of implementation in 2010). Individual strategies were estimated to have likely effects as follows: Raising the cost of travel through VMT fees and Pay-as-you-Drive insurance: 1.2-4.4% reduction off baseline;

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172 Reid Ewing, Keith Bartholomew, Steve Winkelman, Jerry Walters, and Don Chen. "Growing Cooler: The Evidence on Urban Development and Climate Change." 2007. https://www.nrdc.org/sites/default/files/cit_07092401a.pdf

173 Federal Transit Administration. "Public Transportation's Role in Responding to Climate Change." 2010. https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/PublicTransportationsRoleInRespondingToClimateChange2010.pdf

174 Brand, Christian. "Cycling is ten times more important than electric cars for reaching net-zero cities", Down to Earth, March 30, 2021, citing, Brand, Christian et al., "The climate change mitigation impacts of active travel: Evidence from a longitudinal panel study in seven European cities." Global Environmental Change, Vol. 67, March 2021. https://www.downtoearth.org.in/blog/pollution/cycling-is-ten-times-more-important-than-electric-cars-for-reaching-net-zero-cities-76185

175 Axsen, Jonn et al. "Crafting strong, integrated policy mixes for deep CO_2 mitigation in road transportation." 2020. Nature Climate Change 10. https://www.nature.com/articles/s41558-020-0877-y

176 Kay, A. I., Noland, R. B. & Rodier, C. J. "Achieving reductions in greenhouse gases in the US road transportation sector." Energy Policy 69, 536–545. 2014. https://doi.org/10.1016/j.enpol.2014.02.012

177 Tayarani, M., Poorfakhraei, A., Nadafianshahamabadi, R. & Rowangould, G. "Can regional transportation and land-use planning achieve deep reductions in GHG emissions from vehicles?" 2018. https://doi.org/10.1016/j.trd.2018.05.010

land use strategies: 0.3-2.1% reduction off baseline; transit investments: 0.4-1.1% reduction off the baseline forecast for 2050. The report assumes VMT fees of 1 cent per mile (expanded best practice) to 12 cents per mile (maximum effort). It should be noted that these estimates were based on national analysis and these strategies could achieve greater relative reductions at a regional scale.[178] A national synthesis report to Congress from the USDOT, which relied upon some of the same research and other studies, generally estimated similar results.[179] It should be noted that the *Moving Cooler* study was published in 2009 and the USDOT study in 2010, so some of the assumptions underlying these studies may now be outdated.

More recently, the U.S. Environmental Protection Agency (EPA) has supported analyses in a dozen regions of the country over the period 2014 to 2020 to explore the potential effects of what the agency terms "travel efficiency" strategies, which address MSTB strategies (travel demand management, public transit fare changes and service improvements, road and parking pricing, and land use/smart growth strategies).[180] The analyses rely on sketch planning methods and EPA's MOVES model, called the Travel Efficiency Assessment Method (TEAM), with scenarios that varied by region, reflecting the specific interests of the MPOs and other agencies involved in the analyses.

The scenarios varied significantly in aggressiveness – from enhancing transit-oriented development near existing light rail stations and completing the light rail system in the St. Louis region to more aggressive strategies like parking pricing of $7.50 for drive-alone trips in the Atlanta region for work (an estimated 74% increase in average parking cost per trip). Across all the regions and scenarios, transportation pricing strategies like VMT fees and parking pricing showed the greatest potential impact on regional light-duty VMT. Hypothetical pricing strategies of $0.05 to $0.10 per mile were estimated to result in a 3.8% to 9.6% decrease in regional light-duty VMT compared to the future BAU cases. Land use and smart growth strategies also showed relatively large effects. For example, in the Atlanta region, a strategy of shifting population growth to "travel efficient" neighborhood types was projected to achieve a 6.4% decrease in regional light-duty VMT from the BAU level in 2040. Transit improvements and bicycle and pedestrian infrastructure generally showed more modest effects, around 1% or less in relation to BAU.[181] It should be noted that not all of the strategy assumptions were particularly aggressive.

It is important to recognize that there may be synergistic effects where a combined mix of policies/strategies results in a larger emissions reduction benefit than would be apparent from summing the effect of strategies on their own. For instance, transit-oriented development, transit investments, and pricing policies that increase the cost of driving likely would be mutually supportive and result in larger emissions benefits in combination than the sum of each individual strategy. Many studies highlight that the most effective approaches involve an integrated

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178 Cambridge Systematics, Inc. "Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions." 2009. https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/MovingCoolerExecSummaryULI.pdf
179 U.S. Department of Transportation, "Transportation's Role in Reducing U.S. Greenhouse Gas Emissions", Report to Congress, April 2010. http://www.reconnectingamerica.org/assets/Uploads/DOTClimateChangeReport-April2010-Volume1and2.pdf
180 U.S. Environmental Protection Agency. "Travel Efficiency Analysis Method." https://www.epa.gov/state-and-local-transportation/estimating-emission-reductions-travel-efficiency-strategies
181 U.S. Environmental Protection Agency. "Travel Efficiency Assessment Method: Key Takeaways from State and Local Case Studies to Reduce Transportation Emissions." 2020. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100ZN95.pdf

mix of policies.[182] On the other hand, there are some strategies that in combination may result in smaller effects than the sum of individual effects. For instance, increasing transit investment and increasing telework together may result in less than the sum of effects of these strategies individually, since some people who would have shifted from driving to transit may be the same people who would have shifted to telework.

At the regional scale, metropolitan planning organizations (MPOs) in California provide a useful perspective on the potential ability for regions to reduce GHG emissions by curbing VMT using what are commonly considered viable strategies. For nearly a decade now, California's 18 MPOs have been required to demonstrate that their long-range plans will achieve GHG reduction targets established by the California Air Resources Board (CARB), pursuant to the SB 375 legislation. Notably, the MPOs cannot take credit for federal or state programs that improve vehicle fuel efficiency or accelerate EV deployment, but must rely entirely on VMT reduction through Sustainable Communities Strategies. The CARB targets are expressed as a percentage change in per capita passenger vehicle GHG emissions relative to 2005. Targets established for MPOs for per capita reductions to 2035 generally range from a 13% reduction to a maximum 19% reduction in several regions.[183] These targets are considered aggressive, and many of the larger MPOs have found it challenging to demonstrate how their long-range plans would hit the targets. Most urbanized areas, however, are projected to grow in population at higher rates. For instance, in the San Francisco Bay Area, population is forecast to increase by about 27% during the period 2005-2035, so even attaining the CARB target, the magnitude of VMT-related emissions is forecast to increase. A statewide assessment of how well the SB 375 program has actually been reducing VMT and GHG emissions found that progress is not on track to meet the targeted level of VMT per capita reduction across the state to date and recommended additional work by all levels of government.[184]

Most of the literature exploring GHG reduction potential from MSTB strategies tend to construct scenarios based on what seems feasible or potentially aggressive to implement. Few have directly looked at "what would it take" (studies that assess the policies needed) to achieve significant GHG reductions from MSTB strategies at a regional scale. A 2018 scenario study in the Albuquerque, New Mexico region explored this issue, attempting to identify what transportation and land use strategies it would take to reach a 40-70% reduction in light-duty vehicle GHG emissions from 2012 levels by 2040. The scenario analysis suggested that no strategy alone could reach the 40% mark. However, a combination of very compact development, transit enhancements, and a $0.25 per mile VMT fee likely would. According to this analysis, a high VMT fee would achieve the largest reductions, with other strategies playing a smaller role. The addition of incorporating a 20% bike mode share and lane reduction to this combination would result in even more significant reductions of GHG emissions, but the authors noted it is unclear how feasible such a mode share would be to achieve.[185]

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182 Axsen, Jonn et al. "Crafting strong, integrated policy mixes for deep CO_2 mitigation in road transportation." 2020. Nature Climate Change 10. https://www.nature.com/articles/s41558-020-0877-y

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

184 California Air Resources Board. "Tracking Progress – Sustainable Communities: Program Report to the Legislature on Sustainable Communities Implementation." 2018. https://ww2.arb.ca.gov/resources/documents/tracking-progress

185 Mohammad Tayarani, Amir Poorfakhraei, Razieh Nadafianshahamabadi, Gregory Rowangould, "Can regional transportation and land-use planning achieve deep reductions in GHG emissions from vehicles?" 2018. Transportation Research Part D: Transport and Environment, Volume 63. https://doi.org/10.1016/j.trd.2018.05.010.

Highlights of the literature review about specific types of MSTB strategies and their effectiveness are described below.

Pricing Strategies

A considerable body of literature suggests that pricing strategies, particularly if applied across a wide array of travel, are likely to have among the largest effects on VMT of all travel behavior strategies, due to the price incentive to drive less – whether by shifting to alternative modes, combining trips, reducing trip lengths, or simply avoiding travel. A variety of pricing strategies may be implemented, and these often can serve as a tool to reduce carbon emissions in two ways: first, by reducing VMT, and secondarily by allowing traffic to travel at optimal speeds, reducing stop-and-go conditions and traffic congestion that led to higher rates of emissions. Travel "price elasticities" have been developed from a range of studies addressing the price of travel, including parking fees, tolls, and other fees. While the literature shows a range of price elasticities of VMT with respect to the variable cost of travel, ranging from about -0.20 to nearly -1.00, many of the higher elasticity figures are from older studies.[186] A recent review of travel price elasticity studies suggested that a -0.30 elasticity is a good estimate for the U.S., reflecting that a 10% increase in the cost of travel would yield a 3% reduction in VMT.[187] However, the responsiveness to price increases will depend on many factors, including the availability of alternatives to driving and the initial price level. Some different types of pricing strategies are highlighted below.

Freeway/Corridor/Facility Pricing

Tolls charged on freeways, tunnels or bridges can encourage people to shift from driving alone to higher-occupancy modes. Simulation modeling showed that if tolling were applied to all freeways in the Seattle region, overall VMT would decline by 6%.[188] However, spillover effects can occur if drivers opt to use toll-free roads.

Cordon Pricing

Cordon pricing involves charging a toll for entering a specific geographic area, such as a downtown district.[189] Implementation of cordon pricing has resulted in a VMT reduction of approximately 15% in several international cities within the cordon zone. Cordon tolls can vary by vehicle class and time of day. In Stockholm, Sweden, the number of vehicles entering central Stockholm fell 22% within the first few weeks of a cordon trial. After six months, the number of transit passengers had increased by 4-5%. Ultimately, VMT decreased by 14% within the cordon and 1% outside of the cordon. The system paid for itself in four years.[190] A study of cordon pricing in

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[186] Federal Highway Administration, Transportation and Global Climate Change: A Review and Analysis of the Literature. June 1998. Prepared by Apogee Research.

[187] Greenberg, A. and J. Evans. (2015). Pay-to-Save Transportation Pricing Strategies and Comparative Greenhouse Gas Reductions: Responding to Final Federal Rule for Existing Electric Utility Generating Units. *Transportation Research Record: Journal of the Transportation Research Board*, (2530), 114-123.

[188] Seattle Department of Transportation and Booz Allen Hamilton. "Seattle Variable Tolling Study," 2009. http://www.seattle.gov/documents/Departments/SDOT/About/DocumentLibrary/Reports/FINALTollingStudyreportrevised6.25.10.pdf

[189] Austin Stanton. "Congestion Pricing for Climate Capacity, or Communities?" 2019. UCLA Institute of Transportation Studies. https://escholarship.org/content/qt5dc9h3qw/qt5dc9h3qw_noSplash_3a6c9f8f05b76ed1a1af37adb280012e.pdf?t=pzgy7t

[190] Tri-State Transportation Campaign. "Road Pricing in London, Stockholm and Singapore: A Way Forward for New York City." 2018. https://nyc.streetsblog.org/wp-content/uploads/2018/01/TSTC_A_Way_Forward_CPreport_1.4.18_medium.pdf

Manhattan estimated that the pricing scheme would result in considerable growth in transit ridership (+6%) and a reduction of single-occupant vehicles and taxi trips destined for the central business district (CBD) by 30% and 40% respectively under a $20 fee scenario. Overall VMT reduction estimated on the Manhattan road network ranged from 5-14% in different scenarios.[191] It should be noted that cordon pricing is generally targeted to congested CBDs and affects only a portion of regional VMT.

Low Emissions Zones

Low emissions zones (LEZ) regulate which vehicles can enter geographic areas, with different restrictions or charges for different classes of polluting vehicles. Certain vehicle classes may be banned from LEZs altogether or may be required to pay a toll. Sometimes, vehicles can be retrofitted to change classification.[192] The LEZ in London incentivized a shift to less-polluting vehicles.[193] In Berlin, particulate matter emissions from vehicle exhaust fell by 35% in the first year in the LEZ.[194] The impact on GHG emissions has not been studied as much as the impact on air quality. A 2015 review of European LEZs found that German LEZs led to a significant reduction (a few percentage points) in air pollution, but that many other LEZs did not have a significant impact. The impact of an LEZ is dependent on the size of the LEZ, how stringent regulations are, and the level of enforcement.[195]

VMT-based Fees

VMT-based pricing involves charging users directly for each mile traveled. VMT fees initially emerged in response to revenue concerns; when alternative fuel vehicles were introduced in the early 2000s, states worried that fuel tax revenues would no longer be reliable as a major source of funding.[196] VMT-based fees are often considered among the most effective VMT-reduction strategies by providing a strong pricing incentive to drive less. Moreover, since VMT-based fees affect all vehicle travel, they create a financial incentive to drive less for all vehicle trips, as opposed to other strategies that often only address a share of trips (e.g., work trips). Pricing strategies like VMT-based fees and pay-as-you-drive insurance have significant potential to reduce GHG emissions within a short timeframe, as consumers respond directly to price signals and adjust their travel patterns accordingly. A study for USDOT estimated that comprehensive pricing strategies that affect all travel—such as VMT fees or pay-as-you-drive insurance—could reduce total on-road GHG emissions by 0.7 to 3.1%

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[191] Amirhossein Baghestani, Mohammad Tayarani, Mahdieh Allahviranloo and H. Oliver Gao. "Evaluating the Traffic and Emissions Impacts of Congestion Pricing in New York City." 2020. https://www.mdpi.com/2071-1050/12/9/3655/pdf

[192] DieselNet. "EU: Low Emission Zones (LEZ)." 2020. https://dieselnet.com/standards/eu/lez.php

[193] Chukwunonye Ezeah, Keiron Finney, Cukwunoso Nnajide. A Critical Review of the Effectiveness of Low Emission Zones (LEZ) As A Strategy for the Management of Air Quality in Major European Cities." 2015. https://www.researchgate.net/publication/280575118_A_Critical_Review_of_the_Effectiveness_of_Low_Emission_Zones_LEZ_As_A_Strategy_for_the_Management_of_Air_Quality_in_Major_European_Cities/link/55bb5b7c08aed621de0c5669/download

[194] Chukwunonye Ezeah, Keiron Finney, Cukwunoso Nnajide. A Critical Review of the Effectiveness of Low Emission Zones (LEZ) As A Strategy for the Management of Air Quality in Major European Cities." 2015. https://www.researchgate.net/publication/280575118_A_Critical_Review_of_the_Effectiveness_of_Low_Emission_Zones_LEZ_As_A_Strategy_for_the_Management_of_Air_Quality_in_Major_European_Cities/link/55bb5b7c08aed621de0c5669/download

[195] Astrid Amundsen and Ingrid Sundvor. "Low Emission Zones in Europe." 2018. Institute of Transport Economics, Norwegian Centre for Transport Research. https://www.toi.no/getfile.php?mmfileid=49204

[196] Ian Duncan. "VMT tax: Two states tax some drivers by the mile. Many more want to give it a try." 2021. Washington Post. https://www.washingtonpost.com/transportation/interactive/2021/electric-mileage-tax/

within 5 to 10 years. This was estimated based upon an estimated pricing implementation of an additional 2 to 5 cents per mile (which was roughly equivalent to a $0.40 to $1.00/gallon gas at the time).[197]

Some states have already begun to implement voluntary VMT tax programs or commercial truck-specific VMT tax programs. Oregon launched a voluntary program in 2015. Drivers can participate by requesting devices that log how much they drive. These drivers get reimbursed for gas taxes.[198] Utah's Road Usage Charge Program is a voluntary program that applies only to electric vehicles and hybrid vehicles. Instead of paying an annual vehicle alternative fuel vehicle registration fee, which was designed to ensure that alternative fuel vehicle owners were also contributing to road operations and maintenance, these drivers could sign up to pay 1.5 cents per mile. The accumulated fees are capped at the price of the annual registration flat fee, so that drivers would only end up saving money under this program.[199] Additionally, Kentucky, New Mexico, New York, and Oregon, charge a VMT tax on trucks.[200] Considerations include the tax base (which vehicle types would be affected); the tax rate structure (whether the tax would vary based on vehicle specifications, location, and/or time of travel); and implementation methods (odometers, radio-frequency identification readers, or onboard devices).[201] With VMT taxes, states must also determine whether all drivers pay or if there are exemptions for electric vehicles. A VMT tax that applied to all vehicle types would not help incentivize a transition to lower-carbon vehicles (compared to a carbon tax or other carbon pricing policies).

Pay as You Drive Insurance

With Pay-As-You-Drive (PAYD) insurance, also known as distance-based, usage-based, mileage-based, and per-mile premiums, insurance premiums are based on the distance driven during the policy term. PAYD is thus designed to encourage people to reduce VMT; by driving less, plan holders can save money. Ranges of estimate of the impacts of PAYD vary. One study estimated that PAYD would reduce VMT for the average vehicle by 2.7%.[202] Others estimated higher effects, with a PAYD rate of six cents per mile yielding annual VMT reductions of approximately 8-12% per vehicle.[203] Higher-risk motorists typically must pay higher premiums per mile, creating greater incentives to reduce mileage, which may improve safety.[204]

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[197] U.S. Department of Transportation, "Transportation's Role in Reducing U.S. Greenhouse Gas Emissions", Report to Congress, April 2010. http://www.reconnectingamerica.org/assets/Uploads/DOTClimateChangeReport-April2010-Volume1and2.pdf

[198] Ian Duncan. "VMT tax: Two states tax some drivers by the mile. Many more want to give it a try." 2021. Washington Post. https://www.washingtonpost.com/transportation/interactive/2021/electric-mileage-tax/

[199] Utah Department of Transportation. "Utah's Road Usage Charge." 2021. https://roadusagecharge.utah.gov/

[200] 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

[201] 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

[202] Brice Nichols and Kara Kockelman. "Pay-As-You-Drive Insurance: Its Impacts on Household Driving and Welfare." 2014. https://journals.sagepub.com/doi/10.3141/2450-10

[203] Victoria Transport Policy Institute. "Pay-As-You-Drive Vehicle Insurance." https://www.vtpi.org/tdm/tdm79.htm

[204] Victoria Transport Policy Institute. "Pay-As-You-Drive Vehicle Insurance." https://www.vtpi.org/tdm/tdm79.htm

Parking Pricing

Charging for parking or raising parking prices is another strategy that can discourage car use and reduce VT and VMT. It has been estimated that free workplace parking leads to 1,311 additional VMT per employee per year.[205] Many studies focus on workplace parking, and several often-cited studies were conducted over 20 years ago. However, the studies are generally fairly consistent and generally show about a 10% increase in parking price reduces the demand for parking spaces by an average of 3%, ranging from 1.2 to 5.8%, depending on the base parking charge.[206] A separate meta-analysis of parking price elasticity that reviewed 25 articles found a mean parking price elasticity of -0.482 worldwide, and the authors developed a model for the U.S. that yielded a parking price elasticity of -0.39, suggesting that a 10% increase in parking price reduces demand by about 3.9%.[207]

The results can be difficult to interpret given that many employees receive free parking at work, but studies of "parking cash out" (giving employees the option to take cash instead of a free parking space at work) conducted in California in the 1990s found a 12% reduction in VMT for commuting to worksites offering the cash out option.[208] A recent study that relied on elasticity figures from the literature, information on parking prices, the share of employees paying for parking, and other data suggested that, in several cities in the U.S., commute VMT may be reduced by 3 to 20% with a cash-out policy (These figures represent cities, not overall metropolitan areas).[209] A study of residential parking pricing found that car ownership can drop by approximately 30% when residents are charged directly for parking, rather than indirectly.[210] Parking pricing can also differentiate between types of vehicles; for instance, the City of Sacramento has discounted parking programs for electric vehicles. In 2020, the District of Columbia passed a parking cash-out bill, which requires employers with 20 or more employees that offer monthly parking benefits to provide a transportation fringe benefit (e.g., vanpool subsidy, transit passes, or bike commuting reimbursements) that are equal or greater than the market rate for parking; pay a clean air compliance fee, or develop a transportation demand management plan.[211]

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[205] Shoup, Donald. "Parking cash out." 2005. American Planning Association, Planning Advisory Service. https://www.researchgate.net/publication/235359730_Parking_Cash_Out

[206] Steven Spears, Marlon Boarnet, and Susan Handy. "Impacts of Parking Pricing and Parking Management on Passenger Vehicle Use and Greenhouse Gas Emissions." 2014. https://ww2.arb.ca.gov/sites/default/files/2020-06/Impacts_of_Parking_Pricing_Based_on_a_Review_of_the_Empirical_Literature_Policy_Brief.pdf

[207] Concas, Sisinnio and Nagesh Nayak. "A Meta-analysis of Parking Pricing Elasticity." 2012. Transportation Research Board 2012 Annual Meeting. https://www.semanticscholar.org/paper/A-Meta-analysis-of-Parking-Pricing-Elasticity-Concas-Nayak/9987448a5f0d8e7cc26b858e29d406d39e2b1b6c

[208] Shoup, Donald, "Evaluating the Effects of Cashing Out Employer-Paid Parking: Eight Case Studies." 1997. Transport Policy 4(4), 201-216. https://www.sciencedirect.com/science/article/abs/pii/S0967070X9700019X

[209] FHWA, "An Assessment of the Expected Benefits of City-level Parking Cash-Out and Commuter Benefits Ordinances." 2017. https://pdxscholar.library.pdx.edu/cgi/viewcontent.cgi?article=1023&context=trec_webinar

[210] Francis Ostermeijer, Hans Koster, and Jos van Ommeren. "Residential parking costs and car ownership: Implications for parking policy and automated vehicles." 2019. http://dx.doi.org/10.1016/j.regsciurbeco.2019.05.005

[211] D.C. Law 23-113. Transportation Benefits Equity Amendment Act of 2020. https://code.dccouncil.us/dc/council/laws/23-113.html

Public Transportation Expansion, Improvement, and Attraction

Improvements to transit service will typically lead to an increase in transit ridership and a reduction in use of single-occupant vehicles. Transit strategies include frequency improvements, transit travel time reduction, service area expansion, transit reliability improvements, and fare reduction.

Transit Service Improvements

The series of EPA TEAM regional scenario analyses indicated that improvements in transit service frequency and service areas, decreased wait times, and other supportive strategies can yield effects on regional VMT. Case studies showed that increasing transit frequency or reducing wait times would result in a 0.30 to 0.55% decrease in regional VMT.[212] A scenario analysis conducted in 2020 in Austin, Texas estimated that improving transit along a major corridor would yield a 0.76% decrease in light-duty VMT within the affected population with a ½ mile of one of the transit stops, and a scenario with regionwide transit improvements estimated a 0.40% decrease in light-duty VMT within the region.[213] These studies are generally consistent with the regional travel modeling conducted as part of the TPB's LRPTF study, which explored the potential for BRT and transitways, commuter rail enhancements, transit rail extensions, and transit fare policy changes and found each individually would have a less than 1% impact on reducing regional VMT daily compared to the baseline forecast.[214]

Enhancing first-mile/last-mile connections to transit could also yield increased transit ridership. Based on a study for the San Francisco Bay Area, if those who could benefit switched from driving alone to a combination of ride-hailing and rail, peak period VMT could be reduced by around 2%.[215]

Moreover, beyond direct impacts on mode shift, transit improvements can have important impacts on land use development that supports further VMT reduction. Improved transit can indirectly help create compact, transit-oriented communities, resulting in a "multiplier" effect for the benefits of transit. Studies show that by stimulating compact and multimodal development, transit improvements can help make communities places where people drive less and can reduce VMT by up to 21%within these communities (compared to a scenario of a place without transit).[216]

[212] EPA. "Travel Efficiency Assessment Method: Key Takeaways from State and Local Case Studies to Reduce Transportation Emissions." 2020. *https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100ZN95.pdf*
[213] EPA. "Applying TEAM in Regional Sketch Planning: A Case Study in Austin, Texas." 2020. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100ZN87.pdf
[214] MWCOG. "Phase II Executive Summary - An Assessment of Regional Initiatives for the National Capital Region." 2017. https://www.mwcog.org/documents/2017/12/20/long-range-plan-task-force-reports-projects-regional-transportation-priorities-plan-scenario-planning-tpb
[215] Farzad Alemi and Caroline Rodier. "Ride-Hailing Holds Promise for Facilitating More Transit Use in the San Francisco Bay Area." 2020. https://escholarship.org/content/qt6sj207js/qt6sj207js.pdf
[216] Todd Litman. "Evaluating Public Transit Benefits and Costs: Best Practices Guidebook." 2021. https://www.vtpi.org/tranben.pdf

Transit Pricing Policies and Incentives

Transit fare reductions can boost transit ridership. Based on various studies, it is estimated that a 10% decrease in transit fares can increase transit usage by on average 4%.[217] Another review of transit fare price elasticities generally showed figures ranging from -0.2 to -1.0, meaning that a 10% decrease in fares would increase transit ridership by 2 to 10%, with the larger figures representing long-term elasticities; these elasticities vary based on user group, trip type, and quality of substitutes.[218]

A synthesis study of fare-free transit offerings noted that reported increases in transit ridership were substantial and ranged from 21% in Boone, North Carolina, to more than 200% in Hawaii and Macomb, Illinois, with even higher increases experienced in Europe and China. The authors note that the disproportionate increases in ridership beyond what typical elasticity formulas would predict might be attributable to the psychological barriers that are removed when fares are no longer required.[219] It is worth noting that the populations and transit ridership in these study areas was relatively small (i.e., Boone has less than 20,000 residents), so it may be relatively easier to achieve large percentage increases in transit ridership than in a region with significant transit ridership like the Washington, DC region.

The overall effects on reducing VMT depend on to what extent new transit riders shift from driving, which may vary based on different factors. One recent study in Santiago, Chile, found that fare-free public transport increased overall travel by 12%, with a 28% increase in trips made by public-transport in off-peak periods; however, there was no evidence of mode substitution.[220] Other studies have shown much more sizeable benefits. In Mercer County, New Jersey, a fare-free, off-peak demonstration project attracted approximately 2,000 net new riders per day to public transit, and about 50% were previously made by automobile.[221] The EPA TEAM analysis of strategies in the Puget Sound Region in Washington State estimated that transit subsidies for low-income populations could reduce regional VMT by 1.78% compared to BAU.[222]

Active Transportation Expansion and Improvements

Active transportation strategies include enhancing supportive infrastructure (e.g., sidewalks, bicycle lanes, trails) and enhancing safety and connectivity of networks to encourage walking, biking, and the use of other lightweight rolling vehicles, often termed "micromobility."

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[217] Handy, S., Lovejoy, J., Boarnet, M., and Spears, S. "Impacts of Transit Service Strategies on Passenger Vehicle Use and Greenhouse Emissions – Policy Brief." 2013. California Air Resources Board. www.arb.ca.gov/cc/sb375/policies/transitservice/transit_brief.pdf

[218] Todd Litman. "Transit Price Elasticities and Cross-Elasticities." 2020. Victoria Transport Policy Institute. https://www.vtpi.org/tranelas.pdf

[219] Joel Volinski. "Implementation and Outcomes of Fare-Free Transit Systems." 2012. http://www.trb.org/Publications/Blurbs/167498.aspx

[220] Owen Bulla, Juan Carlos Muñoza, and Hugo E. Silva. "The impact of fare-free public transport on travel behavior: Evidence from a randomized controlled trial." 2021. Regional Science and Urban Economics, Vol. 86. https://doi.org/10.1016/j.regsciurbeco.2020.103616

[221] Joel Volinski. "Implementation and Outcomes of Fare-Free Transit Systems." 2012. http://www.trb.org/Publications/Blurbs/167498.aspx

[222] EPA. "Travel Efficiency Assessment Method: Key Takeaways from State and Local Case Studies to Reduce Transportation Emissions." 2020. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100ZN95.pdf

Active Transportation Supportive Infrastructure

Walking and cycling are forms of active transportation that do not generate any GHG emissions. Regions can support active transportation by expanding bike and pedestrian infrastructure and improving the safety of existing facilities. New bicycle lanes can reduce GHG emissions by encouraging the replacement of auto trips with bicycle trips, which reduces VMT.[223] [224] The amount of emission reductions achieved by new bicycle facilities depends on many variables, including regional connectivity, length of the facility, average daily traffic (ADT) on the parallel roadway, proximity to activity centers, and the extent to which cycling trips are replacing auto trips. Bicycle facilities are most effective at reducing VMT and GHG emissions when they improve the connectivity of a regional bicycle network, improve access to popular destinations, and are perceived as safe and convenient by cyclists.

In recent decades, bicycle mode share has increased in many cities around the world.[225] Approximately 48% of trips in the U.S. are less than three miles in length and therefore have the potential to be replaced by an active transportation mode.[226] Some studies in cities have estimated notable emissions reduction potential. For instance, a study in Montreal found that a 7% increase in the length of a bicycle network could reduce GHG emissions by approximately 2%.[227] A longitudinal panel study of seven European cities found that an average person driving one trip per day less and cycling one trip per day more for 200 days per year would decrease mobility-related carbon emissions by approximately 0.5 tons per year.[228]

Still, most studies suggest the effects on overall auto VMT tend to be relatively modest at the regional level, in part because any resulting mode shift tends to replace short automobile trips. Bicycling also is somewhat constrained by factors such as weather, and trip type (e.g., less often used for shopping, going to restaurants, etc. than work or recreation). Bicycle and pedestrian access to transit, however, can also support first-mile/last-mile connections that reduce some longer vehicle trips. Using CARB's Active Transportation Program GHG Emission Reduction Calculator, more than 30,000 bicycle lane miles parallel to roadways with high traffic

[223] Matute, Juan, Herbie Huff, Jamie Lederman, Diego de la Peza, and Kevin Johnson. "Toward Accurate and Valid Estimates of Greenhouse Gas Reductions from Bikeway Projects." 2016. California Department of Transportation, Report CA 17-2919. www.lewis.ucla.edu/wp-content/uploads/sites/2/2016/08/UCCONNECT-Matute-Final-Report-with-Appendices.pdf
[224] Handy, S., Tal, G., and Boarnet, M. "Impacts of Bicycling Strategies on Passenger Vehicle Use and Greenhouse Gas Emissions - Policy Brief." 2014 California Air Resources Board. www.arb.ca.gov/cc/sb375/policies/bicycling/bicycling_brief.pdf
[225] Pucher, John, and Ralph Buehler. "Cycling towards a More Sustainable Transport Future." 2017. Transport Reviews 37. https://doi.org/10.1080/01441647.2017.1340234.
[226] Reed, Trevor. "Micromobility Potential in the US, UK and Germany." 2019. https://inrix.com/campaigns/micromobility-study-2019.
[227] Seyed Amir H. Zahabi, Annie Chang, Luis F. Miranda-Moreno, Zachary Patterson. "Exploring the link between the neighborhood typologies, bicycle infrastructure and commuting cycling over time and the potential impact on commuter GHG emissions." 2016. Transportation Research Part D: Transport and Environment, Vol. 47. https://doi.org/10.1016/j.trd.2016.05.008
[228] Christian Brand, Thomas Götschi, Evi Dons, Regine Gerike, Esther Anaya-Boig, Ione Avila-Palencia, Audrey de Nazelle, Mireia Gascon, Mailin Gaupp-Berghausen, Francesco Iacorossi, Sonja Kahlmeier, Luc Int Panis, Francesca Racioppi, David Rojas-Rueda, Arnout Standaert, Erik Stigell, Simona Sulikova, Sandra Wegener, Mark J. Nieuwenhuijsen. "The climate change mitigation impacts of active travel: Evidence from a longitudinal panel study in seven European cities." 2021. Global Environmental Change, Volume 67. https://doi.org/10.1016/j.gloenvcha.2021.102224

volumes, proximate to economic activity, and near high population density would need to be constructed throughout the state to reduce 1% of annual GHG emissions on the California State Highway System.

Encouraging Micromobility

Micromobility is a broad term used to refer to lightweight, electrified or human-powered private and shared vehicles, such as conventional bicycles, e-scooters, and e-bikes. Shared micromobility systems have existed in the United States since the SmartBike DC public bike share system launched in 2008 (now branded as Capital Bikeshare). Public awareness of this class of vehicles intensified with the launch of shared dockless e-scooter systems in Santa Monica in 2017.

Micromobility modes can reduce GHG emissions primarily by replacing vehicle VMT, as their life cycle emissions are generally lower than automobiles.[229] Note that it is important to consider the service vehicles used to rebalance shared micromobility vehicles, as this can significantly impact life cycle emissions and reduce or potentially could eliminate a GHG emissions net benefit.[230]. Electric rebalancing vehicles and swappable batteries are strategies that can help alleviate this pitfall.

Shared micromobility modes are best suited to replace short car trips that are two miles or less in distance.[231] A meta-analysis of studies has shown that shared micromobility trips replace private and ridehail car trips between 7% and 35% of the time, depending on the micromobility mode and the study city.[232] However, when comparing this impact to VMT and GHG emissions from transportation in an entire region, shared micromobility only contributes a small amount. Kou et al. (2020) studied several bike share systems across the U.S., concluding that they saved only between 0.0002% and 0.077% of each city's transportation sector GHG emissions per year.[233] The small scale of these savings is because usage of shared micromobility systems is relatively small in scale, accounting for only a small portion of a city's total trips. It is worth noting, however, that micromobility provides accessibility and mobility benefits, and can support equity if providing services in previously often underserved or minority communities.

If the portion of daily person miles travelled (PMT) by electrified micromobility vehicle were scaled up, GHG emissions benefits could become more substantial. An estimation study found that a 15% share of PMT by

229 International Transport Forum (ITF). "Good to Go? Assessing the Environmental Performance of New Mobility." 2020. https://www.itf-oecd.org/good-go-assessing-environmental-performance-new-mobility.

230 Hollingsworth, Joseph, Brenna Copeland, and Jeremiah X Johnson. "Are E-Scooters Polluters? The Environmental Impacts of Shared Dockless Electric Scooters." Environmental Research Letters 14, no. 8 (August 2, 2019): 084031. https://doi.org/10.1088/1748-9326/ab2da8.

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

232 McQueen et al. (2020).

233 Kou, Zhaoyu, Xi Wang, Shun Fung (Anthony) Chiu, and Hua Cai. "Quantifying Greenhouse Gas Emissions Reduction from Bike Share Systems: A Model Considering Real-World Trips and Transportation Mode Choice Patterns." Resources, Conservation and Recycling 153 (February 2020): 104534. https://doi.org/10.1016/j.resconrec.2019.104534.

private e-bike could result in a 12% reduction in GHG emissions within a metropolitan region.[234] Reaching such a large level of e-bike use would require large investments in additional active transportation infrastructure and vehicle purchase incentives to encourage uptake. A review of e-bike incentive programs revealed a variety of structures, including partial purchase subsidies, vendor-funded discounts, employer sponsored rentals, and government sponsored interest-free loans. The federal government is currently considering a bill, coined the E-BIKE Act, that would make e-bike tax credit subsidies available to all Americans.[235]

Development Patterns and Density / Land Use Planning

The characteristics and location of land development affects vehicle travel. Locations with higher density, more land use mixing, closer proximity to transit, or better access to destinations will typically exhibit less vehicle travel. Land use strategies can include land use mixing, higher density development, transit-oriented development (TOD), destination accessibility, and more.[236]

Studies show that compact development can reduce VMT by 20 to 40% and combining mixed use and transportation options with doubling residential density can reduce VMT by up to 25% compared to less compact development.[237] Based on a literature review, the following VMT reduction percentages were found (note that some of these concepts are related, and percent VMT reductions generally reflect differences at a neighborhood or development site level):[238]

- Land use mixing -- the degree to which a variety of different functions are allotted or encouraged within a given area, subarea, or specific location through policies such as mixed-use zoning and infill development – can decrease VMT anywhere between 0.01 and 10.88%. A meta-analysis by Spears et al (2014) suggests that a 10% increase in land use mixing (measured using an entropy index) is associated with 0.1% to 1.7% lower VMT.
- Higher density development results in more destinations for residents and employees to walk to and enhances the viability of transit, and can decrease VMT anywhere between 0.8%and 30% compared to less dense development. A meta-analysis of studies analyzing California household and travel data found that a 10% increase in residential density is associated with 0.5% to 1.2% lower VMT.
- Transit-oriented development (TOD) – referring to moderate- to high-density projects built in walkable areas that have easy access to public transit and typically offer a mix of uses, including housing, retail, offices, and/or community facilities – can decrease VMT anywhere between 2 and 15%. A SANDAG calculator tool suggests that residential building in a TOD location will reduce project VMT by up to 15% compared to building the project in a non-TOD location.
- Destination accessibility – the degree of ease with which destinations can be reached at the regional (within a metropolitan area), sub-regional (neighborhood-to-neighborhood), and neighborhood (block-

[234] McQueen, Michael, John MacArthur, and Christopher Cherry. "The E-Bike Potential: Estimating Regional e-Bike Impacts on Greenhouse Gas Emissions." Transportation Research Part D: Transport and Environment 87 (October 2020): 102482. https://doi.org/10.1016/j.trd.2020.102482.
[235] Congressman Panetta Introduces E-BIKE Act to Encourage Use of Electric Bicycles and Reduce Carbon Emissions | Congressman Jimmy Panetta (house.gov)
[236] ICF. "Literature Review and Assessment of VMT and GHG Mitigation Strategies." 2019.
[237] Rebecca Lewis et al. "Reducing greenhouse gas emissions from transportation and land use: Lessons from West Coast states." 2018. https://www.jstor.org/stable/26622407?seq=1#metadata_info_tab_contents
[238] ICF. "Literature Review and Assessment of VMT and GHG Mitigation Strategies." 2019.

to-block) scales – can decrease VMT up to 5.9%. One study found that a 10% improvement in jobs-housing balance at the neighborhood level is associated with a VMT reduction of 0.6% to 3.1%.

Using the EPA's TEAM analysis tools, agencies analyzed the effectiveness of land use and smart growth strategies for reducing VMT. These strategies include increasing residential and jobs density and were estimated to have relatively large impacts on VMT. Atlanta, Georgia analyzed the impact shifting population growth toward "travel efficient" neighborhood types would have on VMT. The results estimated that implementing this strategy could decrease regional VMT by 6.43% (and combined with expanded TDM, transit frequency improvements, and parking pricing could reduce regional VMT by 9.28%) compared to the baseline forecast for 2040.[239] The land use analysis assumed that by 2040, 50% of the region's population would be living in the neighborhood types with the lowest average VMT per person, out of 5 neighborhood types, compared to 37% in the baseline forecast. An analysis of land use strategies in the St. Louis region, with more modest assumptions regarding increasing transit-oriented development (shifting 1% of regional population and 2% of regional jobs to more compact neighborhoods around light-rail stations) and a workforce housing balance initiative (bringing jobs and workers closer together, with 17% of jobs shifted to neighborhoods with higher concentrations of housing and 2% of regional population to more compact neighborhoods near existing job centers) were estimated to reduce regional VMT by 1.66-2.13% compared to the baseline forecast for 2040.[240]

The figures from the EPA studies are generally consistent with work for the TPB's LRPTF study, which suggested that optimizing regional land-use balance, increasing jobs and housing around underutilized rail stations and areas with high-capacity transit, and building more housing to match employment could yield a 3% reduction in VMT daily at the regional level (it would bring in more population to the region), and yield a reduction in GHGs of about 4%.[241]

Travel Demand Management

Travel demand management (TDM) refers to a wide variety of programs and services that help to encourage transportation alternatives, reduce reliance on the private automobile for travel, and reduce VMT. TDM strategies include employer alternative commute option programs, rideshare, telework, carsharing, community-based travel marketing, park and ride facilities, and high-quality broadband infrastructure.[242]

In a 2017 study building on the 2009 National Household Travel Survey, the impact of three TDM policy variables on GHG emissions were analyzed: parking management, promotion of transit use and carpool, and employer-based TDM programs. Parking management policies can include cost-based parking prices for SOVs, parking

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[239] EPA. "Travel Efficiency Assessment Method: Key Takeaways from State and Local Case Studies to Reduce Transportation Emissions." 2020. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100ZN95.pdf EPA. "Applying TEAM in Regional Sketch Planning: Three Case Studies in Atlanta, Orlando, St. Louis." 2016. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100P1XZ.pdf
[240] EPA. "Applying TEAM in Regional Sketch Planning: Three Case Studies in Atlanta, Orlando, St. Louis." 2016. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100P1XZ.pdf
[241] MWCOG. "Phase II Executive Summary - An Assessment of Regional Initiatives for the National Capital Region." 2017. https://www.mwcog.org/documents/2017/12/20/long-range-plan-task-force-reports-projects-regional-transportation-priorities-plan-scenario-planning-tpb/
[242] ICF. "Literature Review and Assessment of VMT and GHG Mitigation Strategies." Prepared for Caltrans, 2019.

cash-out for commuters, and electronic parking guidance systems. Promoting transit use and carpooling methods can include subsidized transit passes, improving real time transit information, park-and-ride, and HOV lanes. Employer-based TDM programs can include providing incentives to use alternative transportation modes, supporting commute options like carpool matching or guaranteed ride home, and telecommuting.[243] Based on a regression analysis, findings suggest that "the average household CO_2 emissions from travel in the areas with such policy instruments in place are 16.77% lower for parking management, 14.45% lower for transit use and carpool promotion, and 4.6% lower for employer-based TDM than households located in areas without such policy instruments.[244]

Employer alternative commute option programs typically offer a suite of services and incentives that aim to reduce single occupant vehicle travel to work. Incentivizing employees to avoid commuting in single occupancy vehicles reduces VMT and GHG emissions by both increasing the number of people in vehicles and decreasing the total number of vehicles used in commuting. Employer alternative commute option programs vary widely but often include one or more of the following: facilities, such as onsite showers or bike parking, to encourage non-vehicle commuting; promotion of shared transportation options, including carpooling; flexible work schedules, including a compressed work week; education and outreach about commuting options; and financial incentives. Based on various studies, VMT reduction findings for employee alternative commute option programs range from 1% to 26% at the worksite. Impacts vary based on the types of incentives and services employers offer. Implementation of a voluntary employer-based alternative commute option program has been shown to reduce VMT associated with the employer site by 4% to 6%. Larger VMT reductions are reported for programs that involve mandatory monitoring, reporting, and targets.[245]

Telecommuting eliminates trips but is not a feasible option for all professions. For a given employer or region, the total VMT impact of telecommuting will depend on the number of workers participating in the program, the number of days per week that participants telecommute, and the VMT reduction per telecommuting day. Based on various studies, telecommuting from telework centers reduces VMT by about 65%, and telecommuting from home reduced VMT by up to 90% for individual commuters on days teleworking. It is interesting to note that many studies found that vehicle trips are not necessarily reduced by telecommuting, since telecommuters are more likely to run errands or take other short trips during the day. However, these trips are much shorter than a standard commute, and the impact on the VMT reduction is minor.[246] A recent analysis of the impacts of the COVID-19 pandemic and potential impacts of on-going remote work arrangements estimated a potential 10-20% reduction in commute vehicle trips, equating to about 2-5% of total annual VMT. The study also estimated a potential sustained 10-30% reduction in personal shopping trips from e-commerce, equating to 1-5% of total

[243] Qing Su. "Travel demand management policy instruments, urban spatial characteristics, and household greenhouse gas emissions from travel in the US urban areas." 2017. http://zbw.eu/econis-archiv/bitstream/11159/1227/1/1005135096.pdf
[244] Qing Su. "Travel demand management policy instruments, urban spatial characteristics, and household greenhouse gas emissions from travel in the US urban areas." 2017. http://zbw.eu/econis-archiv/bitstream/11159/1227/1/1005135096.pdf
[245] ICF. "Literature Review and Assessment of VMT and GHG Mitigation Strategies." Prepared for Caltrans. 2019.
[246] ICF. "Literature Review and Assessment of VMT and GHG Mitigation Strategies." Prepared for Caltrans. 2019.

annual VMT. The study, however, noted many uncertainties, such as whether more telework may encourage city dwellers to move to more suburban locations where they need a car for other trips.[247]

Transportation Systems Management & Operations (TSMO) Strategies

Gas-fueled cars sitting in traffic or moving in stop-and-go conditions consume more fuel and emit more emissions than cars traveling at a steady rate between 35 mph and 65 mph.[248] Consequently, there is some potential to reduce GHG emissions by using technology to enable roadways and vehicles to function more efficiently at smooth flow. Moreover, it is estimated that traffic incidents, weather conditions, special events, and poor traffic signal timing are responsible for over half of the delay on roadways.[249] As a result, in theory, operational strategies that reduce non-recurring delay could have notable effects on reducing emissions associated with traffic congestion. It should be noted, however, that with hybrid vehicles and EVs, the effects of speed and flow on vehicles differ from ICE vehicles; for instance, for hybrid vehicles, energy from braking charges the vehicle's battery, resulting in higher miles per gallon in city driving compared to freeway driving. As a result, the benefits of TSMO strategies on GHGs may be expected to decline as more of the fleet transitions to hybrids and EVs.

Intelligent Transportation Systems (ITS)/Operations strategies

There is a wide array of TSMO strategies, which often rely on Intelligent Transportation Systems (ITS) to reduce delay on the roadway network and improve traffic flow. Analyzing the impacts of enhancing transportation system operations is complex due to the wide array of strategies and impacts that these strategies have on travel, including potential changes in trip-making, mode choice (i.e., via improved traveler information), and route choice, and resulting impacts on travel speeds and operating conditions at different times of the day. Most studies have been limited to individual highways or road segments and have looked at delay and emissions before and after implementation of the ITS/operations treatment, but these studies often do not account for potential longer-term shifts or induced travel from improved traffic flow.

Some examples of studies showing the benefits of TSMO strategies are highlighted below (Note that these studies did not consider the potential for induced vehicle travel):

- **Traffic Signal Management** coordinates traffic signals to improve traffic flow and reduce congestion. A meta-analysis conducted for CARB identified four studies that estimated GHG impacts of signal coordination, three of them outside the U.S..[250] The estimated GHG reductions ranged from 1 to 10% on impacted segments.
- **Traffic Incident Management** programs are intended to quickly respond to vehicle crashes and other highway incidents. Research typically relies on traffic simulation models to estimate the impact of

[247] KPMG. "Automotive's New Reality: Fewer trips, Fewer Miles, Fewer Cars?" 2020. https://advisory.kpmg.us/content/dam/advisory/en/pdfs/2020/automotives-new-reality.pdf
[248] Brian Palmer. "The Speed Sweet Spot." 2015. NRDC. https://www.nrdc.org/onearth/speed-sweet-spot
[249] Federal Highway Administration. "Traffic Congestion and Reliability: Trends and Advanced Strategies for Congestion Mitigation." https://ops.fhwa.dot.gov/congestion_report/executive_summary.htm#what_is_congestion
[250] Rodier, Caroline, Susan Handy, and Marlon Boarnet, "Impacts of Traffic Operations Strategies on Passenger Vehicle Use and Greenhouse Gas Emissions – Policy Brief." 2014. https://ww3.arb.ca.gov/cc/sb375/policies/tsm/tos_brief.pdf

incidents on traffic speeds, and the corresponding benefits of more rapid incident clearance. A meta-analysis conducted for CARB identified three studies that estimated GHG impacts of incident management programs, with fuel use or GHG benefits ranging from 0.07% to 4%. The most relevant of these studies examined clearance of lane blockages on a highway corridor in Montgomery County, Maryland, during the AM peak, finding a 4% reduction in CO_2 emissions.[251]

- **Ramp Metering** is intended to improve freeway traffic flow in congested corridors. Very few research studies have reported on the system-wide GHG emissions impacts of ramp metering. One of the only such studies used simulation modeling to estimate the CO_2 emissions effects of ramp metering on a South Korean highway, finding a 7.3% emission reduction on the roadway.[252] A meta-analysis conducted for CARB identified no other relevant research and noted that any reported impacts could not be generalized beyond the particular region or time period of the study.[253]
- **Roundabouts** reduce GHG emissions by smoothing traffic flow. Available research suggests that roundabouts can reduce emissions in some circumstances but increase emissions in others. A study in Sweden found that replacement of a signalized intersection with a roundabout reduced fuel consumption by 28%, but a study in Maryland found a 5% fuel increase and a 1% CO_2 increase from a similar replacement. A meta-analysis conducted for CARB concludes: "Given the wide range of estimated impacts, it is not possible to conclude that roundabouts will reduce fuel consumption and GHG emissions in all cases."[254]
- **Variable Speed Limits (VSL)** use dynamic speed limit signs that change based on current congestion conditions to increase traffic efficiency. A UK case study found that this technique can improve emissions 2 to 8% on impacted segments.[255] With the rise of connected vehicles, individualized speed limits can also be transmitted to specific cars to further optimize this technique. However, data from a microsimulation analysis did not show any significant difference in CO_2 emissions between individualized and identical dynamic speed limits.[256]
- **High-Occupancy Vehicle (HOV) / High-Occupancy Toll Lanes** can potentially reduce emissions both (1) by enabling smoother traffic flow that results in a lower rate of fuel use and emissions per vehicle, and (2) by encouraging SOV travelers to shift to carpools, thereby reducing VMT. When adding capacity instead of converting existing capacity, HOV lanes induce new vehicle travel in urbanized areas. Regional simulation modeling studies suggest that the additional VMT will at least partially offset any emissions benefits resulting from smoother traffic flow, and in many cases will completely offset the emissions

[251] Avetisyan, H. G., Miller-Hooks, E., Melanta, S., & Qi, B. (2014). Effects of vehicle technologies, traffic volume changes, incidents and work zones on greenhouse gas emissions production. Transportation Research Part D: Transport and Environment, 26, 10-19.
[252] Bae S., T. Heo, and B. Ryu. "An Evaluation of the Ramp Metering Effectiveness in Reducing Carbon Dioxide Emissions," Society for Modeling and Simulation International, Korea, 2012.
[253] Rodier, C., Handy, S., and Boarnet, M., Impacts of Traffic Operations Strategies on Passenger Vehicle Use and Greenhouse Gas Emissions – Policy Brief, 2014. https://ww3.arb.ca.gov/cc/sb375/policies/tsm/tos_brief.pdf
[254] Handy, Susan and Marlon Boarnet, "Impacts of Roundabouts on Passenger Vehicle Use and Greenhouse Gas Emissions: Policy Brief," Prepared for the California Air Resources Board, 2014. https://ww3.arb.ca.gov/cc/sb375/policies/rndabt/roundabout_brief.pdf
[255] Highways Agency, UK. "M25 Controlled Motorways: Summary REport," March 2007. https://www.whatdotheyknow.com/request/216603/response/543229/attach/3/SW06332%20CMBC%20Final%20Summary%20Report%20Mar%2007.pdf.
[256] Grumert, Ellen, Xiaoliang Ma, and Andreas Tapani. "Analysis of a Cooperative Variable Speed Limit System Using Microscopic Traffic Simulation." Transportation Research Part C: Emerging Technologies 52 (March 2015): 173–86. https://doi.org/10.1016/j.trc.2014.11.004.

benefits.[257] [258] These conclusions are also supported by project-level analyses of emissions impacts of HOV and express lane additions reported in recent project environmental documents.[259] [260]. However, the increased freeway capacity may help to divert some traffic from arterials and local roadways.

In order to assess the overall impacts, a study completed for the FHWA involved simulation modeling of several operational improvement strategies (ramp metering, incident management, active signal control, and active transportation demand management – meant to cover multiple improvement systems including lane control, queue warning, junction control, and traveler information) using a modeling framework developed by the Metropolitan Transportation Commission (MTC) in the San Francisco Bay Area. The modeling framework included an activity-based travel model, application of the UrbanSim land use model to incorporate reliability into long-term travel decisions, and postprocessors to refine the speed estimates and calculate emissions using MOVES. The results of this 2014 analysis suggested the impacts of the package of strategies would result in a 2.295% increase in VMT but an overall reduction of vehicle hours of travel of 8.839%. The combined effects, even with an increase in VMT, were estimated to reduce regional vehicle CO_2 emissions by 1.647%, due to the more significant reduction in vehicle hours of travel and delay time.[261]

Eco-driving strategies / Speed control

Eco-driving refers to a collection of strategies that aim to improve fuel economy by smoothing or eliminating acceleration and deceleration, limiting engine RPM, changing gears early, limiting unnecessary idling, and driving below freeway speed limits.[262] Eco-driving can be implemented as a human factors or behavioral change strategy or a vehicle design feature (especially for connected and automated vehicles). A wide range of studies suggest that drivers can reduce their fuel consumption and associated GHG emissions through smart driving principles by 0 to 18%,[263] with many of the most rigorous studies demonstrating average fuel savings of 2% to 7%. For instance, a 2013 study managed to overcome some previous shortcomings of other studies of ecodriving by conducting a study of 118 drivers that reside along Interstate 80 from San Francisco to Reno, NV and collected one month of baseline information and one month of feedback from three types of in-vehicle fuel efficiency devices that conveyed information to drivers. The study achieved a statistically significant average

[257] Johnston, Robert A and Raju Ceerla, "The Effects of New High-Occupancy Vehicle Lanes on Travel and Emissions," Transportation Research Part A, Volume 30, No. 1. 1996. https://doi.org/10.1016/0965-8564(95)00009-7

[258] Dowling, Richard et al, 2005. NCHRP Report 535, Predicting Air Quality Effects of Traffic-Flow Improvements: Final Report and User's Guide. Transportation Research Board. www.trb.org/Publications/Blurbs/155398.aspx

[259] Air Quality Study Report, SR 65 Capacity and Operational Improvements Project, State Route 65, Cities of Roseville, Rocklin, and Lincoln, Placer County, 03-PLA-65-PM R6.2 to R12.8, EA 03-1F170, September 2016.

[260] Sac 50 Phase 2 High Occupancy Vehicle Lanes Project, Draft Initial Study [with Proposed Mitigated Negative Declaration]/ Environmental Assessment with Finding of No Significant Impact. September 2016.

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

[262] Barkenbus, Jack N. "Eco-Driving: An Overlooked Climate Change Initiative." Energy Policy 38, no. 2 (February 1, 2010): 762–69. https://doi.org/10.1016/j.enpol.2009.10.021.

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

reduction in fuel consumption of 2.7%, with the most efficient of the three displays producing a 2.9% decrease in fuel consumption.[264]

Eco-driving can be taught through prescribed driver training courses, however a review of eco-driving training studies found that the impact of training deteriorates in a matter of months, even with financial incentives.[265] A recent meta-analysis of 17 studies involving eco-driving as a behavioral change technique, reinforced with in-vehicle feedback systems, found that eco-driving improved fuel economy by 6.6% on average.[266] However, the data from these studies also suggested that the effectiveness of eco-driving training, even with in-vehicle feedback, wanes over time.

A simulation study investigated the potential emissions impact that speed smoothing could have when implanted in connected and autonomous vehicles (CAVs).[267] Using smoothed nationally standardized drive cycles and the MOVES model, the study found that GHGs could be reduced between 3% and 6.6%, which is comparable to the initial impact from eco-driving behavioral interventions. Without the waning effect seen with human drivers, these GHG emissions results could be expected to persist.

Carbon Pricing - Carbon Taxes, Fuel Pricing, and Cap-and-Trade Policies

Carbon taxes and vehicle fuel pricing both work to create economic incentives that reduce GHG emissions. Unlike VMT-based pricing, by pricing fuel consumption, carbon taxes and fuel taxes encourage both VMT reduction and shifts to purchases of lower emissions vehicles.

Carbon Taxes and Cap-and-Trade Policies

Carbon taxes are policies that tax fossil-fuel-related carbon dioxide emissions. These taxes are typically economy-wide. By setting a price on carbon emissions, these taxes can harness market forces to achieve efficient, low-cost emissions reductions strategies.[268] Carbon taxes set a specific price on carbon emissions and let the market achieve an undetermined amount of emissions reductions, somewhat similar to cap-and-

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[264] 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.

[265] 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.

[266] Sanguinetti, Angela, Ella Queen, Christopher Yee, and Kantapon Akanesuvan. "Average Impact and Important Features of Onboard Eco-Driving Feedback: A Meta-Analysis." 2020. Transportation Research Part F: Traffic Psychology and Behaviour. https://doi.org/10.1016/j.trf.2020.02.010.

[267] Liu, Jun, Kara M. Kockelman, and Aqshems Nichols. "Anticipating the Emissions Impacts of Smoother Driving by Connected and Autonomous Vehicles, Using the Moves Model." Washington, D.C., 2018. https://www.ce.utexas.edu/prof/kockelman/public_html/TRB17CAVEmissions.pdf.

[268] Donald Marron, Eric Toder, and Lydia Austin. "Taxing Carbon: What, Why, and How." 2015. Tax Policy Center. https://www.taxpolicycenter.org/sites/default/files/alfresco/publication-pdfs/2000274-Taxing-Carbon-What-Why-and-How.pdf

trade systems, which place a specific limit on emissions and let the market determine the price of carbon.[269] Under emissions trading schemes, such as cap-and-trade and cap-and-invest policies, the amount of CO_2 that can be produced is capped, with the price of CO_2 increasing as the cap level is reduced.

Carbon taxes can vary in scope, point of taxation, rates, and use of revenues:

- **Scope –** In determining the scope, policymakers decide which substances, such as coal, petroleum, natural gas, or biomass-derived fuels are covered.[270] This decision is important because it creates incentives that will shift consumption of fuels.[271]
- **Point of taxation** – A carbon tax can be levied on upstream sources, such as oil refineries, midstream sources such as pipelines, and/or downstream sources such as vehicles.[272] Ideally, a carbon tax would be levied at the point(s) in the supply chain "where the greatest share of emissions is covered, the fewest number of entities are subject to the tax, and no fuel is inadvertently taxed twice."[273] [274] Upstream taxation is thought to be the most administratively efficient approach because it effectively targets end-use emissions but involves far fewer actors. The benefits of downstream taxation are that consumers may respond more and that there are already structures in place to collect this type of tax, such as fuel taxes. Globally, many major carbon pricing programs use downstream approaches or a combination of upstream and downstream.[275]
- **Tax rate** – The tax rate, according to economic theory, should reflect the social cost of carbon while also considering interactions with other policies.[276] The Biden administration recently set the social cost of carbon to approximately $51 per ton. This cost rises over time – to an estimated $85 per ton by 2050 – as the impacts of climate change intensify.[277] Tax rates can be designed to escalate over time, allowing economic actors to adjust and reflecting the increasing social cost of carbon.[278]
- **Revenues –** Carbon tax revenues can be used for climate-related investments, returned to consumers in the form of dividends, or used to reduce other existing taxes.[279] The use of carbon tax revenues

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[269] Donald Marron, Eric Toder, and Lydia Austin. "Taxing Carbon: What, Why, and How." 2015. Tax Policy Center. https://www.taxpolicycenter.org/sites/default/files/alfresco/publication-pdfs/2000274-Taxing-Carbon-What-Why-and-How.pdf

[270] Center for Climate and Energy Solutions. "Carbon Tax Basics." https://www.c2es.org/content/carbon-tax-basics/

[271] Jason Bordoff and John Larsen. "US Carbon Tax Design: Options and Implications." 2018. https://rhg.com/wp-content/uploads/2018/01/CGEPCarbonTaxDesignOptions118_1.pdf

[272] Center for Climate and Energy Solutions. "Carbon Tax Basics." https://www.c2es.org/content/carbon-tax-basics/

[273] Jason Bordoff and John Larsen. "US Carbon Tax Design: Options and Implications." 2018. https://rhg.com/wp-content/uploads/2018/01/CGEPCarbonTaxDesignOptions118_1.pdf

[274] Kevin Kennedy, Michael Obeiter, and Noah Kaufman, "Putting a Price on Carbon: A Handbook for U.S. Policymakers." 2015. World Resources Institute. https://www.issuelab.org/resources/21767/21767.pdf

[275] Jason Bordoff and John Larsen. "US Carbon Tax Design: Options and Implications." 2018. https://rhg.com/wp-content/uploads/2018/01/CGEPCarbonTaxDesignOptions118_1.pdf

[276] Donald Marron, Eric Toder, and Lydia Austin. "Taxing Carbon: What, Why, and How." 2015. Tax Policy Center. https://www.taxpolicycenter.org/sites/default/files/alfresco/publication-pdfs/2000274-Taxing-Carbon-What-Why-and-How.pdf

[277] Jean Chemnick. "Cost of Carbon Pollution Pegged at $51 a Ton." 2021. E&E News. https://www.scientificamerican.com/article/cost-of-carbon-pollution-pegged-at-51-a-ton/

[278] Donald Marron, Eric Toder, and Lydia Austin. "Taxing Carbon: What, Why, and How." 2015. Tax Policy Center. https://www.taxpolicycenter.org/sites/default/files/alfresco/publication-pdfs/2000274-Taxing-Carbon-What-Why-and-How.pdf

[279] Center for Climate and Energy Solutions. "Carbon Tax Basics." https://www.c2es.org/content/carbon-tax-basics/

ultimately effects the economic impacts, equity implications, political feasibility, and environmental impacts of the tax.

Fuel Taxes

Fuel taxes can be considered a type of carbon tax. Fuel taxes typically charge consumers for each unit of motor fuel purchased. Every U.S. state has a fuel tax. Some states use a fixed cent-per-gallon tax rate, while others use a variable-rate tax that adjusts without regular legislative action, such as with inflation or prices. Even in states that have increased fuel taxes over time, fuel taxes are much lower than in other advanced economies. The average fuel tax rate (combining federal, state, and local taxes) in the U.S. was approximately $0.52 per gallon in 2019.[280] Among the 36 most advanced economies, the average rate is $2.24 per gallon.[281] In addition to excise taxes, many countries levy value-added taxes on gas consumption; only a few U.S. states levy any additional sales taxes.

Impacts on GHG Emissions

The primary ways that carbon taxes and fuel taxes can influence the transportation sector are:[282]

- **Fuel economy choice**: If a carbon tax makes fuel more expensive, households may decide to purchase more fuel-efficient vehicles.[283] Additionally, households with more than one vehicle may choose to drive more fuel-efficient option more frequently.[284]
- **Fuel type switching**: Carbon taxes can also incentivize fuel type switching; households and companies may switch to alternative fuel vehicles.[285]
- **Travel reductions, including mode shifts**: Rising fuel prices can lead to greater transit ridership, especially when alternative modes are readily available and especially for lower-income travelers.[286]

The first carbon tax in North America was introduced in British Columbia, Canada, in 2008. The rate was initially set at $10 CAD per tonne carbon emitted with a planned $5 increase every year. The rate stayed at $30 from

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280 Garrett Watson. "How High are Other Nations' Gas Taxes?" 2019. Tax Foundation. https://taxfoundation.org/oecd-gas-tax/
281 Garrett Watson. "How High are Other Nations' Gas Taxes?" 2019. Tax Foundation. https://taxfoundation.org/oecd-gas-tax/
282 Benjamin Leard, Joshua Linn, and Kathryne Cleary. "Carbon Pricing 202: Pricing Carbon in the Transportation Sector." 2020. Resources for the Future. https://www.rff.org/publications/explainers/carbon-pricing-202-pricing-carbon-transportation-sector/
283 Benjamin Leard, Joshua Linn, and Virginia McConnell. "Fuel Prices, New Vehicle Fuel Economy, and Implications for Attribute-Based Standards." 2016. Resources for the Future. https://www.rff.org/publications/working-papers/fuel-prices-new-vehicle-fuel-economy-and-implications-for-attribute-based-standards/
284 Benjamin Leard, Joshua Linn, and Kathryne Cleary. "Carbon Pricing 202: Pricing Carbon in the Transportation Sector." 2020. Resources for the Future. https://www.rff.org/publications/explainers/carbon-pricing-202-pricing-carbon-transportation-sector/
285 Benjamin Leard, Joshua Linn, and Kathryne Cleary. "Carbon Pricing 202: Pricing Carbon in the Transportation Sector." 2020. Resources for the Future. https://www.rff.org/publications/explainers/carbon-pricing-202-pricing-carbon-transportation-sector/
286 Hojin Jung, Gun Jea Yu, and Kyoung-Min Kwon. "Investigating the Effect of Gasoline Prices on Transit Ridership and Unobserved Heterogeneity." 2016. https://scholarcommons.usf.edu/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=1563&context=jpt

2012 until 2018, when it was raised to $35 per tonne emitted. The tax led to a reduction in gasoline demand.[287] The tax has reduced transportation-related emissions by 5% in the short term, with an estimated 19% reduction in the long term.[288] In Sweden, transportation-related carbon emissions declined by over 10%after implementation of a carbon tax and a value-added tax on transport fuel.[289] In Ireland, a fuel-based carbon tax has been estimated to reduce carbon emissions by at least 1.75%; up to 3.82% if users consider only immediate costs when making trip decisions and if there is a strong substitution capacity between public and private transport.[290]

Taxing motor fuel also has been found to be an effective strategy for both raising revenues and reducing vehicle-based emissions. The literature tends to show relatively low price elasticities for drivers consuming fuel.[291] For vehicle fuel, price elasticities are approximately -0.3 in the short run and -0.7 in the long run.[292] Therefore, a 10% increase in fuel prices could be expected to reduce consumption by 3% in the first one to two years and 7% within five to ten years.[293] Other models have predicted that a 10 cent per gallon increase in the gasoline tax would lead to an approximately 1.5%%decrease in transportation sector carbon emissions.[294] Consequently, large increases in fuel price could yield notable effects on fuel consumption. It is worth noting that price elasticity estimates vary considerably with economic conditions.

There are some equity concerns associated with implementing a carbon tax or significant increases in fuel taxes in the transportation sector, as such a tax could be regressive.[295] However, a potential carbon taxation policy with a lump-sum offset for the German passenger transportation sector found benefits for disadvantaged populations. Low-income households, retirees, single parents, and households with two or more children contribute less emissions and would thus benefit from the proposed taxation scheme.[296] Moreover, the use of

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[287] Nicholas Rivers and Brandon Schaufele. "Salience of carbon taxes in the gasoline market." 2015. Journal of Environmental Economics and Management, Vol. 74. https://doi.org/10.1016/j.jeem.2015.07.002

[288] Felix Pretis. "Does a Carbon Tax Reduce CO_2 Emissions? Evidence from British Columbia?" 2019. http://dx.doi.org/10.2139/ssrn.3329512

[289] Julius Andersson. "Caron Taxes and CO_2 Emissions: Sweden as a Case Study." 2019. American Economic Journal: Economic Policy. Vol. 11, No. 4. https://www.aeaweb.org/articles?id=10.1257/pol.20170144

[290] Miao Fu and J. Andrew Kelly. "Carbon related taxation policies for road transport: Efficacy of ownership and usage taxes, and the role of public transport and motorist cost perception on policy outcomes." 2012. Transport Policy, Vol. 22. https://www.sciencedirect.com/science/article/abs/pii/S0967070X12000741

[291] Elisheba Spiller, Heather Stephens, Christopher Timmins & Allison Smith. "The Effect of Gasoline Taxes and Public Transit Investments on Driving Patterns." 2014. Environmental and Resource Economics. https://link.springer.com/article/10.1007/s10640-013-9753-9

[292] Todd Litman. "Transportation Elasticities: How Prices and Other Factors Affect Travel Behavior." 2013. Victoria Transport Policy Institute. www.vtpi.org/elasticities.pdf.

[293] Todd Litman. "Fuel Taxes: Increasing Fuel Taxes and Fees." 2019. Victoria Transport Policy Institute. https://www.vtpi.org/tdm/tdm17.htm

[294] Lucas Davis and Lutz Kilian. "Estimating the Effect of a Gasoline Tax on Carbon Emissions," 2009. https://www.nber.org/system/files/working_papers/w14685/w14685.pdf

[295] Christine Eisenmann, Felix Steck, Lars Hedemann, Barbara Lenz & Florian Koller. "Distributional effects of carbon taxation in passenger transport with lump-sum offset: low income households, retirees and families would benefit in Germany." 2020. European Transport Research Review. https://etrr.springeropen.com/articles/10.1186/s12544-020-00442-6

[296] Christine Eisenmann, Felix Steck, Lars Hedemann, Barbara Lenz & Florian Koller. "Distributional effects of carbon taxation in passenger transport with lump-sum offset: low income households, retirees and families would benefit in Germany." 2020. European Transport Research Review. https://etrr.springeropen.com/articles/10.1186/s12544-020-00442-6

revenues to fund transit, bicycling, walking and other infrastructure or subsidies (e.g., free transit) could help to support equity.

Next Steps

This literature review highlights some of the actions that agencies are taking to reduce on-road transportation emissions and information about effectiveness, as well as some of the challenges. Overall, the studies suggest that significant reductions in GHG emissions from on-road transportation are feasible technologically and from a behavioral perspective, but likely will be challenging to achieve without significant policy actions to rapidly advance the adoption of ZEVs and reduce use of ICE vehicles, including through mode shifts. The research highlights that the timeframes of achieving reductions in GHG emissions also vary across strategies, with some economic incentives, demand management strategies, and transit and highway operations strategies potentially having very near-term effects while others, such as transit investments, land use changes, and large-scale turn-over of the vehicle fleet will take some time. It is also important to note that the effectiveness of each strategy varies based on local conditions, such as density, policies, and cultural and economic factors. This review will help to inform consideration of possible scenarios for analysis of significant GHG emissions reductions from on-road transportation in the metropolitan Washington region.

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