# MEASURES TO REDUCE GREENHOUSE GAS EMISSIONS FROM TRANSPORTATION AND LAND USE ACROSS THE MET COUNCIL REGION

**Recommendations Report**


By
Dr. Jason Hawkins
Matthew Dean
Dr. Kara Kockelman (Research Supervisor)
Department of Civil, Architectural, and Environmental Engineering
Cockrell School of Engineering
1 University Station, C1700
Austin, TX 78712


July 2021

## EXECUTIVE SUMMARY


Climate change is among the most pressing issues of the 21st Century. Its impacts include more severe weather events and temperature variations, increasing home insurance premiums, increasing repair costs of public facilities, and stresses to the economy and wellbeing of residents (Met Council, 2014b). One of the largest sources of anthropogenic greenhouse gas (GHG) emissions is the transportation sector, accounting for roughly a third of all emissions in the United States. This report's objectives are to outline a range of policy and technology strategies and their relative potentials to reduce GHG emissions from the transportation and land use sectors. This review is then used in the development of a tool for comparing decarbonization strategies in the MSP region.

The GHG scenario planning tool allows users to compare possible futures for land use, buildings, transportation, and urban tree canopies. The tool operates at the level of municipalities and townships. The main inputs are population, land use, transportation, and energy projections for the year 2040. The transportation component of the tool also relies on projections of the adoption of electric vehicles (EVs), autonomous vehicles (AVs), and dynamic ridesharing (DRS). The tool also examines the use of road, parking, and decongestion pricing to reduce VMT, and therefore GHG emissions. Cost and emissions factors are then coupled with demand elasticities to inform comparisons of alternative scenarios to a business-as-usual (BAU) forecast.

The recommended set of decarbonization strategies for MSP are as follows:

1. **Electrification of the private vehicle fleet.** The most critical factors in determining life-cycle GHG emissions in the coming decades are the ICE turnover rate and rate of change in vehicle size and power. Vehicle electrification represents the most effective and feasible means of transportation decarbonization in a region with the modal mix of MSP. Anticipated changes in the electricity grid of Minnesota will decrease the GHG emissions of EVs. However, it is important to ensure these

changes occur, and to push for further decarbonization of the electricity grid. Regardless of changes in the electricity grid or whether the EV mix is dominated by PHEVs or BEVs, a shift towards EVs is the most significant driver of cumulative emission reductions (Craglia & Cullen, 2020). The introduction of DCFC (level 3 chargers) throughout the region would be a major catalyst for EV adoption. It is also recommended that level 2 chargers be a requirement in all new dwellings and parking structures to reduce barriers to adoption.

2. **Electrification of the public transit vehicle fleet.** Public transit buses should be electrified as soon as feasibly possible. However, a dramatic expansion of public transit service is not anticipated to provide any benefit from the perspective of GHG emissions reductions. While recognizing there is a range of factors considered when establishing public transit investment, it was concluded that public transit only provides a decarbonization benefit when there is sufficient demand to fill vehicles (more than about 13 passengers for a standard bus). Right-sizing of vehicles and dynamic vehicle routing should be considered in the decarbonization strategy to increase the average vehicle occupancy.
3. **Shared fleets of vehicles.** While the timeline for automation of road transportation remains uncertain, it is prudent to plan for its eventual arrival. In the short-term, shared fleets of ride-hailing vehicles offer a means of FMLM transit where expected vehicle occupancies are below the necessary threshold to make bus and rail modes effective decarbonization strategies. In the long-term, SAEVs will increase operational efficiency (and therefore reduce GHG emissions), reduce vehicle ownership, and likely decrease the size of vehicles. In addition, there is the potential to reduce requirements for parking structures because vehicles can continue making trips after dropping off a passenger. All these factors have been found to reduce the GHG emissions of transportation (Craglia & Cullen, 2020; Lawal et al., 2020). We recommend regulatory limits on empty VMT of 0% for private AVs and 15% for fleets of SAVs. Such limits would both reduce VMT and encourage the use of SAVs over private vehicles.
4. **Development along transit corridors.** Land use change is a slow process, and it is unlikely that a sufficient density to induce significant decarbonization is possible for the MSP region as a single strategy. However, there is clear support for densification and increased land use diversity along existing and planned transit corridors. Coupling land use densification with locations of frequent transit service is expected to provide strong benefits and increase destination accessibility.

While many technology and policy strategies represent marginal changes in GHG emissions, shifts in the electricity grid will produce step changes in the GHG emissions of transportation. Each additional EV purchased, or dollar increase in decongestion pricing, has an associated incremental decrease in emissions. However, replacing the generation capacity of a single coal-fired power plant with renewables will have a positive impact on the emissions of all EVs on the road, rail stock on the track, and buildings in the region.

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| Abbreviation | Term |
|---|---|
| ACA | Airport Carbon Accreditation Program |
| ACRP | Airport Cooperative Research Program |
| AFDC | Alternative Fuels Data Center |
| AV | Autonomous Vehicle (Automated Vehicle) |
| BEV | Battery Electric Vehicle |
| Carbon Neutral | Zero Greenhouse Gas Emissions Annually on a Net Basis |
| CBD | Central Business District |
| CNG/LNG | Compressed/Liquefied Natural Gas |
| $CO_2$ | Carbon Dioxide |
| DRS | Dynamic Ride-Sharing |
| DCFC | Direct Current Fast Charging (Level 3) |
| EIA | U.S. Energy Information Administration |
| EPA | U.S. Environmental Protection Agency |
| EV | Electric Vehicle |
| EVCS | Electric Vehicle Charging Station |
| EVSE | Electric Vehicle Supply Equipment |
| FMLW | First Mile Last Mile |
| GSE | Ground Support Equipment |
| GHG | Greenhouse Gas |
| HC | Hydrocarbon |
| HEV | Hybrid Electric Vehicle |
| LDV | Light-Duty Vehicle |
| LRT | Light Rail Transit |
| MPCA | Minnesota Pollution Control Act |
| MSP | Minneapolis-St. Paul |
| NEI | National Emissions Inventory |
| $NO_x$ | Nitrogen Oxides |
| PHEV | Plug-in Hybrid Electric Vehicle |
| SAEV | Shared Autonomous Electric Vehicle |
| SAV | Shared Autonomous Vehicle |
| SOV | Single-Occupant Vehicle |
| TOD | Transit-Oriented Development |
| UGB | Urban Growth Boundary |
| UNFCCC | United Nations Framework Convention on Climate Change |
| VMT | Vehicle-Miles Traveled |

## 1. OVERVIEW

Climate change, and associated environmental impacts, caused by the release of greenhouse gas (GHG) emissions is a major challenge facing the Minneapolis-St. Paul Metropolitan Area (MSP), and all species on the planet. Addressing climate change features prominently in both local and state government planning. Met Council's Thrive MSP plan anticipates that more severe weather events and temperature variations associated with climate change will increase home insurance premiums, repair costs of public facilities, and stresses to the economy and wellbeing of residents (Met Council, 2014b). Resiliency and climate change mitigation are central to the plan, including changes in both land use and transportation. The state Next Generation Energy Act of 2007 sets a goal of reducing GHG emissions by 30% by 2025 and 80% by 2050 (Claflin & Steinwand, 2019). There is also strong evidence that climate change will receive a greater focus at the federal level in the coming years (BBC News, 2020). This report focuses on the passenger and freight travel sector as the largest source of GHG emissions that can be readily measured and addressed through local policy. In addition, the mobile nature of transportation means that this sector is more efficiently addressed at the regional scale (i.e., by Met Council), as compared to either building energy or waste, which fall under the purview of individual municipal governments.

Urban form impacts residential choice, trip patterns, and total VMT (Badoe & Miller, 2000; TRB, 2009). Policies to promote infill development or allow sprawl have major long-term effects on GHG emissions, especially those from passenger vehicles. If planners identify investments in public EV charging infrastructure and sustainable, efficient public transportation as key mitigation measures, congruency with land-use regulations that in turn dictate development is just as important. For example, if cities experience the same historical urban growth at low population density, increases in annual VMT could undo improvements in expected vehicle technology and fuels from CAFE standards and low-carbon fuels (Hankey & Marshall, 2010). Once in place, the built environment limits adaptation strategies to mitigate the effects of climate change. Thus, creating land-use regulations that not only permit but promote compact, multifamily residential complexes, with mixed-use zoning, affects the opportunities to take multiple forms of transportation to accessible destinations.

The objectives of this project are as follows:

1. Provide technical support for the regional GHG inventory under development by Met Council.
2. Assist in the development of a land use and transportation scenario planning tool for the MSP Metropolitan Area.
3. Provide feedback on the user interface for the scenario planning tool.
4. Participate in education and outreach surrounding Metro Climate Stats.

The purpose of this report is to assess technology and policy options to reduce the GHG emissions impacts of the transportation and land-use sectors. It then provides recommendations as to the preferred set of technology and policy options for inclusion in the scenario planning tool. A separate report outlines the methodology used in the development of the scenario planning tool. The remainder of this report is structured as follows:

- Section 2 outlines existing conditions in MSP in terms of transportation and land use planning. This section also provides a preliminary assessment of GHG emissions by the community, focusing on transportation and residential land use.
- Section 3 provides a detailed review of potential technology and policy strategies that could be considered for inclusion in the scenario planning tool for passenger transportation.
- Section 4 provides a detailed review of potential technology and policy strategies that could be considered for inclusion in the scenario planning tool for freight transportation.

- Section 5 provides a detailed review of potential technology and policy strategies that could be considered for inclusion in the scenario planning tool for land use.
- Section 6 outlines several examples of quantitative analysis performed in similar-sized metropolitan regions.
- Section 7 outlines the GHG planning tool.
- Section 8 outlines the proposed set of technology and policy strategies for inclusion in the scenario planning tool.

## 2. EXISTING CONDITIONS IN MSP

Like most urban areas in North America, MSP is heavily reliant on its road network for commuting. According to the 2010 travel behavior inventory (TBI), 89% of commuting trips were made by private automobile, 5% by public transit, and 6% by walk or bicycle (Met Council, 2018). However, the trend in mode share is promising, with transit and walking increasing by 25% and 16%, respectively, between 2000 and 2010 (Met Council, 2018). The MnPass high occupancy toll lane system was introduced in 2009. The Metropolitan Transportation Commission (2008) found that an HOT network can reduce PM10 by 10%, $CO_2$ by 7%, and $NO_x$ by 3% compared to an HOV network in the year 2030 (all else being equal). Another promising indicator of transportation investment in MSP is the focus in Thrive MSP on the highway network as a fixed asset, which will be maintained but not significantly expanded in the current planning horizon (Met Council, 2018). Despite its cold winters, MSP is recognized as a leader in the provision of bicycle infrastructure, including the Nice Ride network of shared bikes first deployed in 2010 (Schieferdecker, 2012).

Parking is an understudied component of the transportation system. The capital city of St. Paul did a study of parking utilization in 2015. They found a 73% parking occupancy rate at 10 AM on weekdays (City of St. Paul, 2016). When street parking meters are turned off during evenings and weekends, these on-street spaces fill up and surface lot occupancy drops to 30%. There are 28,000 on/off-street parking facilities in the St. Paul CBD and only 6% of parking in the city is on-street (SRF & Nelson Nygaard, 2015). It is estimated that 98% of automobile trips in the Los Angeles metro area start or end with free parking (Chester et al., 2015). Similarly, our estimate for the MSP area based on the TBI is 99% of trips.

Most climate change mitigation plans - whether at the local, state, or federal level - provide targets for GHG reductions for a forecast year between 2030 and 2050 (in the case of MSP, we set the target as 2050). Large-scale changes in both transportation and land use patterns are necessary to meet any of these targets. Transportation and housing are the largest capital expenditures made by most households and their turnover time should be considered when assessing the feasibility and timing of changes. As such, this report begins with a summary of key statistics for the United States (and MSP where available) to provide context for the decarbonization strategy. Currently, in the United States, only 30% of purchased vehicles are new (U.S. Bureau of Transportation Statistics, 2020a), which means that most households are not replacing their current vehicles with one that meets the highest fuel standards under CAFE or with one of the growing array of alternative fuel vehicles on the market. Similarly, only 9% of residential property sales in 2018-2019 were newly constructed dwellings (National Association of Realtors, 2020; U.S. Census Bureau, 2020b). Capital turnover is not instantaneous (see Figure 1). The average car is owned for 10 years, while lower fuel efficiency pickup trucks are generally kept even longer. One of the major transportation levers under the control of MPOs, such as Met Council, is public transit. Fixed route rail transit is the highest order - carrying the highest density of passenger volume - form of public transit. However, the construction of this infrastructure in the 21$^{st}$ century has been slow. The MSP region has contributed to this recent growth, adding 33 miles of fixed rail transit since 2004 (Metro Transit, 2010;

Met Council, 2014a; "Northstar Line," 2020). This recent construction can be compared with 915 miles of major arterial roadway in the region, which represents 5.3% of the road miles but 48% of VMT (Met Council, 2020). These statistics provide context rather than discouragement for the prospects of decarbonizing transportation in MSP. They suggest that strategies that utilize the existing road infrastructure will likely be more feasible to adopt within the time horizon of 2040.

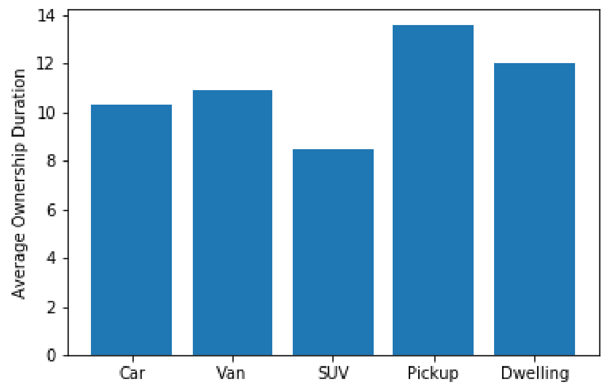



**Figure 1** United States ownership duration for vehicles (by class) and for dwellings (Federal Highway Administration, 2017; U.S. Census Bureau, 2020a)

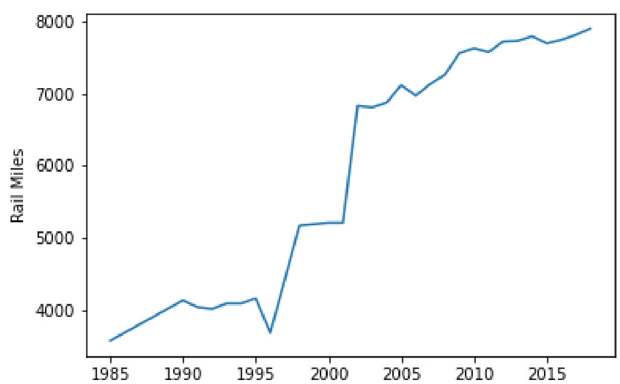



**Figure 2** United States urban passenger rail miles by year (U.S. Bureau of Transportation Statistics, 2020b)

Regarding land use, the proportion of developed land in MSP increased by 9.5%, from 17.4% to 26.9%, over the last 35 years. One of the areas for change that could have a significant effect on climate change is the mix of residential space. As will be outlined in subsequent sections, residential dwelling choice has a significant impact on GHG emissions, not only through the direct consumption of energy but also through its effect on transportation VMT. The proportion of developed land devoted to single-family detached dwellings in the MSP region has remained steady at 68-70% since 1984. The City of Minneapolis is addressing this pattern through an update of its zoning policy, as outlined in its Minneapolis2040 plan. The city has built only 64,000 new homes since 2010 while adding 83,000 households (City of Minneapolis, 2019).

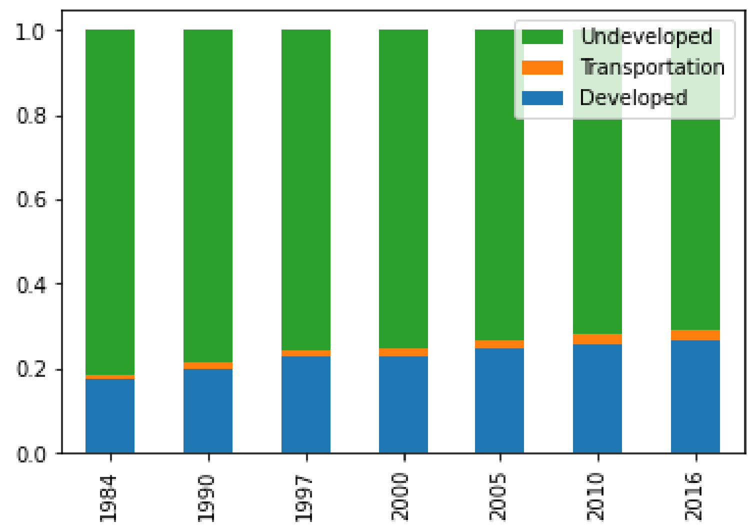


**Figure 3** MSP developed land by year (Met Council, 2017)

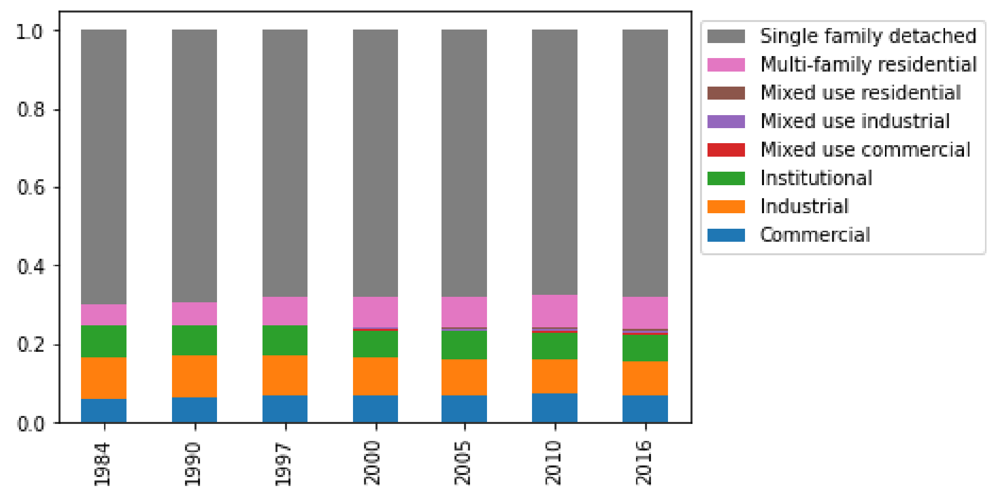


**Figure 4** MSP land use mix by year (Met Council, 2017)

The MSP region is well-provisioned with alternative fuel and EV recharging stations. The Alternative Fuel Data Center (AFDC) provides a map of current biofuel stations, including E85 public stations, which is reproduced below for a section of the MSP region. Owners of FFVs are likely aware of some of these locations, but measures to increase awareness of biofuel station locations could be useful.

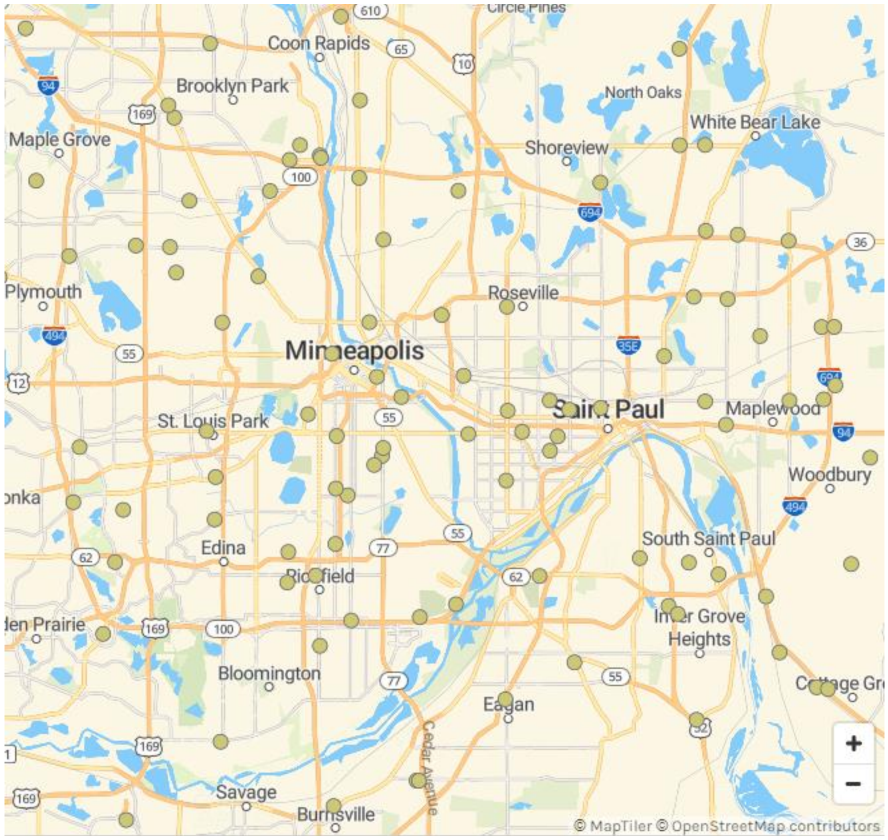



**Figure 5** MSP Ethanol (E85) fuel stations (AFDC, 2020)

EV sales in Minnesota have roughly doubled from 3,917 vehicles in 2011 to 8,175 vehicles in 2019 (see Figure 6). In addition, a larger portion of vehicle sales is now fully electric BEVs rather than HEVs. The region is well-served by EV charging stations (see Figure 7).

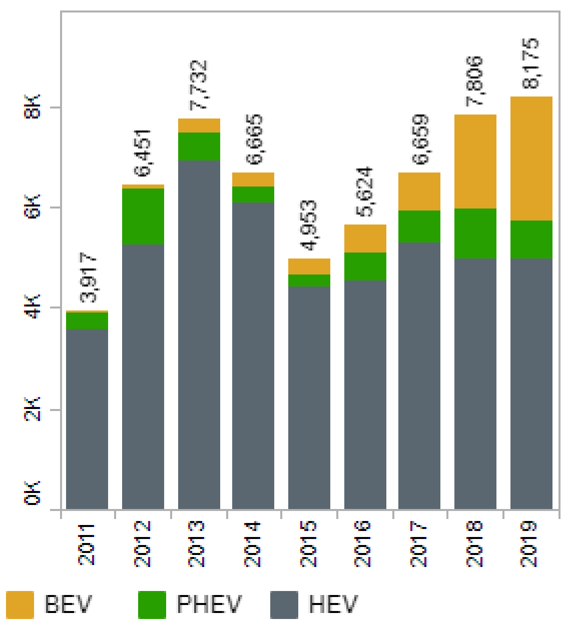



**Figure 6** Historical EV Sales in Minnesota by Class (Auto Alliance, 2020)

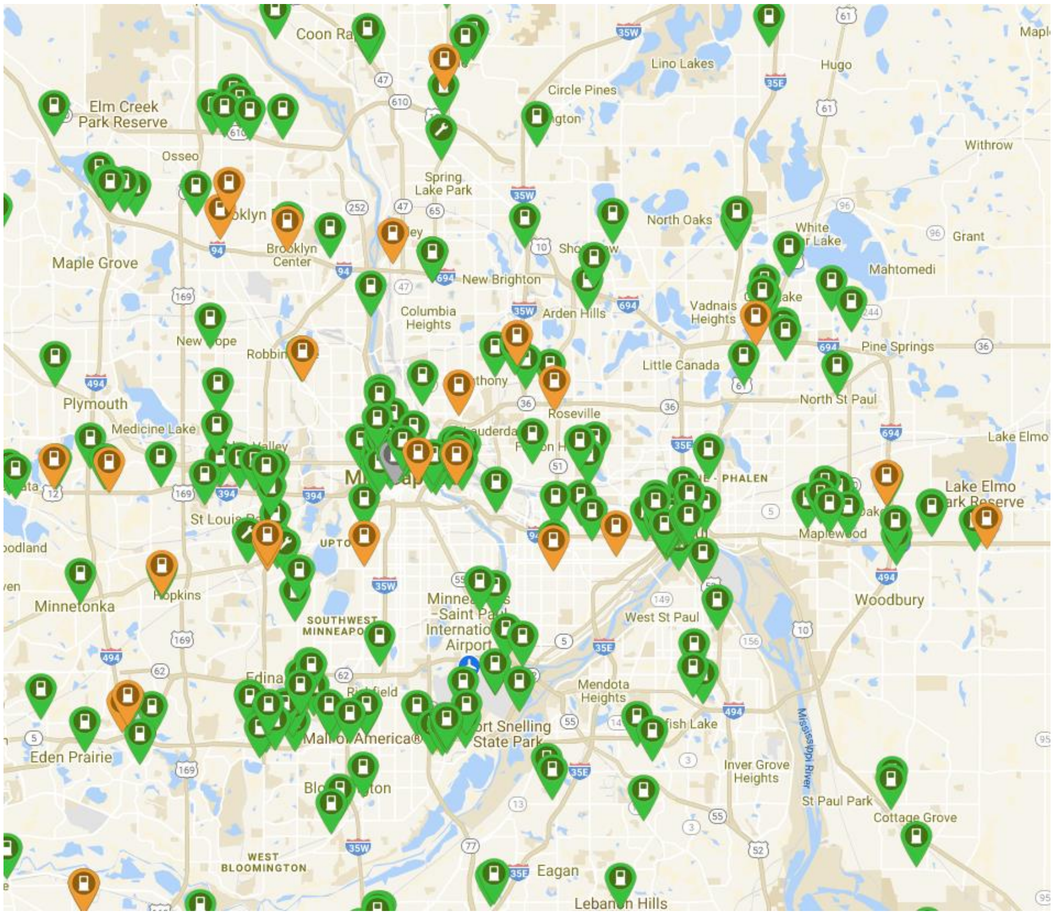
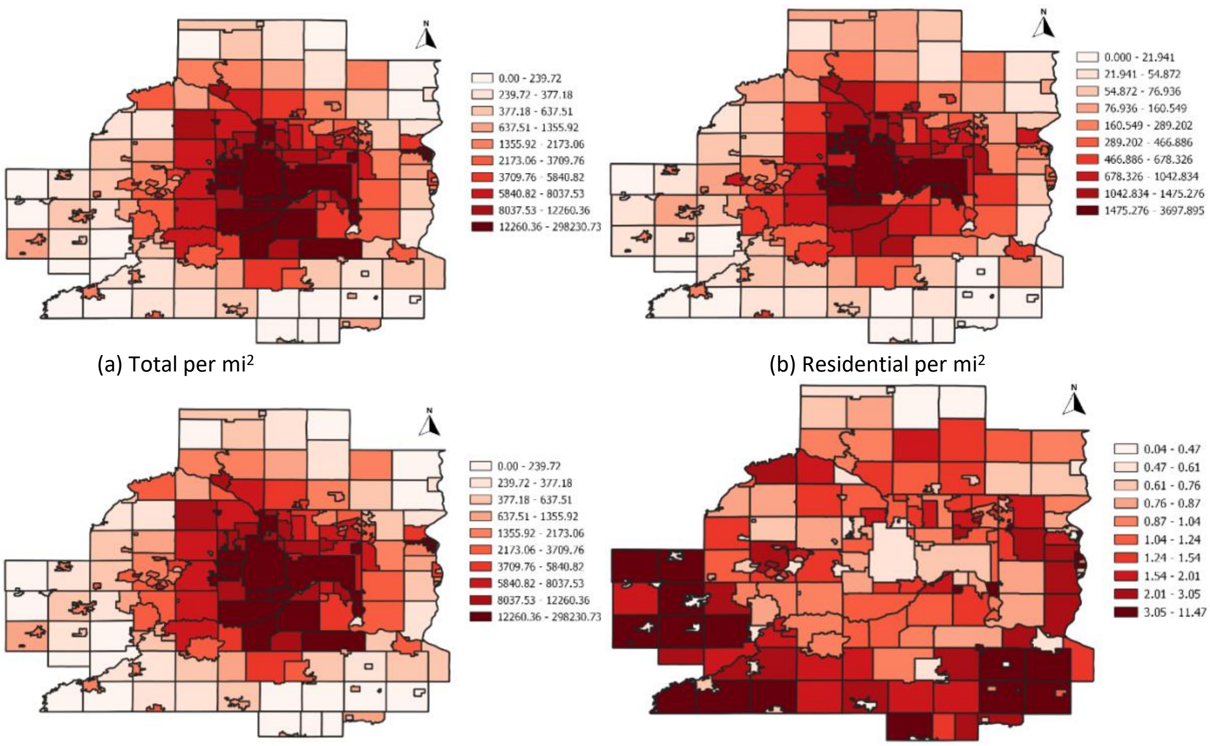



**Figure 7** MSP EV recharging stations (PlugShare, 2020) - green = public and gold = high power

Figure 8a-d are based on data compiled by the Vulcan project at Northern Arizona University (Gurney et al., 2020). This project produced 1-km grid cells at one-hour intervals for GHG emissions for the continental United States for the years 2010 to 2015. The data include estimates for emissions resulting from the combustion of fossil fuels and cement production. Sources are categorized as airports, cement, commercial, commercial marine vessels, industrial, electricity generation, residential, non-road transportation, rail transportation, and road transportation. Emission totals from the EPA National Emissions Inventory (EPA NEI) are spatially and temporally allocated at a detailed scale. In the case of road transportation, emissions are distributed among roads by AADT reported to FHWA. In the absence of reported AADT data, values are imputed from a nearest neighbor analysis of road links with available AADT data. A similar procedure is used to distribute among the hours of the year based on continuous counting station data. For the purposes of the current project, annual totals are sufficient. Residential emissions are available for each county from the EPA NEI nonpoint CO data. These totals are then distributed among 1-km grid cells based on DOE Residential Energy Consumption Survey microdata and FEMA HAZUS (a spatially detailed hazard risk assessment tool). These 1-km grid cells were then redistributed among the 188 communities and townships in MSP, with the totals for grid cells that cross community boundaries being proportionally allocated by area. A clear challenge in presenting emissions results for each community is that they are not uniform in their population or role in the region. For example, transportation emissions will tend to be higher in Minneapolis owing to its disproportionate role as a center of employment. Figure 8a-c standardize emissions by land area based on the focus of this report being the effective use of land and transportation infrastructure for the reduction of emissions. From this perspective, emissions tend to decrease with distance from the central cities (i.e., Minneapolis and St. Paul). Figure 8d then standardizes road transportation emissions per capita using a summation of population and employment. In this case, the emissions profile switches such that outlying areas tend to have higher emission rates. The vehicle inventory conducted as part of the 2019 TBI suggests that part of this result can be attributed to residents of central cities owning smaller and more fuel-efficient vehicles. There is also a higher use of transit and active modes (i.e., walking and cycling) in these more central communities. Finally, by considering both population and employment, this standardization captures the fact that residents of more central communities tend to also work in these communities. As such, in many cases, they will be double-counted in the per capita measure.




(a) Total per mi$^2$

(b) Residential per mi$^2$

(c) Road transportation per mi$^2$

(d) Road transportation per capita (population + employment)

**Figure 8** MSP GHG emissions by source (Gurney et al., 2020)

As will be expanded upon in subsequent sections of this report, synergies between innovations in the transportation, buildings, and electricity generation sectors are critical to any decarbonization strategy. A transition in the vehicle fleet towards EVs or a change in building heating to electricity-based sources will be ineffective in reducing GHG emissions if the electricity grid relies on carbon-intensive sources of generation. Xcel Energy has prepared a set of forecasts for the electricity generation mix in the Upper Midwest Region (Michigan, Minnesota, North Dakota, South Dakota, and Wisconsin). Minnesota represents the largest market for Xcel Energy within the region. The reference scenario assumes that nuclear plants are retired at the end of their life and replaced with imported energy. Coal-fired plants are assumed to represent a diminishing portion of the generation mix as they are phased out. The mitigation scenario assumes that carbon-free generation (i.e., utility-scale solar, onshore wind, biomass, hydro, and nuclear generation) represent 90% of the generation mix in 2050. If enacted, this mitigation scenario would provide significant improvements to decarbonization from the electrification of both transportation and building energy.

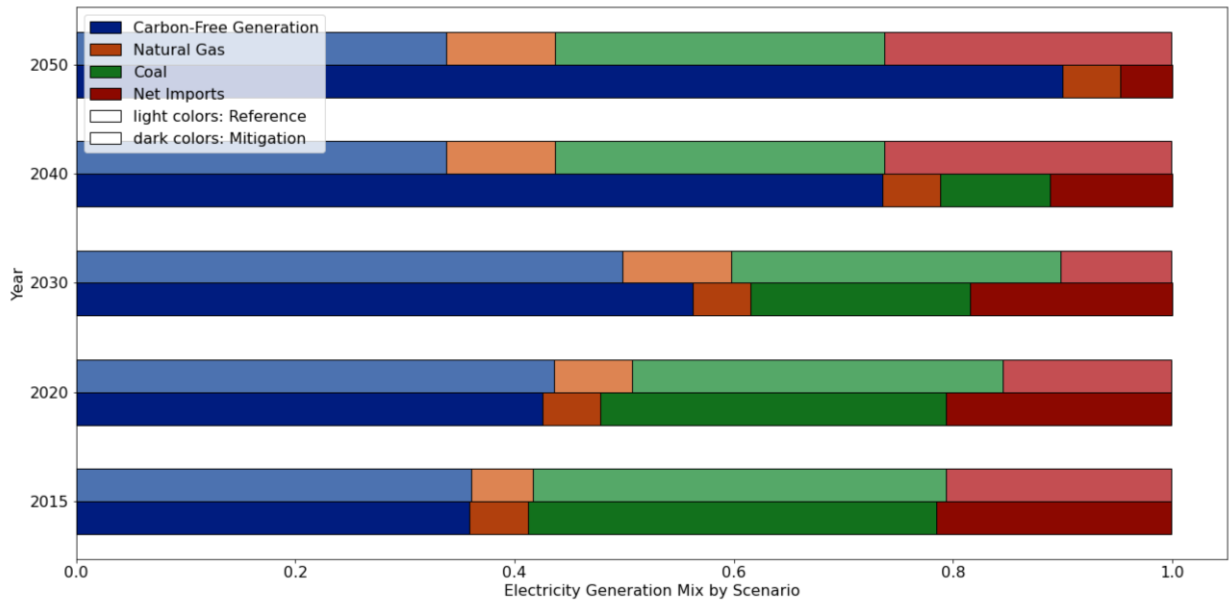



**Figure 9** Reference and mitigation scenarios for electricity mix in Upper Midwest Region (data source: (Xcel Energy, 2019))

### 2.2 Existing Climate Change Plans

The principal source of state legislation regarding climate change is the Next Generation Energy Act. The act requires Minnesota to reduce its GHG emissions by 80% from 2005 levels by 2050 (MPCA, 2019). Interim goals are set at 15% and 30% for 2015 and 2025, respectively. The state was unable to meet its 2015 goal but did reduce emissions by 5% relative to 2005 levels. Under the conditions of the act, the Minnesota Pollution Control Agency (MPCA) is required to produce a bi-annual inventory of emissions produced within the state. The main source of emissions reductions has come in the form of transitions in the electricity generation sector (see Figure 10). MPCA reports that the transportation sector is now the largest source of emissions in the state. In addition, trends towards larger vehicles and more miles traveled are inhibiting more significant reductions in this sector. Emissions from the residential sector increased by 11% between 2005 and 2016. The state government is working to reduce emissions from their activities through electricity efficiency improvements, reducing workspace square footage, and introducing on-site renewable energy generation at agency offices (MPCA, 2019).

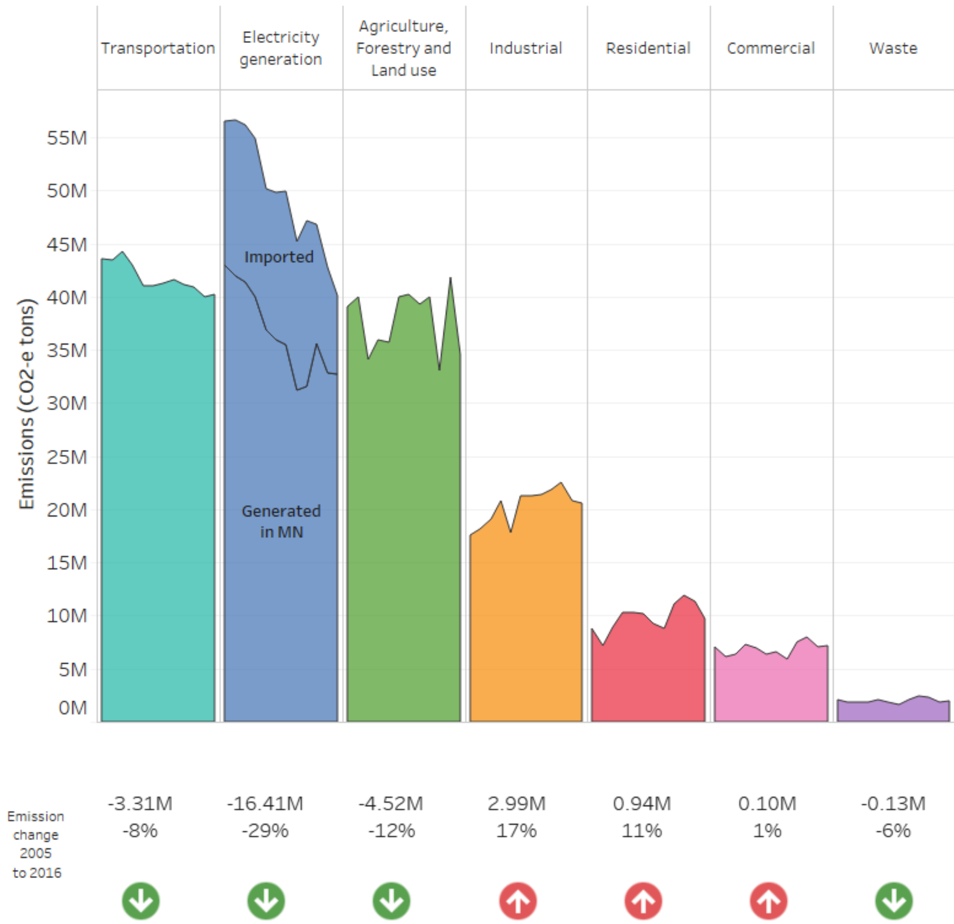



**Figure 10** Minnesota's GHG Emissions by economic sector for the period between 2005 and 2016 (MPCA, 2019)

Improvements in the electricity generation sector are the result of a combination of state regulations. The 2001 Emissions Reduction Rider allowed electricity generators to include the cost of air pollution-reduction programs in customer charges, which encouraged the replacement of coal generation with gas and wind. In 2007, a renewable energy standard was introduced, requiring that 27% of electricity sales in the state come from renewable sources - generators are on track to meet this requirement. Along similar lines, 2013 legislation requires that 1.5% of retail electricity sales by investor-owned generation providers come from solar energy.

The main transportation focus in state climate change plans is encouraging the adoption of electric vehicles (EVs). With promising shifts towards low-emissions sources in the electricity generation profile of the state, a transition to EVs would reduce the emissions of the transportation sector. Minnesota has set the goal that 20% of vehicles on the road are EVs by 2030 (Minnesota Department of Transportation et al., 2019). They plan to achieve this goal through a combination of educational programs and investments in charging infrastructure. Minnesota is receiving $47 million as part of a national settlement with Volkswagen following Volkswagen's violation of vehicle emissions reporting standards (MPCA, 2019). The state intends to use 15% of this settlement to build out a statewide network of EV charging stations.

According to an analysis by the nonpartisan Great Plains Institute (2017), the current tax policy in Minnesota provides a disincentive for  EV ownership. A large portion of this difference is due to the higher sales price on EVs, which increases the motor vehicle sales tax applied to these vehicles. This analysis does not include the additional $75 fee introduced in 2017 to provide a comparable measure to the gas tax for ICE (MNDOT, 2019). The gas tax amounts to about $95 per year, which is included in the calculations summarized in Figure 11.

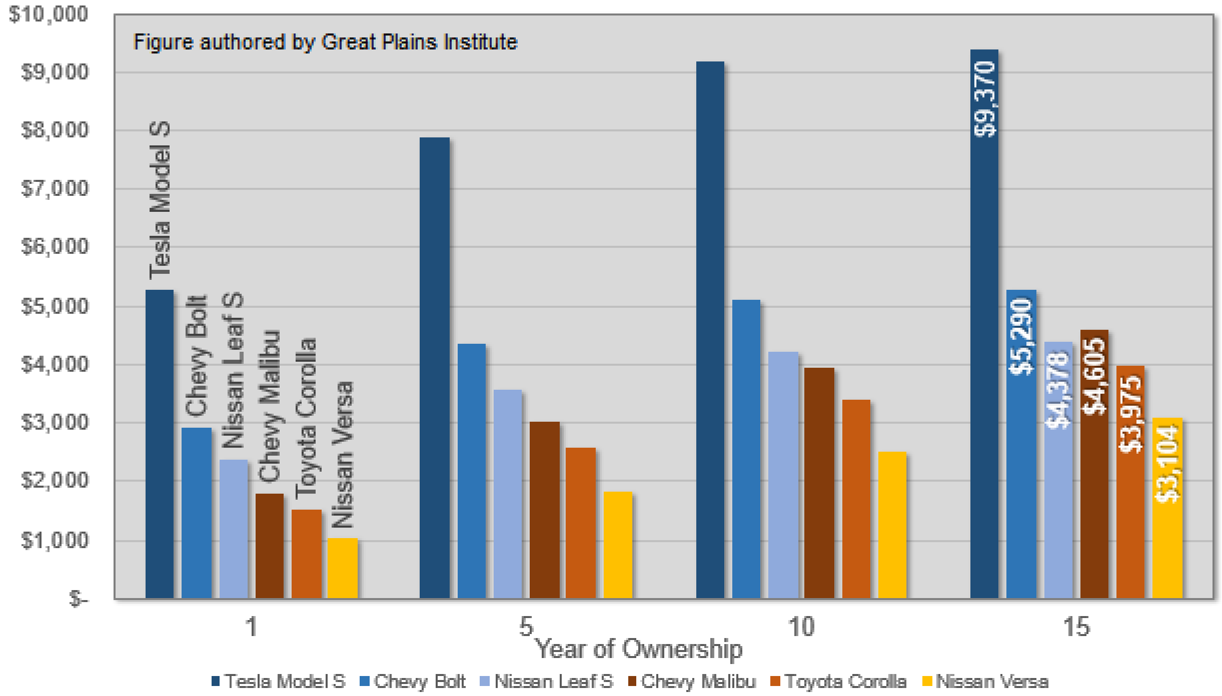



**Figure 11** Cumulative tax paid by typical 2017 EV and ICE automobiles (McFarlane, 2017)

### *2.2.2 Met Council Plans*

The Met Council climate change agenda is largely outlined in the Thrive MSP plan (Met Council, 2014b). Throughout the plan, Met Council focuses on providing alternatives to single-occupant vehicle travel, promoting compact land use patterns, and the protection of industrial and agricultural land. Met Council plays a significant role in providing technical assistance to local governments in developing plans to address climate change - this report is a component of this work. Met Council is working to translate state emissions reporting to the local level so that local governments can better quantify their current emissions profiles and the expected impact of their emissions reduction efforts.

The Thrive MSP transportation plan identifies several traditional travel demand management (TDM) strategies: reduce travel during peak periods, encourage carpooling and transit, and promote flexible work schedules. A plan is outlined for the adoption of electric buses, including where to install charging infrastructure and challenges arising from vehicle range and operation in cold weather. The measures of effectiveness identified by Met Council for transportation performance are robust and have a broad coverage. The focus on providing access to destinations rather than reducing VMT is a good framing of the problem. The plan recognizes that improving vehicle fuel efficiency, and switching to EVs, will reduce gas tax revenue and require consideration of new revenue streams. Transportation investments for MSP are distributed as $15.8B on highways, $35.1B on transit, and $41.2B on local roads/active modes.

*The Thrive Transportation Plan provides the following measure of effectiveness (MOE):*

- Access to jobs

- MnPASS usage
- Percentage of travel by modes other than single-occupant vehicles
- Transit ridership
- Mode participation rate
- Peak-hour excessive delay
- Average aircraft delay at MSP International Airport
- Regional bicycle transportation network implementation

Regarding land use, Thrive MSP identifies aging multifamily housing stock as a focus area. Like many urban regions, MSP has a large stock of rental apartments built in the 1960s and 1970s. These apartments are affordable but require reinvestment to remain functional. Single-family homes represent 58% of the current housing stock, but the MSP region has seen a transition towards more multifamily units. In both 2012 and 2013, more multifamily building permits were issued than for all housing types in 2008, 2009, 2010, or 2011 (Met Council, 2014b). However, this transition will be difficult as much of the region was developed around roads and the private automobile. Intensification of land use will be a challenge.

### *2.2.3 Local Government Plans*

St. Paul has the most comprehensive climate change plan among local governments. It plans to source 100% of retail electricity from carbon-free sources by 2050 and reduce SOV trips by 50% relative to 2015 levels by 2050 (City of Saint Paul, 2019). Intermediate SOV trip reduction targets are identified as 10% by 2030 and 40% by 2040. St. Paul also aims to reduce VMT by 2.5% per annum over this period. These goals will be met through the following TDM initiatives (City of Saint Paul, 2019):

1. Reduce or eliminate citywide minimum parking requirements and set parking maximums for most land-use types and require developers and landlords to “unbundle” parking from rent.
2. Redesign parking fees to capture the full cost of parking in downtown and other high-demand commercial districts.
3. Provide a stable funding source to implement the recommendations of the city’s Comprehensive Plan.
4. Bring together various stakeholders including the city, transit agencies, and community groups to create affordable housing in the transit market areas defined by Met Council.
5. Implement pricing strategies that accurately capture the cost of driving and auto-centric infrastructure on city roads.
6. Identify strategies to mitigate the impacts of inner-city highways including capping, conversion to boulevards, or complete removal.
7. Incentivize infill development by implementing smart growth strategies described in the city’s draft Comprehensive Plan.
8. Increase the number of communities that are mixed-use and higher density.
9. Implement the “Vision Zero” program recommendation of the Comprehensive Plan to achieve zero traffic fatalities on city rights-of-way.

The city set the goal of a 6% increase in transit ridership from 2015 by 2030, 25% by 2040, and 40% by 2050 based on the following transit initiatives (City of Saint Paul, 2019):

1. Ensure shared mobility options are located within 0.25 miles of transit service to increase options for the first and last mile.

2. Work with city, state, regional, and federal stakeholders to identify long-term sustainable funding strategies to complete the planned build-out of transit lines.
3. Create high-frequency rapid transit in all parts of the transit market areas defined by Met Council.
4. Increase transit coverage in concentrated areas of poverty to increase access to jobs and destinations in the downtown core; ensure mobility options remain public and accessible.
5. Support transit with last-mile solutions including electric car-share, standard or e-bike share, and scooters that will become more broadly available at mobility charging hubs.
6. Streamline services to prevent redundancy and enable passengers to easily understand routes and schedules.
7. Strategically place stops to improve transit speed and reliability.
8. Upgrade and refurbish highly used transit stops to include amenities such as benches, shelters, trash cans, wayfinding signs, and lighting.
9. Relocate stops that feel unsafe or are placed near high-speed vehicle traffic.
10. Invest in all-door boarding and off-board fare payment.
11. Improve accessibility at transit stops for those in wheelchairs or with limited mobility. Continue to add ADA-compliant pads, and prioritize improvements in neighborhoods experiencing poverty.
12. Create a framework where ride-hailing services reduce overall trips by combining them with other tools such as walking, biking, transit, shared rides, and compact development.

Building goals include green building standards, energy conservation programs, and stricter energy codes in new developments. St. Paul has a goal of diverting 40% of waste from landfills by 2020 and 80% by 2030. The plan includes a set of fifteen efforts to improve bicycle and walking facilities to encourage a shift to these modes, including buildout of the bicycle network, incentives for bike-share membership, and filling 327 miles of gaps in sidewalk connectivity.

St. Paul also addresses vehicle electrification. It sets a timeline for EV fleet penetration of 33% by 2030, 80% by 2040, and 100% by 2050. In support of this goal, the city plans to install 64 level-2 chargers by 2030, 600 by 2040, and as many chargers as required by 2050. St. Paul also plans to have 75 charging hubs by 2030, 100 by 2040, and 300 by 2050. It supports these goals through the following planned regulations and initiatives (City of Saint Paul, 2019):

1. Continue to increase access to shared electric vehicles in partnership with car-sharing services and Xcel Energy.
2. Ensure all residents are within a quarter-mile of a mobility charging hub.
3. Incentivize electric vehicle sales by providing charging at city-owned parking lots and working with employers to provide workplace charging.
4. Provide a regulatory framework to permit charging on residential streets in front of multifamily dwellings.
5. Proactively encourage the safe use of non-car electric vehicles such as e-bikes and scooters on city rights-of-way.
6. Implement building ordinances that require new developments to have wiring capacity to charge electric vehicles and reserve a percentage of new parking spots for exclusive EV use.

7. Encourage electric car-sharing programs to help familiarize residents with EVs, while reducing total driving demand. Prioritize deployment of these programs in areas with low levels of car ownership.

## 3. PASSENGER GHG REDUCTION STRATEGIES

This section provides a summary of potential GHG-reducing measures that could be implemented by Met Council for the passenger transportation sector.

### 3.1 Roadway Design Improvements

There are several "easy wins" in roadway design that have been shown to reduce GHG emissions. Roundabouts are well known to offer accident reduction, long-term maintenance costs, and lower stopped delay benefits. Several studies have computed the emission benefits of roundabouts to traditional signalized intersections either as before-after treatments (Mandavilli et al., 2003; Várhelyi, 2002) or simulations (Hesch, 2007). A roundabout treatment yields decreases of 16-29% in $CO_2$, 16-21% in $NO_x$, 19-21% in CO, 18-26% in HC, and 28% in fuel consumption compared to existing levels of a signalized intersection[1]. However, roundabouts may increase the amount of acceleration and deceleration of vehicles such that expected average emission benefits are highly dependent on driver behavior (Hallmark et al., 2011). Finally, roundabouts are not a feasible solution at many intersections and the reconstruction of the intersection includes non-negligible emissions that are not included in the above estimates.

The synchronization of signals (green waves) has been shown to reduce emissions of $CO_2$, $NO_x$, and $PM_{10}$ by 10-40% relative to an unsynchronized signal design (De Coensel et al., 2012). It should be noted that reductions for both roundabouts and signal synchronization are measured only for emissions produced at the intersection and are not given relative to total GHG emissions. As such, the cumulative impact on the emissions for the MSP region would be small.

### 3.2 Vehicle Fuels

Vehicle fuels contribute to GHG emissions through well-to-pump (WTP) and pump-to-wheel (PTW) emissions if a holistic inventory is taken. PTW emissions are declining on a per-mile basis as the efficiency of vehicles increases and fleet turnover cycles out less efficient vehicles (Wu, 2006). Biofuels, made from organic matter, have long been proposed as petroleum alternatives. In the U.S, corn-based ethanol is the main blending component in gasoline, typically up to 10% ethanol by volume, also known as E10. Demand for higher ethanol blends (E15 and E85) remains limited, mostly because of infrastructure, economic, and distribution barriers. Additionally, fuels containing between 51% and 83% ethanol by volume require special engines, which require the purchase of a flex-fuel vehicle (FFV) (EIA, 2021). Over their lifetime, FFVs, using corn-based ethanol in place of petroleum-based gasoline, reduce GHG emissions by 34%, considering land-use changes to grow corn. However, the actual reduction is dependent upon the frequency of refueling with E85 versus E10 blends (Wang et al., 2015).

Biodiesel is produced domestically from vegetable oils, animal fat, or recycled restaurant grease. Biodiesel is commonly blended with petroleum-based diesel to produce B5 and is consumed at a rate of 1,985 million gallons annually (AFDC, 2020). Biodiesel blends beyond B5 are problematic in colder climates and

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[1] Mandavilli et al. (2003) found significantly larger reductions in the PM hours across sites in Kansas and Nevada (42% in CO, 59% in CO2, 48% in $NO_x$, 65% in HC) than reductions in the AM hours.

do not provide any additional benefit of added lubrication from a higher cetane number. Biofuels can reduce emissions if the combustion is offset by the carbon dioxide absorbed from growing soybeans.

### 3.3 Personal Vehicle Electrification

Electrification of vehicles is a core GHG emission reduction strategy identified in most forecasts. However, the ability of EVs to produce significant reductions in GHG emissions will require a shift in the electricity generation grid and adoption well beyond current market trends. Currently, there are more than 1.18 million electric vehicles (plug-in hybrid electric vehicles - PHEVs, hybrid electric vehicles - HEVs, and battery electric vehicles - BEVs) on the road in the U.S., with sales up 81% in 2018 over 2017 (EEI, 2019). BEVs made up 66% of the U.S. EV market share in 2018, compared with 53% and 54% in 2016 and 2017, respectively. China, long favoring BEVs over PHEVs, has a market share of 75% BEVs while the European Union is at 54% BEVs. About 2.1% of all light-duty vehicle sales in 2018 were EVs, up from 0.7% in 2015; mostly because of a strong performance by the Tesla Model 3, taking in 40% of the market share (Hertzke et al., 2019). At a starting price of $35,000[2], the Model 3 is not an affordable entry into the EV market. Experts predict that, with battery cost reductions, cost parity with internal combustion engine vehicles (ICEVs) is attainable between 2024 and 2029 for a 150 to 300-mile range EV (ICCT, 2019). Once cost parity with ICEVs is reached, policies akin to polluter-pays taxation, public charging infrastructure build-out and subsidization, and consumer campaigns are critical to fast-track adoption of EVs. Since early adopters tend to have a stronger interest in environmental benefits and improved fuel economies than the overall population, estimates of gasoline reductions should more appropriately compare EVs to a more fuel-efficient ICEV rather than an average ICEV. After cost parity, the switch to EVs will truly offset gasoline consumption from fuel-inefficient vehicles.

PHEVs are promoted as a low-cost entry into vehicle electrification. PHEVs directly shift fossil-fuel consumption to lower carbon-intensive electricity while also releasing zero localized emissions when driven in electric mode. Even in markets where electricity generation has a high carbon content, power plants could take advantage of scale to implement carbon capture and sequestration and result in lower point source emissions than vehicle tailpipes for the same energy output per mile. If PHEVs or BEVs become a market success, then utilities must rapidly change their feedstock to low-carbon fuels and make investments in technologies to meet regulatory criteria air pollutant standards (Kockelman et al. 2008). Estimating the reduction of GHGs from PHEVs is complicated by the variety of fuel sources of an electric utility's feedstock, estimations of VMT in electric or hybrid mode, and charging frequency (especially if households do not have access to overnight charging). One study capturing the distribution of daily driving patterns noted that vehicles with electric ranges between 20 and 40 miles could capture 50-75% of an average driver's trips, assuming nighttime at-home charging was available. Assuming a base PHEV with a 25-mile electric range[3], the annual tailpipe emissions that could be abated are 440-650 kg of $CO_2$[4] (Paul et al., 2011; N Quarles & Kockelman, 2017).

With the popularity of Tesla's Model 3, General Motor's announcement of retiring the Chevrolet Volt, and increased electric-range development in mass-produced batteries, BEVs are expected to constitute 90% of all EV sales by 2040 (BNEF, 2020). Compared to PHEVs, which have flexibility in their fuel source, BEVs

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[2] Not considering EV tax credits that may be available to consumers.
[3] Based on the 2020 Toyota Prius Prime with an annual VMT of 11,244 from AFDC (2018).
[4] The reduction of $CO_2$ emissions, if accounting for the production and distribution of fuel (including electricity), can be between 1,012 and 1,518 kg (US DOE, 2017)

are driven less than other similar vehicles (refer to Gohlke & Zhou, 2018 for sources). Not only will electrification of VMT reduce total emissions, but it will also generally reduce annual VMT, by up to 15%, particularly for short-range BEVs. Future effects of electrification when coupled with automated vehicles (AVs) and shared automated vehicles (SAVs), which are expected to increase annual VMT, are unknown but will certainly lower localized emissions relative to ICEVs (Lawal et al., 2020; Neil Quarles et al., 2019).

Advances in electric battery storage are increasing the range of electric miles for PHEVs, from an initial all-electric range of 10 miles to 30 miles today. According to the 2013 "Transitions to Alternative Vehicles and Fuels" report (National Research Council, 2013), a 10-mile range PHEV runs 19% of its miles on electricity and a 40-mile range PHEV runs 55% of its miles on electricity. Using their baseline, GHG emissions reductions are in the range of 36% to 60% and 51% to 70% for PHEV-10 and PHEV-40, respectively, based on a 2030 electricity grid. Travis County, Texas (surrounding Austin) projected the effects of a 20%, 40%, and 80% BEV share of the total light-duty vehicles for 2050 on energy requirements and avoided $CO_2$eq emissions. A 20% BEV share (300,000 vehicles) would require an additional 900,000 MWh of energy, which would offset about 1.59 metric tons of $CO_2$eq annually if the added energy came from renewables. This conservative scenario would only increase utility electricity demand by 7% of current sales (City of Austin, 2015).

Milovanoff et al. (2020) compare the life-cycle emissions (i.e., battery production, fuel production, fuel use, and vehicle production) for several ICEV and BEV vehicle classes and scenarios for potential 2030 U.S. electricity grids (see Figure 12). They find that, in all cases, BEVs offer a significant improvement in GHG emissions over ICEVs. However, there remain significant impacts associated with fuel production, that is anticipated emissions from electricity generation.

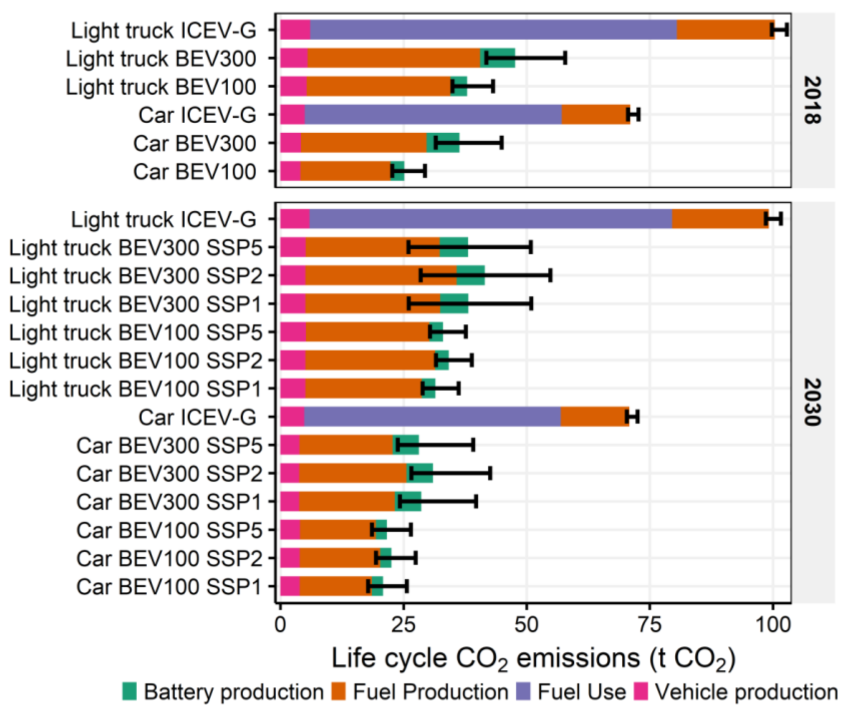


**Figure 12** Life-cycle $CO_2$ emissions aggregated at a vehicle level for 2018 and 2030 model-year, under three electricity production scenarios (SSP1, SP2, and SSP5) (Milovanoff et al., 2020)

Figure 13 shows a range of forecasts of BEV penetration to 2050. As noted above, the city of St. Paul has set a goal of 100% of vehicle sales being EVs[5] by 2050, which would translate to EVs being about 80-90% of the light-duty vehicle (LDV) fleet by that year. Absent policy changes, all forecasts anticipate BEV penetration of less than 20% by 2050. The most ambitious NREL scenario (NREL-High) predicts a market penetration of 60%, or 80% with the addition of PHEVs. A recently completed national study of pathways to deep decarbonization (Zero Carbon Action Plan or ZCAP) finds that penetration needs to be closer to 95% by 2050 to meet a 1.5˚C target using only fuel shifting and electrification policy strategies (Sustainable Development Solutions Network, 2020). Other research finds that meeting the transportation component of a 2˚C threshold on global warming with EVs alone would require a fleet of 350 million vehicles (or about 90% of the fleet) by 2050 (Milovanoff et al., 2020) and that the electricity required would represent half the national electricity demand if charging times are not coordinated (Muratori, 2018).

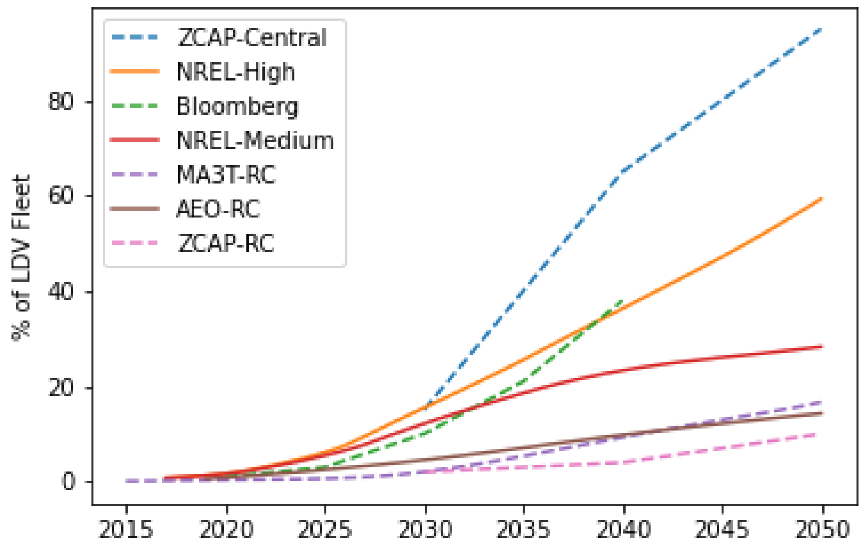


**Figure 13** Range of BEV forecasts from several sources (BNEF, 2020; EIA, 2021; Lin & Greene, 2013; Mai et al., 2018; Sustainable Development Solutions Network, 2020)

Clearly, there is a range of factors that influence the adoption of EVs and a high degree of uncertainty as to their market penetration within the forecast horizon of 2040. These changes are dramatic but recent efforts to address COVID-19 and deploy vaccines provide some indication of our collective ability to act for the common good. Several sources that consider EV adoption also discuss the need for policies to encourage the adoption of lighter and more efficient vehicles within the existing ICE vehicle stock (Pacala & Socolow, 2004). Milovanoff et al. (2020) provide the following summary of the mitigation gap associated with EV adoption. In this figure, SSP 1-5 represent a range of expectations for future socio-economic conditions. SSP 1 represents a globalized economy with an emphasis on rapid technology development with low carbon and energy intensity. SSP 2 represents a business-as-usual scenario with large variations in social development between countries and moderate technological development to address climate change. SSP 5 is included as an example of continued reliance on fossil fuels but with highly engineered solutions (i.e., carbon capture and storage). SAFE standards are the current emissions standards for the U.S., replacing the stricter standards set under CAFE (National Highway Traffic Safety

[5] The City of St. Paul does not provide specifics on the definition of EV in their plans. Given the references to charging infrastructure, it can be assumed that they are referring to BEVs and possibly PHEVs.

Administration & Agency, 2018). EV30@30 denotes an IEA objective of 30% of vehicle sales in 2030 being EVs (IEA, 2019). The effect of EVs on decarbonization depends on the composition of the electricity grid, which is represented by "2018ef" (2018 emissions factors) and "ren" (100% renewables). This analysis shows that EV adoption is insufficient to meet decarbonization objectives under any of the scenarios. It requires the widescale adoption of renewable electricity generation and more stringent emissions standards on the extant ICE vehicle fleet. Note that these results depend on a highly uncertain $CO_2$ emissions budget. With other assumptions, the set of measures included in Figure 14 do not meet the 2°C goal even with a 30% EV sales penetration, a 100% renewable grid, and the reinstatement of more stringent fuel economy standards (only satisfying about half of the mitigation gap).

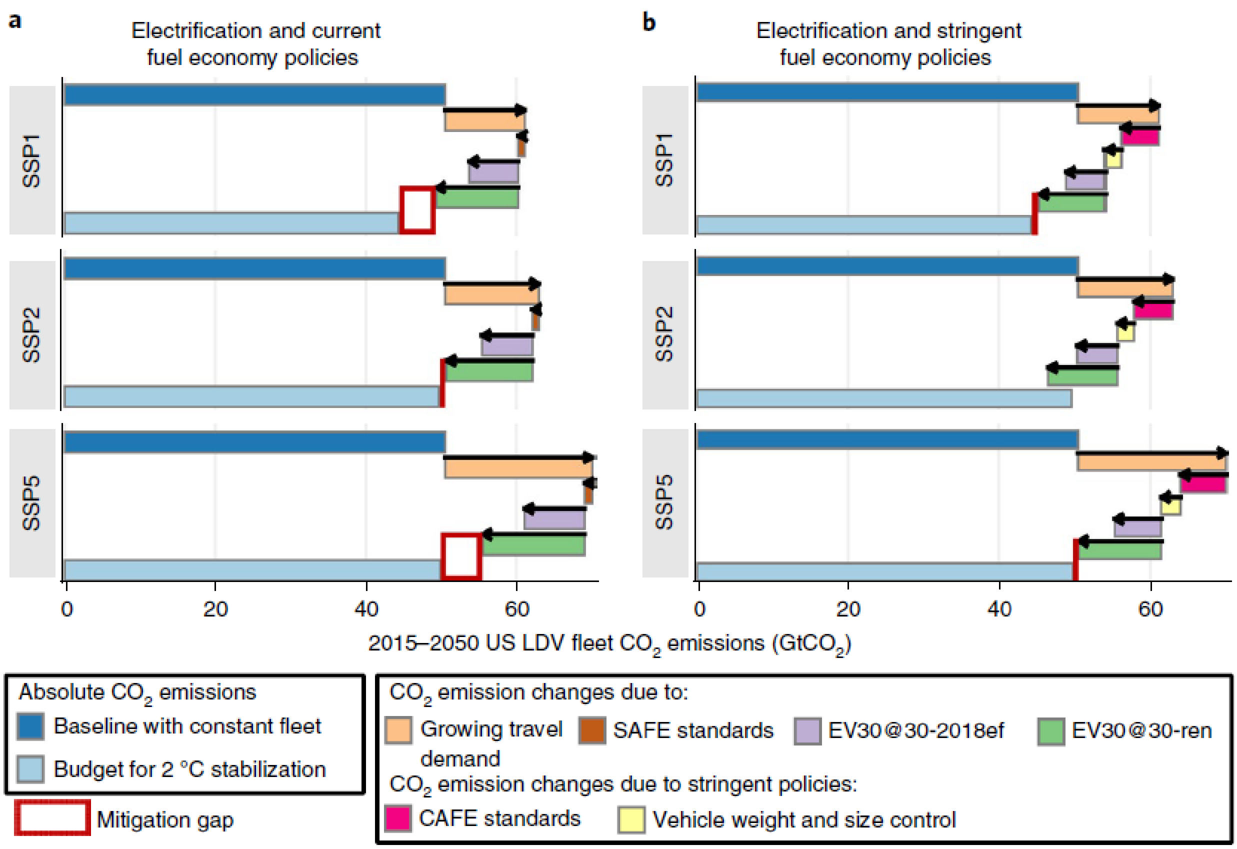


**Figure 14** 2015-2050 U.S. LDV fleet $CO_2$ emissions in a baseline case (top dark blue bar) and changes associated with growing LDV fleet, policies, and electrification under the EV30@30 compared to 2 °C 2015-2050 $CO_2$ emission budget (Milovanoff et al., 2020)

With the above caveats, recent trends suggest an increasing probability of high EV adoption. As recent as 2008, researchers were assuming EVs would not "account for a significant fraction of new vehicle sales (e.g., equal to or greater than 5 percent)" (Bodek & Heywood, 2008) in Europe by 2035. Yet, an October 2020 sales report found that total EVs (BEV+PHEV+HEV) now account for 25% of vehicle sales across 27 European markets (JATO, 2020). However, there are further considerations in assessing EV market penetration in the United States due to differences in willingness to accept market intervention and variation in income. The current market leader in EV adoption is Norway, which has a high taxation rate to support large EV purchase subsidies (about US$15,000 to US$18,000). It also has among the highest carbon prices at about US$59 per metric tonne of $CO_2$eq (Axsen et al., 2020). Throughout this report, it is emphasized that reliance on a single technology or policy will not be enough to address climate change due to the uncertainty of technology adoption and policy effectiveness.

There are several ways in which regional governments can encourage the adoption of EVs: making charging stations accessible or easy to add into existing facilities, allowing for flexible consumer incentives like rebates for the vehicle or charger equipment, and creating bulk purchasing programs to lower prices for businesses and individuals. Cities can assuage range anxiety by installing public chargers at municipal parking lots, frequently accessed public spaces like parks, and in neighborhoods with limited off-street parking or garages by installing curbside EV chargers (Bloomberg Philanthropies, 2019). Providing infrastructure should also be coupled with public service announcements, advertisement campaigns, and ensuring clear online charging station maps to differentiate between city and non-city chargers, Level 2 or Level 3 (DC faster chargers or DCFC), and the number of chargers at a location (City of Sacramento, 2020). If the deployment of infrastructure is deemed too costly, mandating EV-readiness (i.e., installing electrical capacity) during the construction of new residential homes or public parking facilities can reduce costs during eventual installation by $1,000 - $1,600 per space in garages or up to $5,000 in parking lots (San Francisco County Transportation Authority, 2016). A low-carbon fuel standard (LCFS) could consider electricity as a low-carbon fuel (contingent upon the regional generation mix). However, these standards are generally set at the national or state level. A zero-emissions vehicle (ZEV) mandate is an alternative that could be implemented at the metropolitan level. ZEV mandates were pioneered by California in 1990 and have seen subsequent applications in ten other states, two Canadian provinces, and China. British Columbia has the strictest and longest time horizon mandate, requiring 30% ZEV sales by 2030 and 100% sales by 2040 (Axsen et al., 2020). An alternative approach is an ICEV ban, which has been announced by several cities[6]. As part of its ZEV mandate, British Columbia will also impose penalties for non-compliance after 2040. ZEV incentives can also be used to encourage the purchase of EVs. Such incentives include purchase subsidies, exemptions from tolls, access to high-occupancy vehicle lanes or bus lanes, or publicly funded charging stations. However, road facility access incentives are found to have a fairly weak influence on ZEV adoption (Axsen et al., 2020).

A final note on the effects of temperature effects on batteries is warranted given the cold climate of MSP. A common concern by residents of cities with cold winters is that they will lose range. These concerns are not without reason. A study of regional temperature on EV efficiency and range in the United States finds that the average range of a Nissan Leaf on the coldest day of the year drops from 70 miles in the Pacific Northwest to less than 45 miles in the Upper Midwest. However, this range loss is minimal on most days (see Figure 15). The study included two cities in Minnesota. On a typical day, an MSP resident can expect to experience a similar range to Phoenix, Arizona (which suffers from reduced range due to AC loading).

[6] Paris, Madrid, Mexico City, and Athens intend to ban the most polluting vehicles by 2025 (Harvey, 2016). Various other cities and nations have proposed ICEV bans ranging from only the most polluting, to partial bans in specific sections of the city or on weekends, to complete bans (Bendix, 2019).

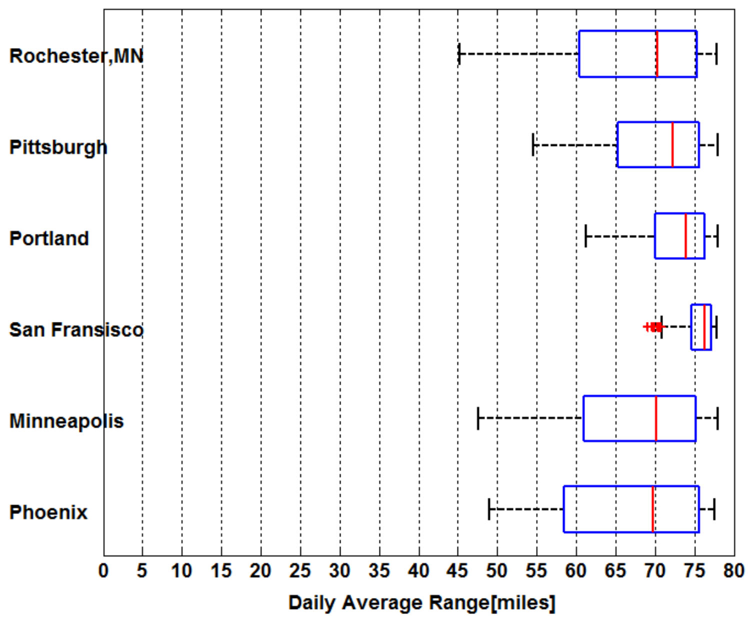


**Figure 15** Box plot of daily driving range distributions for selected cities. Note: Red lines indicate the median range, blue boxes indicate the 2nd and 3rd quartiles across days of the year, the whiskers extend to the most extreme data points that are not considered outliers, and the red + symbols indicate outlier days.

### 3.4 Public Transit Bus Electrification

Municipal and transit fleet vehicles, including buses, should also transition from ICEVs to EVs. Fleet vehicles have the advantage of higher utilization, more predictable routes and destinations, and centralized parking and maintenance facilities (Bloomberg Philanthropies 2019). If the U.S. were to replace all transit and school diesel buses today, an average of 7.3 million tons of $CO_2$eq emissions would be avoided (Casale & Mahoney, 2018)[7]. The upfront costs are higher than diesel technology but can be substantially reduced with grants from the FTA's four-year Low or No Emission Bus Program and utility providers (FTA 2020, Casale & Mahoney 2018). Additionally, the lifetime fuel and maintenance savings of electric buses are about $400,000 and $170,000 for transit and school buses, respectively (Casale & Mahoney, 2018).

Wellik et al. (2020) assess the cost-effectiveness of battery electric buses (BEB) for both transit operators and electric utility managers. Three scenarios are compared: a "smart charging" (SC) scenario, a "charge-as-needed" scenario, and a baseline scenario using diesel buses. "Smart charging" represents a strategy of discharging BEBs based on utility manager requests for additional energy to stabilize intermittent renewable supply. Austin is used as a case study. They find that the capital cost of a BEB is currently twice that of a diesel bus. However, the daily fueling cost is 4.6x lower for a BEB due to the lower cost of electricity compared to diesel. Their analysis suggests that the utility manager would save about $84M annually in the SC scenario, giving them an incentive to subsidize electricity demand by the transit operator. Overall, the non-SC scenario saves $2.6M (0.41% savings relative to the current state)

[7] Using Argonne National Laboratory's Heavy-Duty Vehicle Emissions Factor, replacing a Minnesota diesel-engine transit bus with an electric bus, assuming a 12-year lifespan and 250,000 miles, will avoid 220 t $CO_2$ emissions (Argonne National Laboratory, 2019).

and the SC scenario saves $94.6M (15.1% savings relative to the current state) when GHG emission costs are included at a reasonable pricing rate.

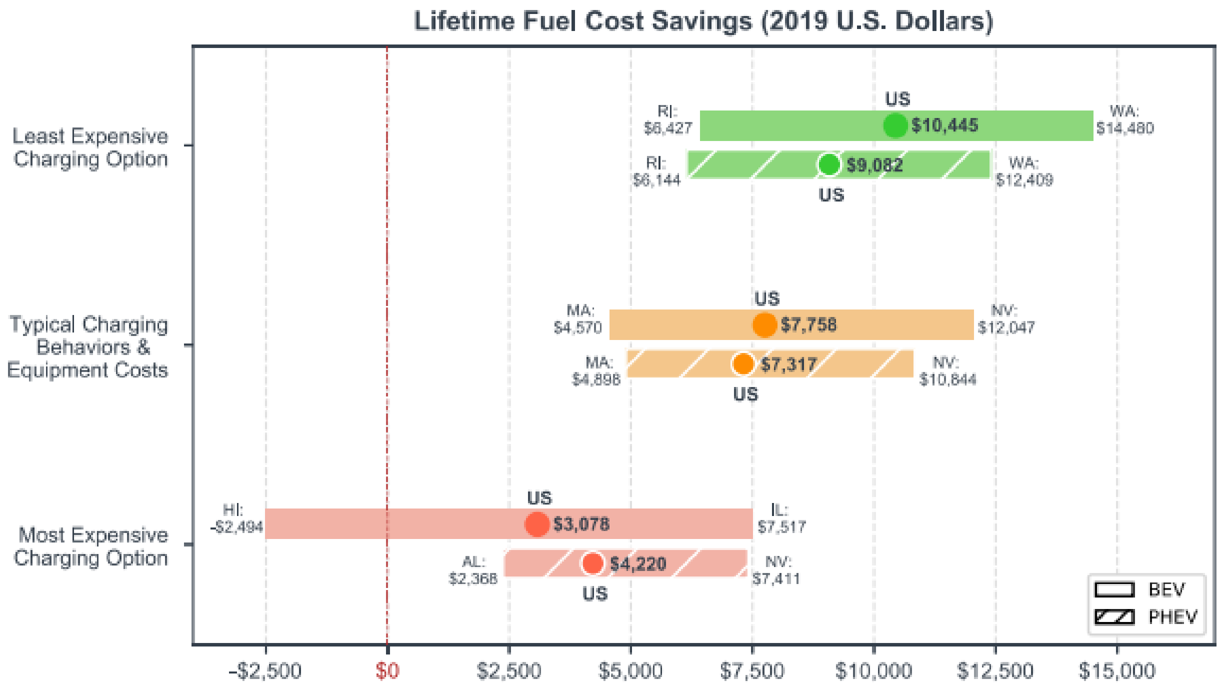


**Figure 16** State-Level Variability in LFCS for Low, Baseline, and High-Charging-Cost Scenarios (Borlaug et al., 2020)

### 3.5 AVs, SAVs, and SAEVs

Advancements in automation have emerged rapidly in the last ten years with high expectations and differing opinions on the effects of AVs. While initially heralded for their crash reduction potential, advocates argue AVs will make driving greener, cheaper, and faster too. The appeal of AVs is expected to induce further driving, thereby offsetting any travel time or congestion benefits of AVs and generating about 8% new VMT for empty travel when the vehicle is driving to a passenger or to a home destination (Fagnant & Kockelman, 2014; Fagnant et al., 2016). The low-density sprawl that is ubiquitous in American cities will magnify the empty VMT due to vehicle repositioning if vehicles are allowed to drive without human passengers between trips. Lee and Kockelman (2019) evaluate the possible impacts from automated vehicles and their net energy impacts and find that transitioning to electric drivetrains would deliver 44% energy savings, which more than offsets added VMT energy demands and energy demands from increased hardware and computer technology. If automated vehicles still utilized gasoline-powered ICEVs, the average decrease in energy consumption would be about 12-14% (Jooyong Lee & Kockelman, 2019). Fortunately, self-driving vehicles are projected to have at least a 36% market share of electric vehicles by 2050, reducing pollution externalities and offering reduced costs for SAVs ( Quarles & Kockelman, 2017; Quarles et al., 2019).

Pooling or ride-sharing has been proposed as a strategy to serve the same passenger demand miles in fewer vehicles, which relieves congestion and lowers travel time. Farhan and Chen (2018) report a 22% decrease in VMT with dynamic ride sharing (DRS) relative to a scenario without pooling. A similar study using baseline scenarios from Chen et al. (2016) varied the DRS vehicle capacity and finds a 23%

reduction in GHG emissions with four passengers sharing a ride (Gawron et al., 2019). There are concerns that any measures to promote pooling will further erode public transit ridership as driving becomes more attractive. The promotion of pooling should then be accompanied by policies that make driving less attractive and land use laws that establish compact development with high connectivity for sustainable urban mobility (Naumov et al., 2020). Naumov et al. (2020) use a binomial logit model to estimate commuters' choices between driving a car or riding transit, adding an AV mode in one scenario and an SAV mode in another scenario. A marginal increase in average vehicle occupancy (AVO) up to 1.25 reduces driving time, at which point any further increase in AVO leads to a slow transit collapse, lowering the quality of transit and further pushing riders towards driving. If investments in public transit are not effective in curbing utilization of AVs, then the AVO of SAVs needs to be above 2.8 to be effective in creating a mode of right-sized, automobile-based transit system that has no additional empty VMT alone compared to before the introduction of SAVs (Naumov et al., 2020). Model results suggest a 22% decrease in VMT and a 23% decrease in GHG emissions with the introduction of DRS. They also find elasticities of -0.675 and -0.055 for GHG emissions with respect to AVO for car and bus modes, respectively. Lastly, they propose a 20 cent-per-mile tax with 1% reinvestment into transit leading to lower travel times for drivers and higher quality of service for transit riders because of a new revenue source.

Shared autonomous electric vehicles (SAEVs) also have synergies with the electrical grid and can provide ancillary services to support the transition to renewable energy as mobile storage devices (through vehicle-to-grid) or as mobile energy consumers to absorb excess power generation. Considering the pairing of AVs with EVs (AEVs), Jones and Leibowicz (2019) find that high vehicle occupancy through sharing can reduce $CO_2$ emissions for both the transportation sector and the grid, especially if charging can be aligned with solar or wind generation profiles. The authors also posit that in the near term, SAV adoption with high vehicle occupancy can have a wider impact on decarbonizing vehicle travel than a carbon tax. SAEVs must also have adequate private charging station depots and supporting public fast-charging infrastructure that can minimize the distance between demand and depots to be most effective. Supporting fast charging infrastructure will not only support privately-owned electric vehicle adoption in the short-term, but will allow SAEV fleets to maintain high service performance (Vosooghi et al., 2019). If SAEVs are chosen to accompany a deep decarbonization of the electrical grid due to a mix of federal and state regulations, the potential for added co-benefits of vehicle rightsizing can further lead to an 87-94% decrease in per-mile GHG emissions by 2030 for conventional ICEVs and 63-82% below projected 2030 GHG emissions using hybrid vehicles (Greenblatt & Saxena, 2015). It is anticipated that SAEVs would reduce parking demand by 90%, freeing up land for other uses (Millard-Ball, 2019; Soteropoulos et al., 2019).

### 3.6 AVs, SAVs, and SAEVs as FMLM Transit

A sub-category of the previous technology solution is using fleets of shared (potentially autonomous) vehicles as a first mile last mile (FMLM) complement to transit. It is often the case that transit is an infeasible modal alternative for a portion of a trip due to its ineffectiveness in low-density areas. There may be a good LRT or commuter rail connection to the workplace but poor transit service to the rail station. In such situations, SAVs could act as a low-cost and dynamic ride-sharing (DRS) paratransit complement to existing transit services. In simulation experiments, Huang et al. (2020; 2021) consider the use of SAVs as DRS for LRT in Austin, Texas. The simulated service includes the flexibility to pick up additional travelers en-route to the train station. Vehicles are assumed to be dispatched from parking depots placed around each train station. The service is separated into two service areas to increase the probability of a vehicle being nearby and reduce travel times. They find that coordinating the DRS service with train departure time increases the proportion of on-time connections (i.e., passengers arriving in time to catch the next train) from 57% to 87%.

Kumar and Khani (2020) provide an interesting extension to the FMLM problem and an application in MSP. Traditionally, the problem is contextualized around fixed rail transit services. However, in many cases, frequent bus service is the most effective transit mode. Metro Transit runs three BRT lines and other regional transit agencies (Southwest Transit, Minnesota Valley Transit Authority, and Maple Grove Transit) run several express bus routes. The larger number of stops and higher unreliability of bus service make the optimization of DRS more complex. Kumar and Khani (2020) focus on the computational and operational complexity of the problem. Another feature to consider is that providing access to the closest bus stop may not provide the fastest travel time for the customer. They find that the combination of DRS and transit reduce the travel time for both the driver and the passenger. These are preliminary results, but they suggest DRS as an FMLM solution may be a good option for transit agencies to investigate further. The SW Prime service by Southwest Transit provides a promising early example of FMLM DRS in the MSP region.

**3.7 Carsharing and Ridesharing**

Municipalities can launch their own sustainable commuting program for public sector employees or require private employers to provide monetary and non-monetary incentives for employees' commutes. Monetary incentives include parking cash-outs, transit and rideshare passes, and pre-tax transit and rideshare benefits (Bloomberg Philanthropies, 2019). Non-monetary incentives can include shuttles to/from transit, flexible work schedules, ridesharing assistance, and bike lockers and showers. Cities can also require pooled transportation management associations (TMAs) for large employer spaces, such as downtown office complexes, medical centers, and industrial parks, to implement TDM strategies that can reduce 10% of total automobile HBW-trips (City of Glendale, 2006; VTPI, 2008). When households join carsharing organizations, most households increase their emissions by gaining access to additional automobiles, but collectively, a net reduction in GHG emissions is observed by a few households giving up personal automobile ownership (Martin & Shaheen, 2011). Carsharing can reduce household VMT by upwards of 27%, contributing to a net reduction of 0.84 metric tons of GHG per year per household (roughly 5.5% of United States per capita emissions (Oak Ridge National Laboratory, 2020)).

Yan et al. (2020) provide a detailed study of emissions associated with ridesharing using taxi and ride-hail data for Beijing at the level of individual road links. A shared ride algorithm is applied to taxi trips to determine the ability to share rides under each of two scenarios: 1) an *oracle* scenario wherein it is assumed that trips are pre-booked and differences in the start time of up to 10 minutes are allowable and 2) an *online* scenario wherein trips are dynamically pooled assuming a maximum start time difference of 1 minute. These start times could be alternatively considered as detour time on the route. They find a reduction in GHG emissions of 22.9% in the *oracle* scenario and 15.1% in the *online* scenario.

### *3.2.2 Shift from Automobile to Traditional Alternatives Modes*

Reducing and shifting travel from private motor vehicles to other more efficient modes is an important component of a holistic GHG reduction strategy. However, the reliance and attractiveness of a personal automobile suggest that *supplementing* these vehicles and providing clear paths towards *reducing reliance* is the best action. Improvements in bikeway density and active transportation connectivity are shown to have the potential to supplement individuals' existing motorized trips, thereby reducing reliance on personal automobiles while modifying traveler behavior (Guo et al., 2007).

The GHG emissions reductions associated with a shift from private automobiles to public transit depend on two major factors: average vehicle occupancy (AVO) and fuel source. Mikhail Chester and colleagues have been studying the life-cycle comparison of the private automobile and public transit for the past decade (Chester & Horvath, 2010, 2009b; Chester et al., 2010; Kimball et al., 2013). They find that the inclusion of life-cycle components (vehicle manufacturing, infrastructure construction, fuel production) increases the GHG emissions of transportation by 42% to 91% beyond vehicle propulsion emissions (Chester et al., 2012). In Los Angeles, they find that the Orange BRT and Gold LRT have lower life-cycle emissions than a standard 35 mpg automobile. However, this advantage disappears for the LRT when considering a higher efficiency 55 mpg automobile. Critically, the largest portions of the emissions are electricity production and vehicle population for the LRT and BRT/ automobile, respectively. Assuming 100% renewable energy, the vehicle manufacturing component dominates and is larger for automobiles. Focusing on vehicle occupancy, they find that BRT and LRT are GHG equivalent with a 5-passenger automobile with 64 and 105 passengers, respectively. They are equivalent to a single-passenger automobile with 13 and 21 passengers, respectively. A synthesis report by USDOT provides a useful national comparison of vehicle propulsion GHG emissions (see Figure 17). Chester and Horvath provide a summary of their work on the LCA impacts of transportation (see Figure 18). Further, recent research by Chester and Cano (2016) finds that the GHG emissions benefits of rail transit tend to increase over time due to the anticipated decarbonization of the electricity grid.

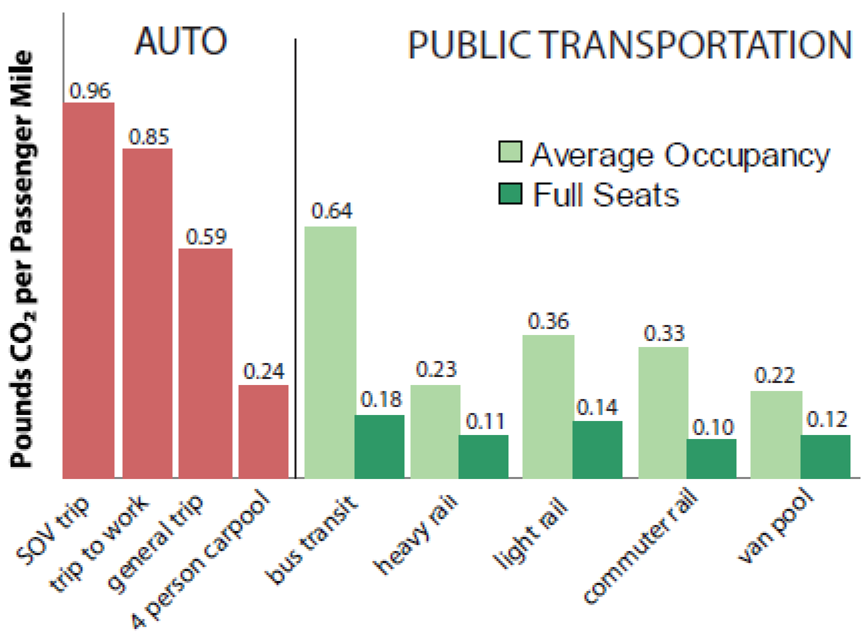


**Figure 17** Summary of GHG emissions per PMT for average and full occupancy (US DOT, 2010)

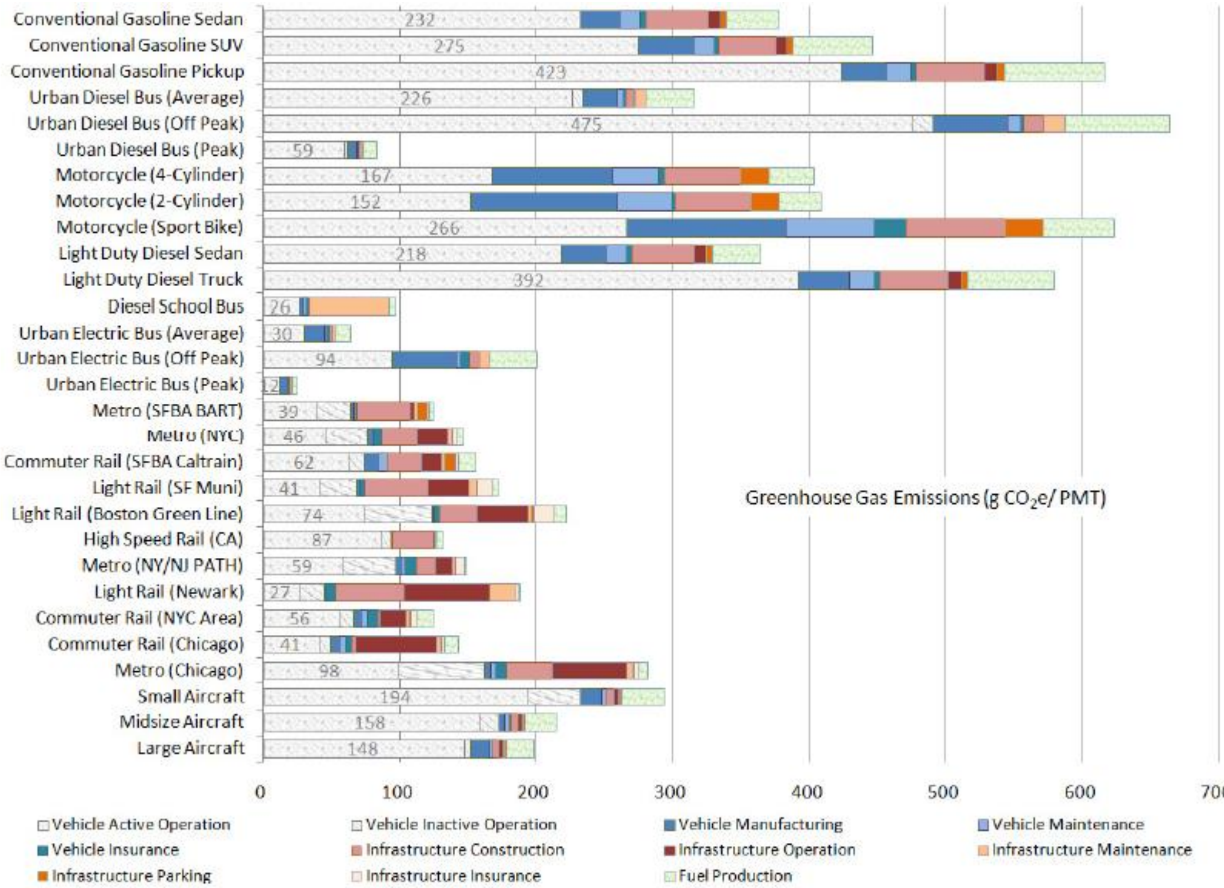


**Figure 18** Summary of GHG emissions in g $CO_2$eq per PMT (Chester & Horvath, 2009a)

Saxe et al. (2017) come to a similar conclusion for the subway, as compared to the bus. No savings are found for a shift from bus to subway if ridership is low. In the case of the Sheppard Line in Toronto, net GHG emissions increased for 6 years when accounting for the full life-cycle emissions of construction. Overall, they find a net reduction of 66.4 kt $CO_2$eq over the lifespan of the subway line, but this result depends on an assumption of no induced VMT on Sheppard Ave due to reduced congestion from the removal of bus routes.

Overall, it was estimated that bus and rail transit provide meaningful improvements in GHG emissions relative to private automobile travel. However, this is only true on routes with sufficient occupancy - the impacts of a bus with four occupants will be worse than that of a private automobile with the same number of occupants. As with many of the other transportation technologies reviewed in this report, electrification of vehicles and decarbonization of the electricity grid is key. While the electrification of private automobiles relies on the decisions of many millions of private owners, transit has the advantage of being under the control of a small number of public owners. Electrification of bus fleets is a clear initial step in the decarbonization of transportation. Rail transit is even better situated for decarbonization given that it is already powered by electricity. Increasing occupancy may be achievable by eliminating lower-demand fixed-route services and replacing them with flexible, on-demand transit and other strategies to attract choice riders. Additional reductions in GHGs may be achievable with bus electrification and alternative fuel sources like biodiesel, CNG/LNG, or hydrogen. Portland, Oregon developed a residential parking permit trade-in program to ease motorists into a multi-modal lifestyle with a "transportation wallet" that holds passes and credits for transit, streetcar, bikeshare, and scooters (PBOT, 2020)[8].

Although empirical evidence is still mixed, some research suggests a *land-use effect of transit* theory holds under the right circumstances (Gallivan et al., 2015). Public transit investments beget greater compact development which in turn lowers VMT and increases walking and cycling. Public transit is undergoing significant changes with the rise of ride-hail services (also known as TNCs) and micromobility vendors offering bicycles, scooters, and moped rentals. In response, several cities have invested heavily in more frequent service (defined as headways of 15 minutes or less) and restructured meandering routes into grids. Within the last five years, Seattle, Houston, and Austin have restructured bus networks and are reporting an increase in ridership; bucking the trend across the nation. The smaller transit service areas that have revamped bus networks (e.g., Columbus, Richmond, and Indianapolis) are also gaining ridership (TransitCenter, 2019).

Walking and bicycling are important modes for both short trips and commute trips, for the case of bicycling. Although many studies show an association between active transportation investments and mode split (Henao et al., 2015; Krizek et al., 2009; Pucher & Buehler, 2008), longitudinal data reveals that exposure from using the infrastructure as opposed to residential proximity was significant in having a lasting shift from automobile use to walking and cycling (Song et al., 2017).

### 3.8 Micromobility

Micromobility is a general term used to refer to bicycles, scooters, skateboards, segways, and hoverboards. The term is typically associated with shared fleet vehicles rather than personal ownership of these modes. Micromobility offers a convenient means of addressing first-mile/last-mile travel. It is well-suited for trips under 3 miles, representing 50-60% of total PMT in the United States (Abduljabbar et al., 2021). Micromobility began in Europe as a system of haphazardly placed bicycles in the 1970s. It has since gone through an evolution of bicycles with docking stations (providing increased security and certainty of availability) in the early 2000s, docked bicycles with a user fee and increased infrastructure technology for charging and bicycle locating, and now systems of dockless bicycles and scooters that provide a high level of flexibility and information to the user.

Research suggests that the main environmental impacts of micromobility are associated with manufacturing because operational emissions are zero, or negligible, and infrastructure requirements and deterioration are negligible (Abduljabbar et al., 2021). Micromobility offers an effective option for reducing the GHG emissions of the transportation system. However, its implementation requires careful consideration to ensure these benefits. For example, a micromobility trip that replaces a walking or transit trip may have a negative environmental impact. Additional research is required to better understand in which contexts micromobility acts as a complement to sustainable transportation and in which cases it is a substitute. Ideally, micromobility would replace either a private vehicle trip or a low occupancy bus route. There is great potential for micromobility to be used as a first-mile/last-mile complement to high throughput transit (i.e., BRT, LRT, and commuter rail).

[8] It is not clear if program participants became car-free or if they simply found an off-street parking option. Nonetheless, the benefit of this wallet is to provide cost-free exposure to transit and bicycle modes.

### 3.9 Decongestion Pricing

Decongestion pricing of roadways, beyond tolling for the purpose of 'paying as you go', ensures that travelers pay for the delay costs they impose on others (Kockelman, 2004) and aims to lower higher emissions resulting from stop-and-go traffic. The rise of high occupancy tolling (HOT) and the transition from HOV to HOT express lanes in Northern Virginia represents a movement to rationalize road networks to reduce the number of SOVs on the road, reduce peak-hour congestion, and total travel time. PSRC (2008) estimated that GPS-based variable network pricing would reduce regional VMT by 12% and total travel by 7%. Variable pricing to incentivize off-peak period travel can lead to delayed trips and overall time savings. A program in Lee County, Florida to discount tolls in the off-peak period reported 71% of motorists shifting their travel time to take advantage of reduced rates. The Port Authority of New York and New Jersey implemented variable tolling and found an initial time savings of up to 20 minutes at select bridges and tunnels (Higgins et al., 2011). Regardless of the implementation structure, if the U.S. were to price road access such that VMT reduced by 12% for 1% of all drivers, there would be about 0.023% less $CO_2$ emitted annually (Tirumalachetty et al., 2013). The well-cited 2003 implementation of an urban congestion scheme in London reduced $NO_x$ and $PM_{10}$ emissions by about 12% while also increasing vehicle speeds, thus substantially reducing emissions at slower speeds (Beevers & Carslaw, 2005). Other research suggests a reduction in $CO_2$ of 2-13% and a corresponding decrease in VMT of 4-22% (Axsen et al., 2020). There are also credible reasons to support HOT over HOV road networks to reduce emissions. A study by the Bay Area Metropolitan Transportation Commission found that during the two-hour AM peak period, a 10% reduction in $PM_{10}$, 7% in $CO_2$, 3% in $NO_x$, and 2% in reactive organic gases (ROGs) is associated with a HOT network compared to an HOV network in the year 2030 (Metropolitan Transportation Commission, 2008). The report does mention that these estimates do not consider the effect tolling has on parallel non-tolled arterials and holds constant VMT. The effectiveness and public support for decongestion pricing, especially for express facilities is bolstered when pricing is coupled with alternative travel options including HOV services, TDMs, active transportation, park-and-ride infrastructure, and employers providing flexible work hours (Higgins et al., 2011).

There are several challenges associated with implementing decongestion pricing, of which three are of note. The first challenge is finding suitable technologies to track vehicle movements and apply pricing at a reasonable operational cost. The second challenge is ensuring equity for all residents. The final challenge is the public perception of pricing as a tax on travel.

Decongestion pricing requires a means of tracking vehicle movements and a means of charging individuals for their use of the road. Early implementations of decongestion pricing relied on a fixed toll at cordon locations that was based on historical traffic volumes. Advancements in technology have allowed for more dynamic pricing that varies in response to real-time traffic conditions. However, most applications continue to rely on cordon tolling for its ease of implementation. A full-scale decongestion pricing scheme on all roads would require a system of vehicle tracking and dynamic pricing. Video-based systems, dedicated short-range communication (DSRC), and cellular-based systems offer avenues towards more dynamic and widespread adoption of decongestion pricing at a reasonable implementation cost (Clements et al., 2020). In addition, the development of a 5G network and the ubiquity of GPS systems are promising technologies for the dynamic and accurate pricing of roadways.

A common criticism of decongestion pricing is that it is a regressive policy, meaning that it disproportionately affects low-income individuals. In general, the same price is charged to all road users, regardless of their ability to bear the cost. This effect can make private auto travel infeasible for some households, thus negatively impacting their mobility. One way to alleviate this negative welfare effect is through the adoption of credit-based decongestion pricing (CBCP). Under CBCP, all individuals receive a travel credit each month. The advantage of the CBCP approach is that individuals with small values of travel time savings (VTTS), generally those with lower incomes, may receive a credit for traveling during off-peak times (Kockelman et al., 2005). They can then use these credits to pay for travel during higher-priced (congested) time periods, to purchase a transit pass, or on whatever other expense they deem suitable.

We use the term "decongestion pricing" rather than the more common "congestion pricing" to frame the policy objective as reducing congestion rather than penalizing travel. Nixon and Agrawal (2019) provide a useful analysis of the framing of transportation pricing based on seven years of public opinion survey data. Their focus is a gas tax or mileage fee, but we expect similar results for other types of road pricing. They find a 36-percentage point increase in support of a 10 cent per gallon increase in the gas tax (current federal gas tax is 18.4 cents per gallon) when the revenue is spent on "projects to maintain streets, roads, and highways" and a 16 percentage point increase when revenue is spent on "transportation projects to reduce global warming". Further, they find that a 1 cent mileage fee is more acceptable (19 percentage points relative to the reference) when tied to the vehicular pollution level. These findings support the notion of a "green label" increasing support for road pricing, since it signals to the public that revenue will be re-invested to improve the transportation system rather than simply being another tax avenue for general government spending.

### 3.10 Pay-As-You-Drive Auto Insurance

An alternative approach to pricing auto trips is pay-as-you-drive auto insurance. In this model, individuals purchase auto insurance that scales with their VMT. An individual would pay a flat rate of perhaps $30 per month and an additional fee of 6 cents per mile (Metromile, 2020). Increasing the cost to drive would, in effect, lower the demand for travel by reducing the amount of travel that can be done at a fixed budget. For reference, the current cost of driving is 53 to 79 cents per mile (AAA, 2020) - cost increasing with annual vehicle mileage. According to Cambridge Systematics & Urban Land Institute (2009), a 1.2-4.4% reduction in GHG emissions could be achieved by introducing this pricing scheme. Nichols and Kockelman (2014) found that such a system would reduce VMT by only 2.7% and provide an average consumer benefit of $2.00 per vehicle.

### 3.11 Parking Provisions

Many cities have minimum parking requirements designed to ensure developments can meet recurring peak demands for facilities, without regard for travel demand management programs to reduce the occurrence of driving. Additionally, these parking mandates serve to subsidize parking lots at the expense of travelers without car ownership or access to a vehicle, which raises issues of equity. Converting parking to other land uses can also help address issues of equity by making land available for affordable housing (Chester et al., 2015). As a result of studies documenting added congestion and as much as 2000 extra VMT per curb space every year from drivers spending time looking for cheap curbside parking (D. C. Shoup, 2006; Shoup & Hampshire, 2018), U.S. cities have relaxed parking minimums[9] or replaced them with parking maximums. A related challenge is the lack of reliable accounts of parking availability that include

[9] See Buffalo, NY and specific implementations in Hartford, CT, Lexington, KY, Portland, OR, Seattle, WA, and Washington D.C. (Spivak, 2018).

on-street parking, off-street parking, driveways, etc., which makes it advisable to err on the side of conservatism when setting parking requirements for new developments. It is also important to take into account how the existing parking supply impacts other proposed policies, such as those that encourage transit and active modes or upzoning (Chester et al., 2015).

There are several economic and regulatory mechanisms to reduce total parking in cities or better internalize the costs of personal vehicle use. Experts recommend keeping parking occupancy rates at 85% by setting parking fees to ensure that desirable parking spots are used by only those most willing to pay for the privilege of convenience. Smart parking solutions like dynamic pricing and dynamic parking capacity signs to inform drivers of available parking readjust prices to match the market value and reduce cruising miles. A combination of searching penalties and optimal parking capacities can lead to a reduction of 5.7-7.6% in $CO_2$ (Caicedo et al. 2016). San Francisco adopted a goal of 60-80% occupancy for metered parking to reduce double parking and cruising for parking. One study estimated cruising dropped 50% as a result of higher parking pricing (Millard-Ball et al. 2014). Amsterdam and London boroughs have even implemented emissions-based residential parking permits – a form of 'polluter pays.' Nottingham, UK implemented a tax on companies providing more than 10 parking spaces for employers whereas Hamburg, Germany gave businesses a variance to zoning parking minimums if monthly transit passes were provided to employees (Kodransky & Hermann, G., 2011). If 1% of households in multifamily units were charged market rates for residential on-street parking, one could expect a 0.054% reduction in U.S. transport GHG emissions as a result of lower household vehicle ownership. (Bomberg et al., 2009). A nested logit model of the Pittsburgh region suggested a 5%, 10%, and 15% increase in parking cost could reduce GHG emissions by 7.3%, 9%, and 13.2%, respectively, due to increased carpooling (Khattak et al., 2017).

| **Parking Policies** | SOV Share Reduction or VMT Reduction | VMT Reduction per Worker or HH (per year) | CO2e Reduction per Worker or HH Affected (lbs/year) | U.S. CO2e Savings if 1% of Workers or HHs Affected (metric tons/year) |
|---|---|---|---|---|
| Paid employee parking[1a] | 10-30% SOV share | 451-1352 | 563-1691 | 322,188-966,564 |
| $50/month residential parking[1b] | 30% VMT | 5,378 | 6,723 | 3,843,172 |
| Change front and side parking to rear lot[1b] | 36% SOV share | 1,317 | 1,646 | 941,141 |
| Market priced curb parking[2a] | n/a | 182.5 | 228 | 142,759 |

Sources: (1) VTPI (2007) & (2) Shoup (1997).
Assumptions: Vehicles average 20 mpg, average number of work trips per person per year is 565, average work trip distance is 12 miles, and average cruising distance is one half mile; Number of affected workers is 1.27 million. (Census 2000)
Note: Curb parking VMT reduction is based only on cruising parking and does not account for reduced trip generation due to higher parking costs. Superscript "a" is for VMT reduction per worker & "b" is for VMT reduction per HH.

**Figure 19** Parking policies and effects on $CO_2$ (Bomberg et al., 2009)

Kim and Hanley (1996) modeled the impacts of increases in parking charges, the fuel tax, or a combination of both, in Chicago, assuming that the parking fee increases affected only work trips. The most effective policies involved increasing the fuel tax, largely because of the assumptions made (i.e., only 40% of journeys would be affected by parking controls). The most effective policies were a $3 additional parking and $0.5 per gallon of fuel fee, or a $1 per gallon tax on its own. These policies resulted in a 26% and 25% reduction in VMT, respectively. The highest parking charge policy studied (a $3 charge) resulted in a 13%

reduction in VMT. A general rule of thumb is an elasticity of -0.1 to -0.3, meaning a 10% increase in parking price reduces automobile demand by 1-3% (Higgins et al., 2011). However, limits on private parking may have unforeseen impacts on travel demand, trip patterns, and congestion. Restrictions in one area may lead to trips migrating to another area within the city, or on the outskirts, or to another district altogether. The fact that nearby local authorities often operate very different parking policies is a complicating factor. Immediately after doubling parking charges in the central business district of Gothenburg, occupancy reduced by 20%, but one year later, the occupancy had returned to almost the same level as before (OECD, 1994). Reducing the number of parking spaces may also reduce car use. Dasgupta et al. (1994) modeled the effect of halving the number of parking places in the central area of a city. The study found that the share of cars within the central area declined by about 36%. However, when the increase in journeys outside the central area as a result of redistributed trips was considered, the overall reduction was only about 3 to 5%. It has been suggested that there is a strong association between the proportion of employees with a parking space available at their place of work and the proportion who use cars for commuting (Department of Transport, 1993).

Parking restrictions need not only be effective at workplaces and traffic attractors but also at residential locations where most transportation trips originate. Bundling the price of parking with housing (i.e., providing on-site or off-site parking) reduces ideal stock for car-free households, reduces the opportunity cost of vehicle ownership, and increases vehicle utilization, even when transit is nearby. American households that have parking built into the cost of housing are 50-75% less likely to be car-free than households without bundled parking (Manville, 2017). Masking the cost of vehicle ownership when the cost of parking is including in housing disincentives the alternative of living vehicle-free. In fact, removing free parking subsidies, be it at the residence or trip attractor results in a noticeable shift to carpools or public transit (Cloke et al., 1998).

### 3.12 Telecommuting

Telecommuting is a policy that has seen increasing prominence with the development of better information and communication technologies (ICT) and most recently the COVID-19 pandemic. Telecommuting can be defined as the replacement of commuting to a designated workplace with working from the home (or another nearby location). In theory, telecommuting eliminates the need to travel and thus reduces the GHG emissions associated with travel. However, several complicating factors make this effect less clear or may even induce higher emissions.

The first topic to address is whether telecommuting can effectively replace all work activities. Many industries (e.g., healthcare, manufacturing, food services) require workers to be on-site and cannot be replaced by telecommuting. Even in industries where telecommuting is possible, there are arguments to be made for the effectiveness of in-person meetings and education (Mokhtarian, 2009). The office provides other benefits beyond the exchange of information. It is also a venue for socializing and provides opportunities for serendipitous exchanges of ideas.

The most frequently cited question about telecommuting is whether it induces additional travel (Mokhtarian, 2009). Workers may choose to make additional trips in response to the additional time provided to them by not having to commute to a workplace each day. Mokhtarian (2009) finds that the direct effect of telecommuting on induced travel is minimal. However, more recent research by Mokhtarian and others (Kim, 2017; Kim et al., 2015; Lachapelle et al., 2018) considers the impact of telecommuting on overall household travel. Kim et al. (2015) find that the effect of telecommuting on trip induction partially depends on household vehicle ownership. In households in Seoul, South Korea that have only one vehicle per employed member, telecommuting makes the vehicle available for use by other household members for commuting or other uses. Households that have sufficient vehicles do not see the same degree of rebound effect because other household members already have access to a vehicle to make their trips. They find that additional travel may occur but are unable to attribute its cause to telecommuting. Subsequently, Kim (2017) sets the magnitude of person-kilometer induction from telecommuting at 2 km. However, this effect may not be as strong in MSP because vehicle ownership is much higher than in the study region of Kim - Seoul, South Korea. One aspect of the findings that will hold in MSP is that telecommuting tends to allow for suburban living, leading to longer and more frequent trips by private vehicle. Telecommuting tends to increase trip lengths for nonmandatory travel (i.e., shopping and recreation) because dedicated trips are required whereas when working from the workplace, individuals can make a side trip for shopping or recreation that may be shorter (Asgari et al., 2016; Shabanpour et al., 2018). Shabanpour et al. (2018) find that if 50% of Chicago commuters could work from home, VMT would be reduced by only 0.69%. If the objective of the policy is to reduce congestion, then telecommuting will help, but it does not appear to be a solution to reducing overall travel and thus GHG emissions.

An often overlooked aspect of the decarbonization impacts of telecommuting is its relationship with building use. O'Brien and Yazdani Aliabadi (2020) provide a critical review of the literature. In general, office buildings have more efficient heating, cooling, and lighting systems that respond to occupancy. In contrast, a telecommuting worker will often heat their entire home, despite it being largely unoccupied. Another consideration is that telecommuters generally only work from home a few days out of the week. As such, office space must still be heated for them throughout the week unless their employer has implemented a "hot-desking" strategy whereby employees are not provided with a dedicated workspace. They provide the following summary of studies that include both the transportation and building energy impacts of telecommuting.

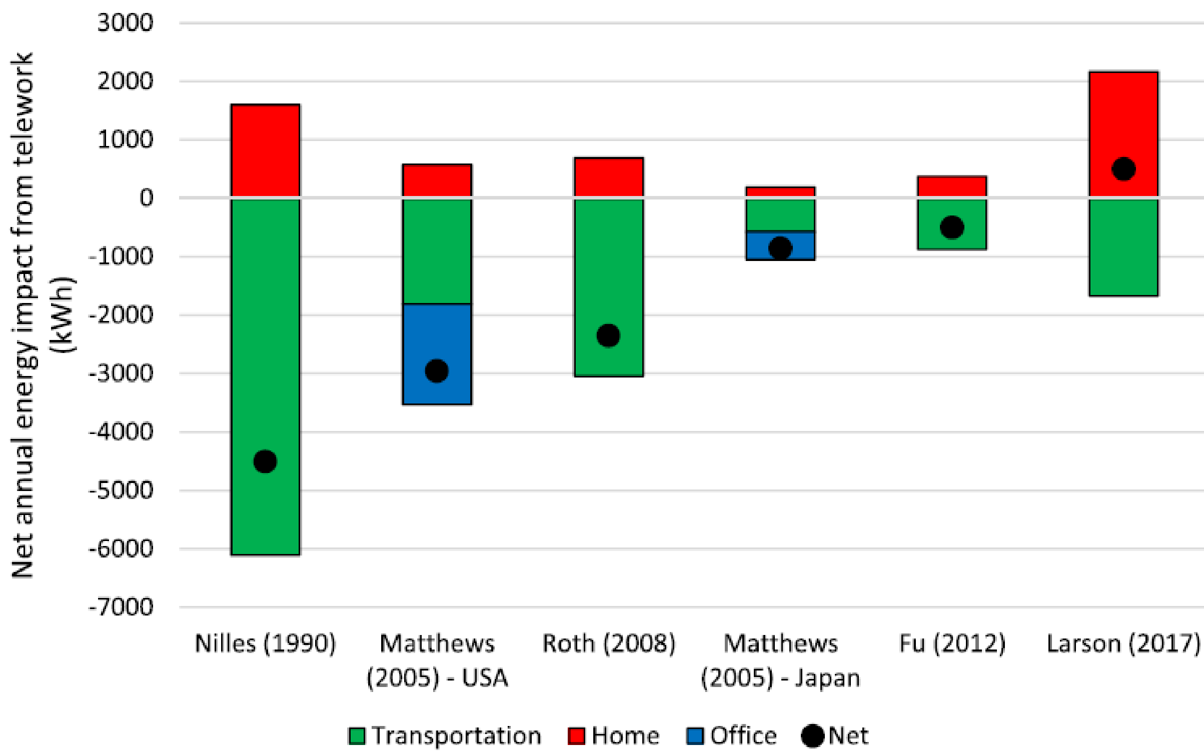


**Figure 20** Estimated impact of one-day-per-week teleworking vs. no teleworking on annual energy, where positive net energy indicates that teleworking uses more energy than non-teleworking (O'Brien & Yazdani Aliabadi, 2020)

O'Brien and Yazdani Aliabadi (2020) conclude that the literature suggests a net overall reduction in energy use with telecommuting but that the impact grows smaller (and potentially reverses sign) as we gain more knowledge of rebound effects and broaden the scope of analysis. One of the factors that is absent from existing research on the topic is the impact of EVs. Figure 20 suggests that the widespread adoption of EVs would have a significant impact on the energy balance, particularly if there is a corresponding shift in the mix of electricity generation sources towards lower carbon-intensity alternatives.

Finally, unanticipated benefits are stemming from the current telecommuting pattern resulting from the COVID-19 pandemic. The ModernTO plan in Toronto, Ontario exemplifies these benefits (City of Toronto, 2020). Due to the widespread adoption of telecommuting since March 2020, the City of Toronto has begun work to reduce their office space by 33%, freeing capital for improvements in existing office space to better accommodate flexible working patterns. Another key benefit of such changes is that municipal land is made available for conversion to affordable housing.

### 3.13 Long-Distance Travel

Between personal and business trips, long-distance travel accounts for about 30% of person miles in the United States (Li et al., 2020). Long-distance personal travel is usually for tourism and leisure: visiting family and friends or sightseeing. Physical participation is the main objective of the trip. In contrast, most business travel (for similar reasons to telecommuting) could be replaced by videoconferencing. In a survey of Austinites, Li et al. (2020) find that 75.1% of respondents deemed their long-distance travel "impossible" to replace with a remote alternative. While long-distance travel by its definition crosses the boundaries of Met Council jurisdiction, there are several ways that Met Council could influence the emissions associated with this travel. Li et al. (2020) suggest that autonomous vehicles could replace some of these long-distance trips. Supportive policy and infrastructure investment in the region could help to shift long-distance travel in this direction. Met Council could also encourage remote events in lieu of local conferences. While business travelers bring in revenue to the city through expenditures at local restaurants, it may be possible to balance these expenditures from local businesses that save money from reduced travel expenses. Additional analysis would be required to determine the details of the strategy and its potential to counterbalance lost revenue from business travelers.

The future of long-distance business travel is currently unclear given the ongoing COVID-19 pandemic. About 77% of Global Business Travel Association members estimated domestic travel would resume this fall (GBTA, 2020). IATA anticipates flight fares will level out at 54% above pre-COVID levels (Garcia, 2020). An Oxford Economics study found every dollar spent on business travel resulted in $12.50 in incremental revenue (Oxford Economics USA, 2009).

## **4**. FREIGHT TRANSPORTATION STRATEGIES

Globally, the freight transportation sector represents roughly 6% of total GHG emissions (ICCT et al., 2017). Most of those emissions are from trucking (see Figure 21). The technological advancement of e-commerce has given rise to increased deliveries by parcel delivery trucks and vans while also lowering the number of household shopping trips (Lockridge, 2019; Mcguckin et al., 2018). Road freight transportation has thereby faced the greatest scrutiny because it represents the largest share of greenhouse gases - 53% of total international trade-related $CO_2$ (International Transport Forum, 2015).

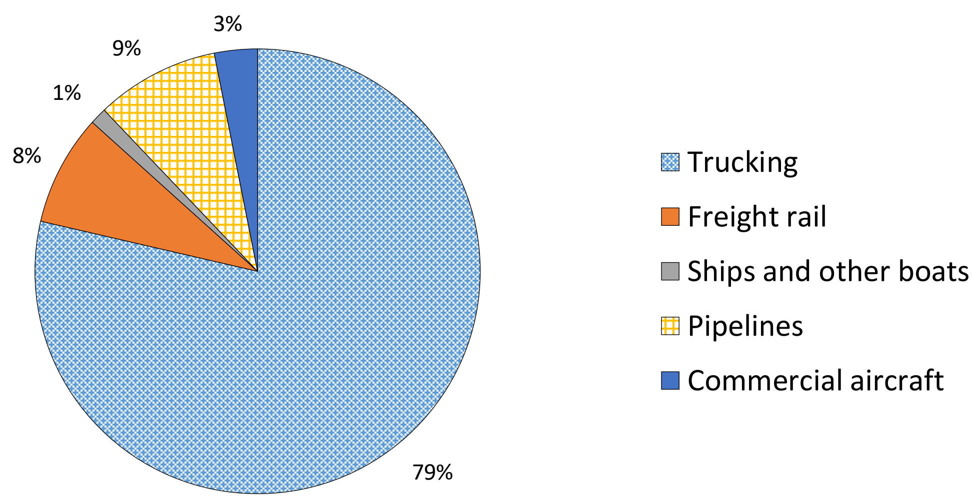


**Figure 21** Distribution of freight transportation GHG emissions in the United States (FHWA, 2016)

Smaller regional distribution hubs are increasing across the nation, coinciding with a fall in average trip lengths, suggesting a higher increase in last-mile delivery (LMD) truck registrations to long-haul equipment. Increasing returns of online orders, faster delivery times, and "white glove" deliveries of bulky items all appear to lead to a decentralization of fulfillment and distribution networks. An agent-based model with dynamic traffic assignment of the Chicago region examined the in-person shopping/home-delivery tradeoff and the net effects on VMT and energy use. In a scenario in which e-commerce increased deliveries to 2.5 times the current rate, retail shopping VMT decreases by 20% while VMT for freight deliveries doubled. However, replacing retail trips with an added stop on a delivery route is 40-50% more efficient for energy use (Stinson et al., 2019). If current trends hold and e-commerce delivery vans adopt efficient vehicle technologies, the small decline in VMT overall and large savings in fuel and electricity would make significant changes in metropolitan areas.

Table 1 illustrates that road freight is by far the most emissions-producing mode of freight transportation. However, it is generally quite difficult to replace it with other modes: trains are generally only effective for long-distance transport of large volumes of goods and container ships are clearly only useable in a subset of geographies. The main methods of reducing emissions explored in the literature are alternative fuels and route optimization.

**Table 1** Summary of Lifecycle GHG Emissions for Various Forms of Freight Transportation (Nahlik et al., 2015)

| **Vehicle Category** | **Lifecycle GHG emissions (lbs CO2eq/ton-mi)** |
|---|---|
| Medium-Duty Truck (19.5-33k lbs GVW) | 0.724 |
| Heavy Duty Truck (>33k lbs GVW) | 1.094 |
| Freight train | 0.161 |
| Container ship | 0.129 |

Battery charging is the major concern with EVs in the freight market. Research generally recommends a higher mix of hydrogen fuel or biofuels. Last-mile delivery collaboration is found to provide improvements in emissions but requires more study of conditions conducive to horizontal collaboration among companies (Meyer, 2020).

Many studies find a cost increase when optimizing routes for emissions (Meyer, 2020). For example, Soysal et al. (2015) find a 2.5% decrease in fuel consumption with a cost increase of 10.8%. Collaboration among logistics providers could reduce costs and emissions with Irannezhad et al. (2018) estimating fuel savings of 40%. Platooning is also being studied as a mitigation strategy, leading to reductions in aerodynamic drag, finding fuel savings of up to 10% if operating on the same route (Meyer, 2020). Coordination of routes and partial platooning has minimal savings. Minimizing empty miles can also be an effective measure (Demir et al., 2015). Hammond et al. (2020) find that the combination of a carbon tax, an LCFS, and a ZEV mandate is required to reach GHG goals. These measures target vehicle fuel, but a carbon tax can also influence route optimization by monetizing the cost of the higher emissions associated with inefficient routes. They suggest that a singular focus on density ignores the impact of land and transportation costs on total consumptive energy requirements.

## 5. LAND USE STRATEGIES

Increasing density is critical to moving people more efficiently on public transit and providing access to goods and services within walking and cycling distance. Compact cities with increased density allowing for a diversity of services and uses, accessible destinations, and interconnected streets, have 20-40% less VMT than low-density, sprawling cities (Ewing et al., 2009). Duranton and Turner (2018) find an elasticity of VMT with a population density between -0.07 and -0.10. However, they use density to represent a variety of built environment factors. Of the "5 Ds" of the built environment (density, design, diversity, destination accessibility, and distance to transit), destination accessibility has the largest impact on VMT (Ewing et al., 2014; Stevens, 2017). Ewing and Cervero (2010) find that the elasticity of VMT with density alone is only -0.04 on average, whereas the literature suggests that the average effect of density, when used as a proxy for all of the 5Ds, is closer to -0.3. Gallivan et al. (2015) recommend the use of the larger -0.3 elasticity for density since the other 5Ds are more challenging to represent in a model or tool. Density is generally associated with these other measures and can act as an aggregate measure. Moving beyond general density strategies to specific compact growth strategies is necessary to produce major reductions in household VMT since density alone has a very small impact on VMT. Using household energy estimates for the 125 largest MSAs in the United States, Lee and Lee (2014) find that a doubling of the population-weighted density of a metropolitan area is associated with a 48% reduction in household travel emissions and a 38% reduction in residential energy emissions. This result does not mean that the population density must be doubled across the metropolitan area. Concentration of density in specific areas can have a similar effect. If only 60% of new population growth were directed into compact growth patterns, the cumulative effect would be equivalent to those same people driving a fuel-efficient hybrid vehicle in business as usual development patterns (Ewing et al., 2009). In another study, Lee and Lee find strong support for planned density, which focuses development along commercial and transit corridors. Suzuki et al. (2013) demonstrate this difference through a comparison of the linear density along major transit corridors in Curitiba and unplanned density in Sao Paulo.

The energy and GHG emissions impacts of urban form is a complex topic, with sometimes counterintuitive results. Research in Helsinki, Finland (Heinonen et al., 2011) finds that households in the denser urban center have higher life-cycle emissions considering their transportation, dwellings, and consumption. Their results give 14.7 and 12.0 tonnes of life-cycle $CO_2$eq per capita for downtown and suburban households, respectively. However, the major difference is due to the consumption of clothes and other household goods. Rather than being a function of built form, the difference is largely driven by downtown households having higher incomes (about 33% higher than suburban households). These results are likely not applicable to MSP as there are significant differences in the energy consumption profiles of American and European cities (Mindali et al., 2004). Most American cities exhibit the opposite relationship between income and density and, in fact, this is likely magnified by suburban households consuming goods at a higher rate than urban households due to the larger size of their dwellings (Murphy, 2018). Also, the suburbs of Helsinki have a residential built form closer to that of central Minneapolis and St. Paul - only one-fifth of dwellings are single-family detached in the suburbs of Helsinki. Wiedenhofer et al. (2013) conduct a similar study in the more comparable environment of Australia. In that study, direct energy consumption is higher in the suburbs due to longer travel times by automobile. However, indirect energy due to consumption is generally lower for these households because they must spend a larger portion of their household budget on transportation costs.

### 5.1 Upzoning at the Regional Scale

Planners already have many tools at their disposal to increase density, with varying degrees of success at shifting travel behavior to efficient and low-carbon modes. Upzoning is a process to increase the legal maximum density assigned to the zoning of parcels and may be solely within the same type of land use (i.e., from R1 to R3) or by permitting other land uses than from what was previously allowed. Higher density in housing (e.g., apartment buildings to detached houses) also has the benefit of reduced marginal energy demands (Stephan et al., 2013). Upzoning is necessary to create housing and business stock if the objective is to limit additional sprawl. Single-family zoning in the United States varies widely between cities. Only 15% of residential land in New York is zoned for single-family detached dwellings, in Minneapolis it is 70%, while in other cities (San Jose, CA and Arlington, TX) the share of residential land is

90% or higher (Badger & Bui, 2019). An advantage of Upzoning over other land-use policies is that it does not necessarily mandate the type of residential development. Rather, it provides developers with the ability to choose among a wider variety of zoning alternatives.

Nichols and Kockelman (2014a) find that suburban communities - characterized by single-family detached dwellings - consume up to 320% more embodied energy, 150% more operational energy, and 160% more life-cycle energy than densely developed communities - characterized by low-rise apartments and semi-detached dwellings – on a per-capita basis. Norman et al. (2006) perform a similar comparison in Toronto, Canada that considers the life-cycle energy requirements from the embodied emissions in building materials, transportation fuel, and building heating and electricity. Their results are summarized in Figure 22 below. Glaeser and Kahn (2010) study variations in emissions across MSA in the United States. They find that urban areas generally have significantly lower GHG emissions than suburban areas based on the sum of driving, transit, home heating, and electricity energy consumption. For Minneapolis-St Paul, they find lower net $CO_2$ emissions of 3.5 tonnes for households located in the city versus suburbs (Note: calculations by Glaeser and Kahn give a household average for the region of 39.4t $CO_2$ for building energy.). These findings support the need for a change in zoning to encourage these denser development patterns.

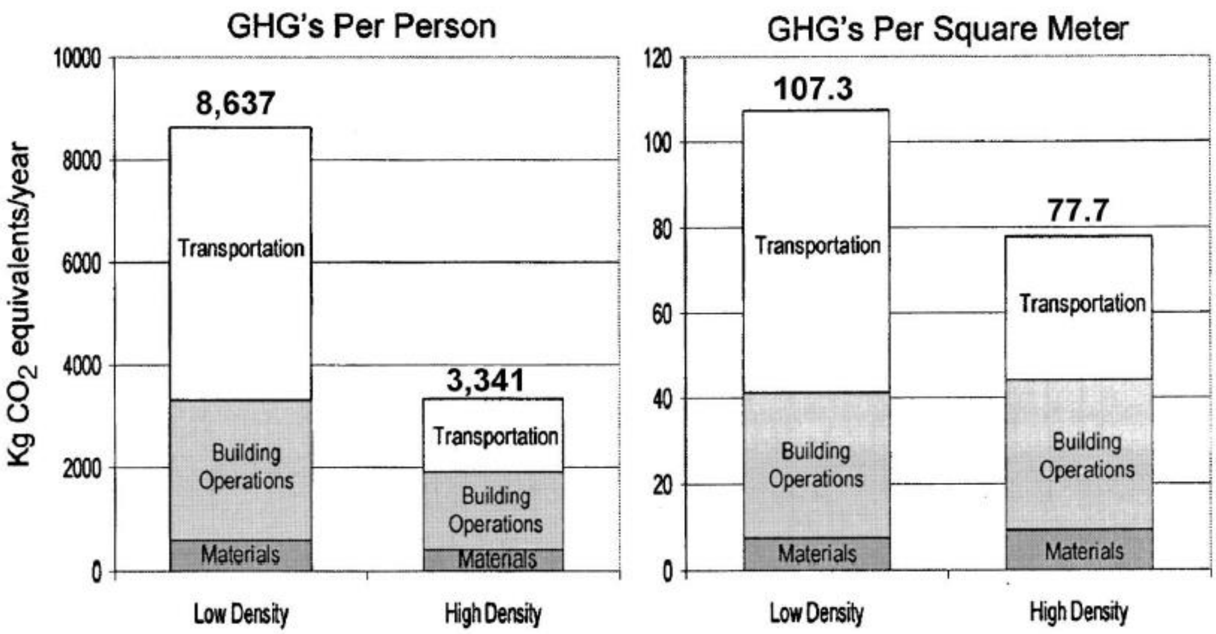


**Figure 22** Annual GHG emissions associated with low and high-density development (Norman et al., 2006)

Minneapolis is a leader in the adoption of upzoning policy. Their Minneapolis 2020 plan allows for three dwelling units (i.e., a triplex) on a single lot as a lower limit to density, with higher limits in more central locations and along transit corridors (City of Minneapolis, 2019). Wider adoption of such a policy across the jurisdiction of Met Council would directly address GHG emissions from the building sector. It would also provide an indirect benefit to transportation by reducing travel distances.

One of the major impediments to the adoption of upzoning in the United States is the perception of opposition by the public. However, recent research by Levine Einstein, Palmer, and Glick (2019) shows that this opposition originates in a single, unrepresentative segment of the population. They argue that this bias can be addressed through measures to encourage participation by renters and potential residents of multi-unit dwellings in addition to property-owning abutters.

### 5.2 Urban Growth Boundary

Urban growth boundaries (UBGs) can be used to prohibit urban sprawl and encourage densification and infill development by refusing outright, or with special use permits, development beyond rural or single-family homes on lots outside of the UGB. When UGBs are combined with upzoning, the market responds by developing up and not out. Characteristics of compact development are connectivity for all transportation modes, land use diversity, and increased access to goods and services. McDonald-Buller et al. (2010) find that the introduction of a UGB in Austin, TX would reduce VMT by 25-30% relative to a BAU forecast to 2030. In a related study, they found that GHG emissions would be reduced by 13.1% relative to BAU (compared with a 4.5% reduction in a scenario with a doubling of gas prices and a toll of 10 centers per mile on all roads). Pan et al. (2020) simulate land-use change in Stockholm, Sweden to consider the effect of various land-use policies. They consider a managed zoning strategy that identifies growth that would lead to high future GHG emissions and prohibits development in these areas. This approach removes 72.5% of the increased emissions anticipated from growth under the BAU scenario.

### 5.3 Transit-Oriented Development

Transit-oriented developments (TODs) are intentional compact developments where commute trips are best served by transit and local non-work trips are best served by active modes. Active and transit modes are utilized at higher rates with dense development, which will inherently increase property values and lead to gentrification[10]. Facilitating pedestrian-oriented designs and networks can also serve bicycles side-by-side if shared-use paths are employed. TODs must also ensure that commercial businesses have efficient road networks for freight delivery and vehicular traffic, but also avoid big box stores that require personal vehicle access. Rather, mixed-use developments with bordering mini-anchor stores can provide amenities closer to housing without sacrificing critical goods and services necessary to attract residents. According to a study of the Chicago metropolitan region, living in a neighborhood within a half-mile of public transportation lowers the average household's GHG emissions by 43%, relative to a household with no access to transit (Haas et al., 2010). Moreover, constraining growth in population and businesses in TODs can reduce VMT-related GHG emissions by 36-40%, because of more alternative transportation usage and a decline in automobile VMT (Nahlik & Chester, 2014). TODs also generate additional secondary emission reduction benefits from increased density and compact development that are not captured in traditional VMT-related GHG numbers. For example, increased residential density can lower building energy use. The density surrounding public transit investments can magnify the VMT-related benefits on the order of three to four times (Bailey et al., 2008). Kimball et al. (2013) find that TOD along an LRT route in Phoenix would reduce GHG emissions from transportation and buildings by 370 tonnes of $CO_2$eq per dwelling unit. They also find an annual energy savings of 5.7 TJ per dwelling unit (the equivalent of all the dwelling units in the BAU scenario being turned off for 3 days of the year).

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[10] Planners may wish to offer density bonuses in exchange for affordable housing to counteract displacement, which fulfills both equitable housing goals and lowers GHG emission targets by granting higher density.

5.4 Infill Development

Infill and brownfield development strategies explicitly promote developing undervalued property that is currently unused or not productively used (e.g., gravel parking lots or contaminated former industrial sites) while taking advantage of nearby public infrastructure and destinations (Ewing et al., 2009). Infill development has the effect of reducing VMT and increasing alternative mode share for new residents, but not necessarily for existing residents (Merlin 2018). Brownfield developments require one-time clean-up costs but offer savings in VMT-related expenses (fuel, driving time, air pollution). A study of 16 brownfield and conventional greenfield developments across the U.S. found that dense brownfield developments reduce VMT by 52% compared to traditional new development patterns (Mashayekh et al., 2012). Other studies report ranges anywhere from 30%, 36%, and even up to 80% (Mashayekh et al., 2015; Nagengast et al., 2011).

Improved neighborhood design, particularly infill development and purposeful densification will facilitate reductions in trip lengths due to increased opportunities and destinations. Increased density is an ideal characteristic of quality transit and non-motorized travel, so long as facilities exist to constitute a viable mode of transportation. In summary, shifting to compact development could reduce VMT by 20-40% (Ewing et al., 2009). If infill development was prioritized such that residential density was to double, VMT could be reduced by 5-12%, but promoting a mix of land uses with viable transportation alternatives would further reduce VMT by up to 25% (Cambridge Systematics & Urban Land Institute, 2009; TRB, 2009).

## 6. CASE STUDIES FROM OTHER CITIES

This section provides a series of case studies that have performed a quantitative analysis of scenarios for GHG reduction. Emphasis is placed on similarly sized cities and those with comparable climates to MSP. In most cases, analysis is conducted in the central city rather than the metropolitan region, so some policies may not be applicable for all municipalities within MSP (e.g., where baseline transit infrastructure and population density are low).

### 6.1 Boston, Massachusetts

In 2019, Boston completed an extensive study of deep decarbonization in partnership with Boston University and several consulting firms (Cleveland et al., 2019). The study included transportation, building, energy, and waste components. This summary will focus on the transportation findings. Boston is the most similar to MSP among the case studies in its climate, particularly winter low temperatures.

Three major strategies are identified for the transportation sector: shifting trips from automobile to transit, cycling, and walking; reducing automobile trips via land use planning and encouraging denser development and transit-oriented development; and shifting automobiles, trucks, buses, and trains to zero-GHG electricity sources.

The Boston study highlights the importance of a broad-based approach. The complete electrification of the vehicle fleet could enable GHG neutrality. However, it does not address congestion and the GHG burden of low-density land-use patterns nor the equity implications of housing prices. They find that anticipated improvements in fuel efficiency and EV adoption will lead to the GHG emissions trend shown in Figure 23 for the transportation sector. There is a diminishing reduction in impacts past 2035 as the existing vehicle fleet is replaced by a more efficient vehicle fleet. However, there are technological limits to the possible improvements offered by vehicle efficiency for ICE vehicles.

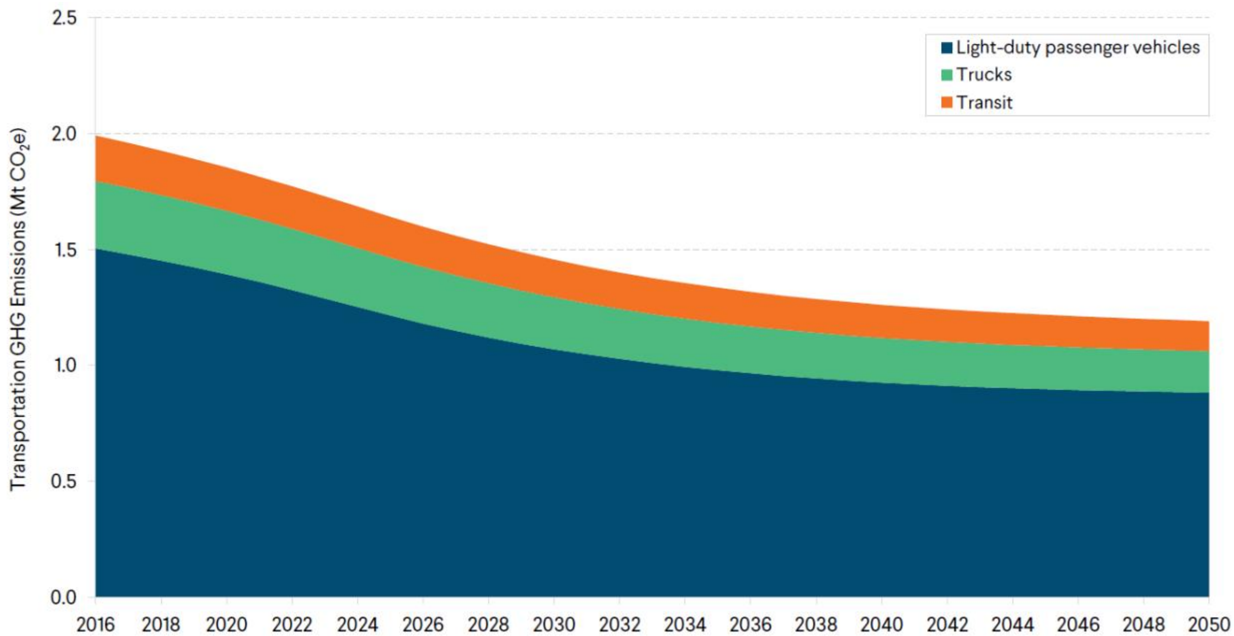


**Figure 23** Baseline projection of Boston-generated transportation GHG emissions (Porter et al., 2019)

The Boston study proposes a range of technology and policy strategies including:

- Electrification of the light and medium-duty vehicle markets
- Shift new population growth away from high VMT and towards low VMT areas of the city
- Improvements in transit service
- Different levels of AV market penetration
- Different levels of market penetration of shared ride-hail services
- Several traditional TDM strategies (i.e., reduce transit fares for work trips, reduce work trip VMT to reflect TDM program impacts observed in the literature)

EV scenarios are based on sales and vehicle population projects derived from the MA3T model developed by ORNL. Vehicle electrification produces an increase of 3.4% in 2050 transportation GHG emissions in the baseline scenario (relative to BAU) but a reduction of 61.4-90.6%, assuming the most optimistic projections of EV market penetration. In comparison with 2016 emissions, the baseline EV scenario results in no reductions by 2030 and 45.1% by 2050. The most optimistic scenarios produce 2050 emissions reductions of 79.4%-94.9% relative to 2016.

Other policies produced more modest changes in GHG emissions. Directing three-quarters of the new population to TOD neighborhoods reduced VMT by 3%, with associated reductions in transportation emissions. However, this scenario is measured relative to a fairly high BAU assumption regarding densification in Boston and does not include emission reductions relative to the 2016 base total resulting from building-level emissions from heating, etc. Proposed transit improvements are anticipated to reduce VMT by about 4%. Walking and cycling strategies would reduce emissions by about 1%.

Technology solutions (AV and shared ride-hailing) have more mixed results. The unmanaged adoption of privately owned AVs increases VMT by 2% by 2050 with 20% market penetration and 6% with 50% market penetration. With the introduction of a user fee, emissions decreased by 1% to 3% relative to the BAU scenario. The shared ride-hailing scenario assumes a 10% market penetration of the service and results are summarized in Figure ***24***.

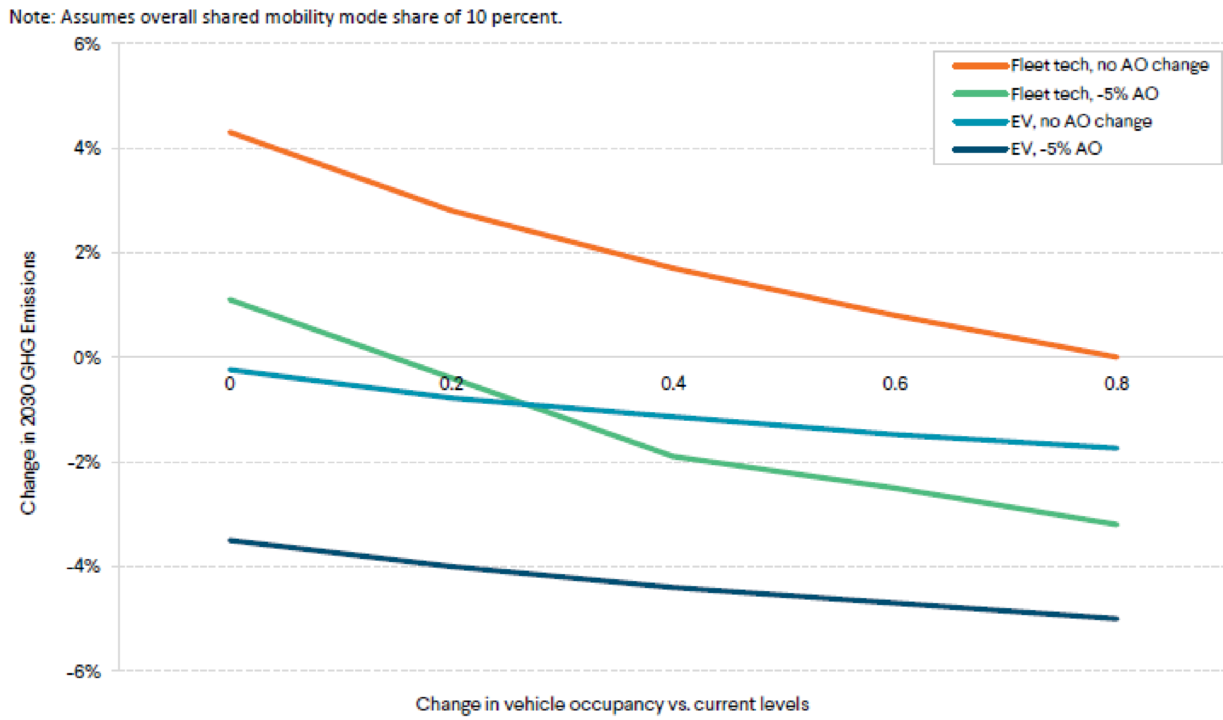


**Figure 24** Change in 2030 GHG Emissions for Shared Mobility, by Technology and Auto Ownership (AO) (Porter et al., 2019)

A variety of travel pricing scenarios were considered in the Boston study. They find a reduction in GHG emissions ranging from 0.6% assuming a $0.05 VMT fee to 3% assuming a $10-15 per day charge to enter central Boston. The TDM policies were estimated to only reduce VMT (and emissions) by about 0.5%. More aggressive policies could reduce emissions by about 1.3% by 2050.

A combination of policies is necessary to reach deep decarbonization in a way that assumes a feasible level of EV market penetration and takes  land use impacts into account. Such a combination is considered in the Boston study and summarized in Figure 25. These results provide several insights into the path towards deep decarbonization. First, unmanaged adoption of new transportation technologies will not necessarily reduce emissions. Given the current mix of modes in American cities, EV adoption is the most effective means of reducing emissions. However, this policy relies on a corresponding shift in electricity generation towards low-emissions sources. Pricing and land use policies play a smaller but significant role in reducing emissions. However, these policies have secondary benefits from new revenue generation (in the first case) and a more dynamic and efficient built form (in the second case).

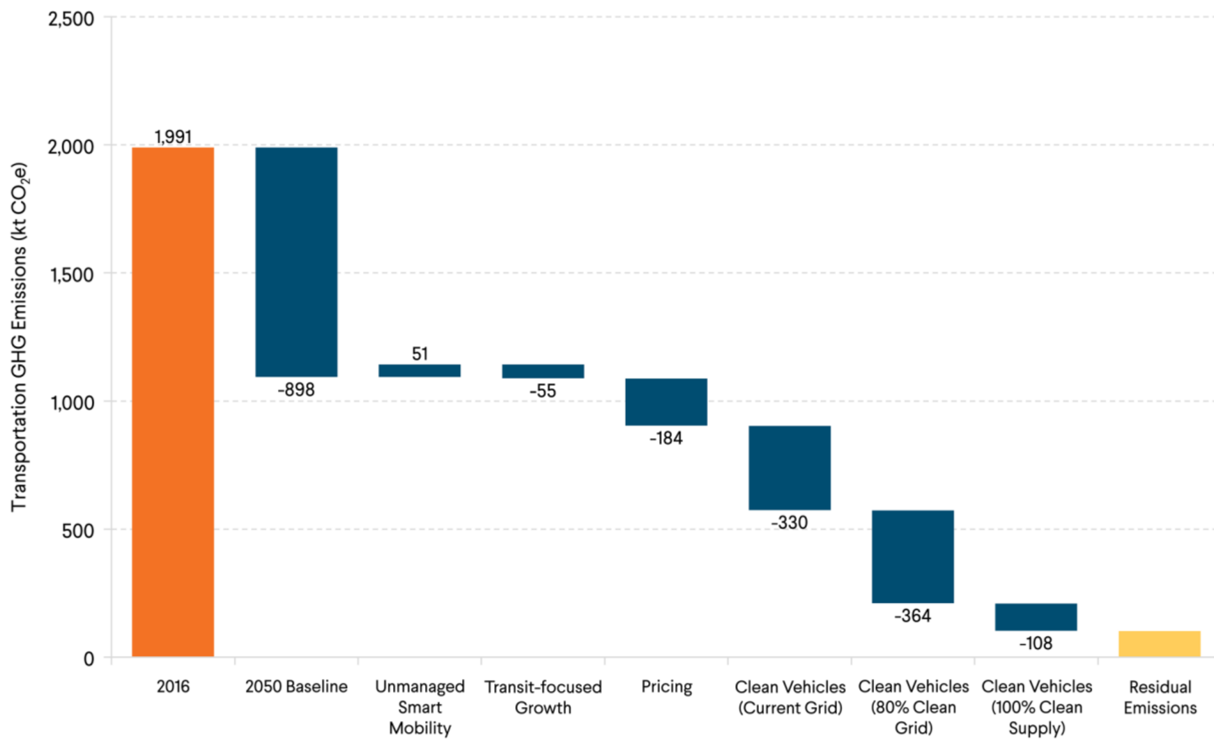


**Figure 25** Contributions to 2050 Transportation GHG Reductions (Porter et al., 2019)

### 6.2 Seattle, Washington

A 2013 study in Seattle using the Long-range Energy Alternatives Planning (LEAP) tool developed by the study authors to consider the effects of the policies is outlined in Table 2. Focusing on transportation strategies, transit service is assumed to improve such that its mode share improves from 8% to 25% by 2050, and Seattle is assumed to implement its Pedestrian and Bicycle Master Plan. Road pricing takes the form of a 12 cent per mile VMT fee in 2020, rising to 25 cents by 2050, and an additional congestion charge of 65 cents per mile. EV penetration is projected to be 80% by 2050 in the LDV market, with more modest penetration rates in freight transportation. This combination of strategies results in a 90% reduction in transportation GHG emissions by 2050. The combination of strategies, including buildings, energy, and waste sectors, results in a similar reduction in overall GHG emissions by 2050 compared to a 2008 reference.

**Table 2** Summary of Policies Considered in Seattle Study (Lazarus et al., 2013)

| | |
|---|---|
| **Passenger Transportation**<br>1. VMT Reduction and Mode Shift:<br>a) Transit, b) VMT Pricing, c) Pay as You Drive (PAYD) Insurance, d) Parking, e) Bicycle/Pedestrian Infrastructure, f) Trip Reduction Programs<br>2. Electrification<br>3. Fuel Economy<br>4. Biofuels | **Freight Transportation**<br>1. VMT Reduction and Mode Shift:<br>a) Pricing, b) Road to Rail, c) Smaller trucks<br>2. Electrification<br>3. Fuel Economy<br>4. Biofuels |
| **Residential Buildings**<br>1. New Building Design<br>2. Building Retrofit and Renovation<br>3. Switch to District Energy (MF) and Heat Pumps | **Commercial Buildings**<br>1. New Building Design<br>2. Building Retrofit and Renovation<br>3. Switch to District Energy and Heat Pumps |
| **Energy Supply**<br>1. Distributed Electricity Production<br>2. District Energy<br>3. Biomass Energy | **Waste**<br>1. Recycling and Composting |

### 6.3 Austin, Texas

The City of Austin, Texas, is currently revising its 2050 Climate Plan, which was adopted in 2015. In the existing plan, Austin prioritized three actions under the transportation and land-use sector: support transportation demand management programs for large employers to shift commute trips from automobiles to other modes (or reduce total trips in general), support programs that address first and last-mile barriers, and support programs to increase electric or alternative vehicle adoption rates. Using a base year of 2010, Austin estimates that implementing the emission reduction strategies in the Capital Area MPO (CAMPO) 2035 Plan *ceteris paribus* would cause emissions to increase 25% from the 2010 baseline. To further decrease emissions from a BAU scenario, 5% each could be attributed to land-use policies, transportation demand management, and pricing strategies, as well as new infrastructure or services. The majority of the reduction of emissions (40%) from BAU would be achieved from vehicle and fuel efficiency improvements, which can only be spurred on by quickly adopting and rolling over into efficient vehicles (City of Austin, 2015).

A summary of actions that will be taken under “phase one” is shown below in Table 3. However, some of these actions are not codified in any plans adopted by Austin or are marked as “new” as opposed to “developing” or “planning” for implementation.

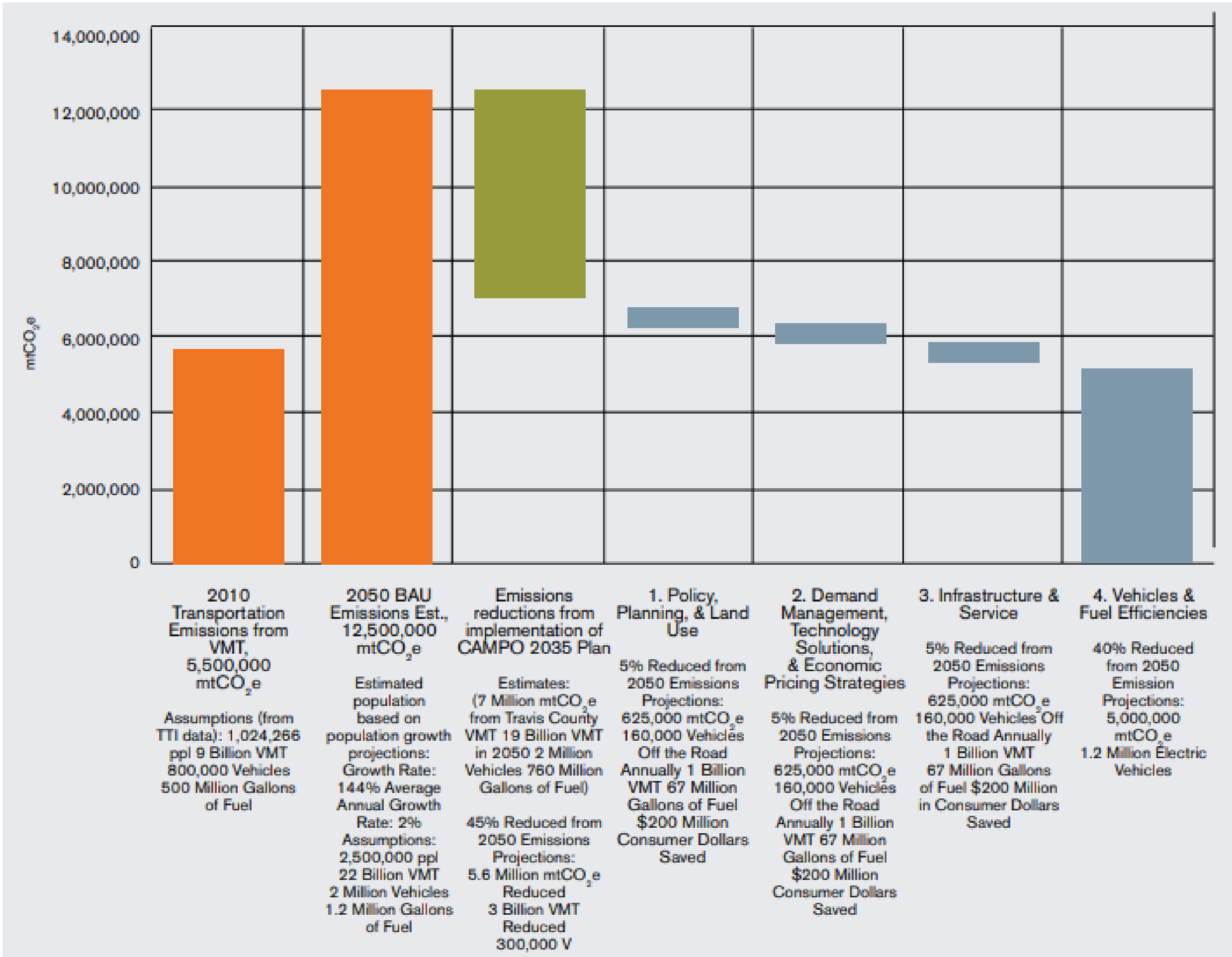


**Figure 26** Austin, Texas GHG emission reduction strategy impacts (City of Austin, 2015)

**Table 3** Austin, Texas GHG Phase 1 Actions (City of Austin, 2015)

| Strategy | Actions |
|---|---|
| Infrastructure & Service | IS-1: Develop high-capacity transit, including intracity and intercity systems<br>IS-2: Increase mobility while protecting the safety of all modes (traffic signal synchronization, speed limit reductions, installing roundabouts, collect traffic count data for vehicles and bicycles, install pedestrian hybrid beacons (PHBs))<br>IS-3: Extend transit into suburban areas (park-and-ride facilities, interconnections, and vehicle amenities) |
| Land Use | LU-1: Prioritize mixed-use development integrated with transit and develop compact places<br>LU-2: Promote growth in designated activity centers (infill development, LU-1 development)<br>LU-3: Create pedestrian- and bicycle-friendly districts with connectivity to urban centers and transit<br>LU-4: Ensure residential neighborhoods are within ¼ mile of existing or funded transit options<br>LU-5: Ensure code revisions reduce barriers to multi-family residences |
| Transportation Demand Management | TDM-1: Shift commuting patterns of large employers and academic institutions<br>TDM-2: Seek funding to increase transit frequency and service hours<br>TDM-3: Increase short bicycle commute trips and bike to school safety programs (increase scope and tools of bike promotional events)<br>TDM-4: Support first mile last mile (FMLM) transit connections for commute trips (flex route, bike-share, vanpool services, free circulator buses)<br>TDM-5: Work with major event promotors to create innovative transportation plans for attendees<br>TDM-6: Outreach and education for fleet owners on evaluating current practices and locate incentives for new vehicles<br>TDM-7: Provide amenities for active modes (bike lockers, tree shading, repair stations)<br>TDM-8: Inform residents of other alternatives to Single Occupancy Vehicle (SOVs) |
| Policy & Planning | PP-1: Establish agreements between neighboring municipalities to commit to the congruency of development goals |
| Vehicles & Fuel Efficiencies | VFE-1: Support electric and alternative fuel infrastructure, purchasing incentives, and code options for "charger-ready" parking |
| Economic & Pricing Systems | EPS-1: Pursue demand-based commodity pricing of parking<br>EPS-2: Permit high occupancy vehicles (HOVs) and zero occupancy vehicles (ZOVs) access to toll facilities for free or reduced rates |

### 6.4 Reykjavik, Iceland

Reykjavik provides an international example. Although it has a much smaller population than MSP, the Reykjavik study provides an example of a city with a comparably long winter and an interesting comparison of transportation technology and land-use strategies (see Figure 27). It is also the only study to include a scenario of worsening climate policy (S6). They find that electrification of the vehicle fleet and reduction of car ownership through the adoption of mobility-as-a-service (MaaS) and uptake of public transit are the most influential strategies, accounting for 57% and 42% of the reduction in GHG emissions, respectively. Technological scenarios with high uptake of EVs, but no MaaS perpetuate a high auto ownership rate and lead to high indirect emissions from vehicle manufacturing.

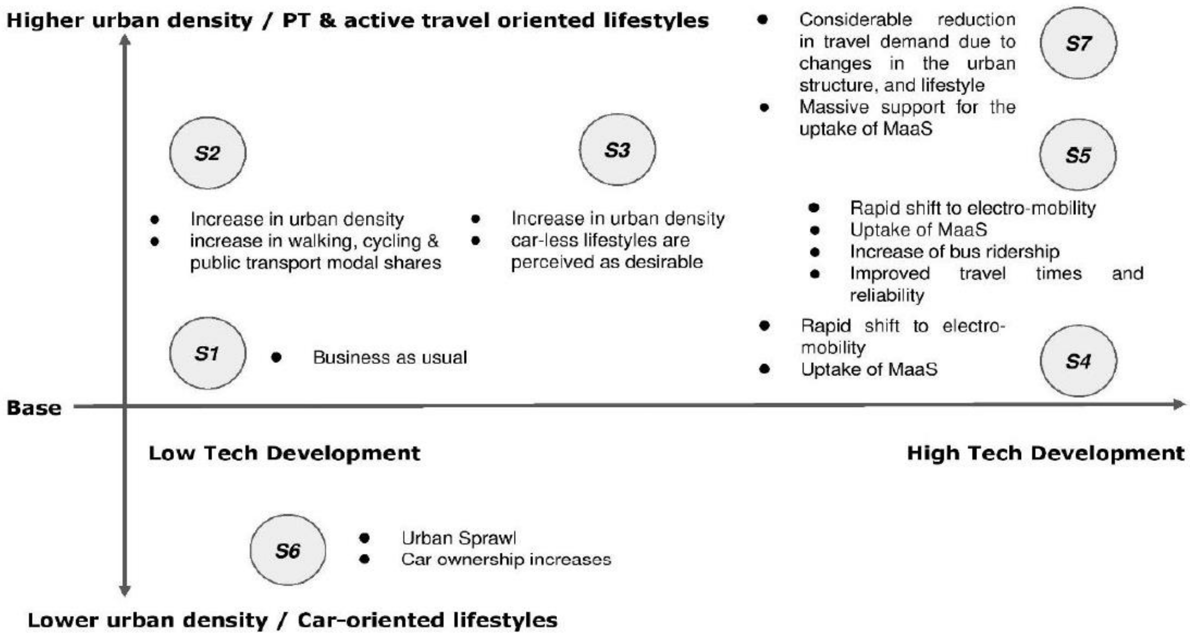


**Figure 27** Scenarios by density and technology change (Dillman et al., 2020)

### 6.5 Toronto, Canada

The final case study is for the City of Toronto in Canada. Like Boston, Toronto is similar to MSP in its winter weather and has a slightly larger metropolitan population. In its 2018 TransformTO plan (Sustainability Solutions Group, 2017), the city set a goal of a 30% reduction in GHG emissions by 2020, 65% by 2030, and net-zero by 2050, relative to 1990 levels. The density of Toronto relative to MSP means that buildings are a larger focus in Toronto, representing 52% of emissions compared with 38% for transportation.

Transportation changes include several car-free zones in downtown Toronto, a four-day workweek, more short trips by walking and cycling, and frequent transit in all areas of the city. These changes have a minimal impact on mode share (about 2%) because most areas with these treatments already have high transit mode shares. TransformTO also seeks 100% of the vehicle fleet to be electrified by 2050 and 100% of 2030 vehicle sales by EVs. Scenario analysis assumes that AVs increase energy consumption due to an increase in VMT. The study does not consider a shared fleet option, which would likely remove this effect. Freight transportation is assumed to be more efficient than the current fleet, but no specific assumptions are made about the transition of the fuel mix. The Toronto Transit Commission (TTC) currently has the largest fleet of BEBs in North America, with 60 vehicles (TTC, 2020).

There are several important lessons to be learned from the Toronto case study. First, existing planned changes by the city are expected to reduce emissions by 53% in 2050, relative to 1990, and the city has already reduced its emissions by about 35%. The distribution of emissions by sector and fuel source are shown in Figure ***28*** for the business as planned (BAP) scenario. TransformTO also includes consideration of district energy in areas with sufficient density. In addition to transportation plans, focusing development along existing and planned transit corridors and in areas appropriate for district energy would reduce GHG emissions by a further 60 kt $CO_2$eq relative to the BAU scenario. Finally, the TransformTO plan showcases the importance of tracking intermediate progress. Each year, the Environment and Energy Division publishes a report that quantitatively outlines progress towards the 2050 objectives. In some cases, numbers are carried forward between years (i.e., 2017 numbers are still reported in 2019 for some benchmarks). However, the process of intermediate reporting of the most up-to-date figures is an important component of accountability and transparency.

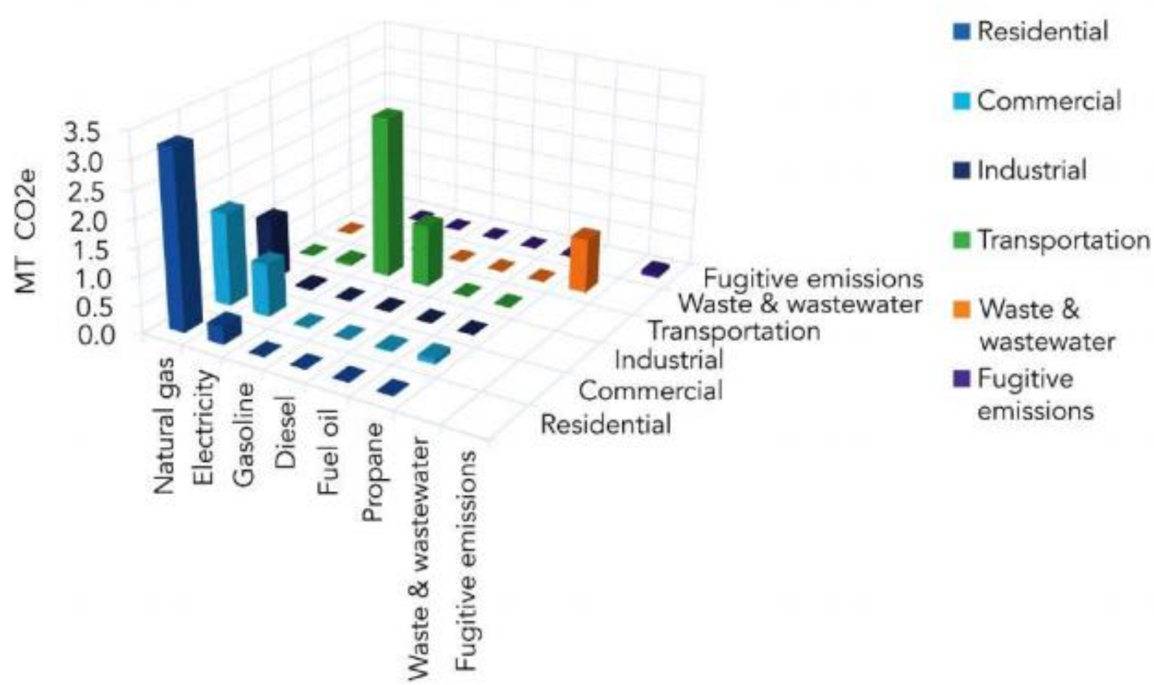


**Figure 28** Emissions by sector and fuel/source in BAP 2050 scenario (Sustainability Solutions Group, 2017)

Figure 29 summarizes results for the scenario with additional strategies outlined in TransformTO. It shows a dramatic reduction in fossil fuel emissions and a modest reduction in electricity emissions (despite a complete transition to EVs) due to a shift in the electricity generation sector towards renewable and lower emissions alternatives.

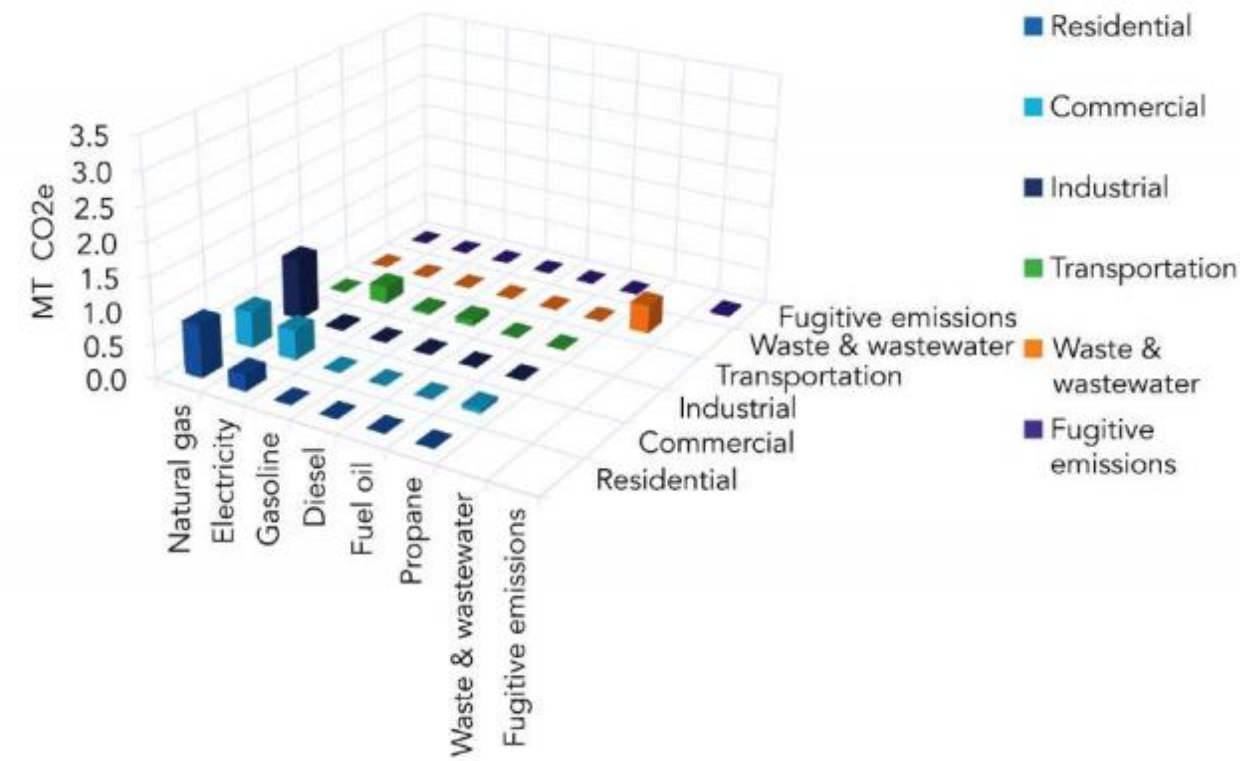


**Figure 29** Emissions by sector and fuel/source in Low Carbon 2050 scenario (Sustainability Solutions Group, 2017)

## 7. OVERVIEW OF GHG ASSESSMENT TOOL

The objective of this report is to inform the development of a tool for comparing decarbonization strategies in the MSP region. The tool allows users to compare scenarios in a dynamic environment. For example, EV penetration is uncertain and its effect on GHG emissions will depend on the carbon intensity of the electricity grid. The user can adjust these parameters to see the effect on GHG emissions for the transportation sector. The main inputs to the tool are as follows:

- Population and employment projections by municipality
- Current and anticipated travel by mode in annual vehicle-miles of travel
- Current and anticipated land use by type
- Baseline projections of EV market share and electricity generation mix
- Emissions factors for transportation technologies

The tool includes both passenger and freight transportation, as well as a basic representation of land use. In addition to the above inputs, elasticities and other parameters were compiled from the literature to inform the development of the tool. These values are used to define technology and policy strategies, which the user can select for inclusion in a scenario. Comparisons can then be made with the BAU scenario, including both graphical and tabular summaries of results. The tool also includes cost estimates for each scenario to provide the user with a more complete picture of the costs and benefits associated with each decarbonization strategy.

## 8. PREFERRED TRANSPORTATION DECARBONIZATION STRATEGIES

Decarbonization strategies can be categorized according to the avoid-shift-improve framework (Creutzig et al., 2018). In the context of transportation, 'avoid' includes measures to reduce VMT, 'shift' includes measures to shift to a lower emission energy source, and 'improve' includes measures to improve vehicle efficiency and fuel carbon intensity. Federal interventions such as the Corporate Average Fuel Economy (CAFE) or fuel content changes (e.g., ethanol additions or admixtures) only provide marginal improvements to the existing transportation system. To achieve substantial reductions (50% to 80%) in GHG emissions, major behavioral shifts, motivated by federal fuel economy legislation, energy taxes, and household-level carbon budgets are required (Bomberg et al., 2009). Absent federal government intervention, shifting transportation modes and promoting compact development patterns to reduce VMT are the focuses of most current policies (Lewis et al., 2018). Mode shifts away from SOV to carpooling and transit modes lead to GHG savings if current occupancy levels are maintained or improved; however, this path forward is not estimated to come close to the savings in electricity generation and vehicular technologies. Improving the efficiency of passenger vehicles is imperative, given American's reluctance to change personal travel behavior, and will yield long-term benefits through fleet electrification (Bomberg et al., 2009). Absent federal initiatives, states, regions, and local governing bodies can enact mitigation measures making meaningful impacts on the region's GHG output.

Numerical models, such as that to be developed in this project, rely on a large set of input variables (i.e., forecasts of alternative fuel vehicles, fuel efficiencies, mode shares, etc.). These inputs are highly uncertain and it can be challenging to determine which policies have the highest probability of reducing GHG emissions. Craglia and Cullen (2020) examine this uncertainty through sensitivity analysis for the transportation sector using standard scenarios of EV adoption, vehicle occupancy, and induced demand effects. Based on their analysis and that of the other studies reviewed in this report, the recommended set of decarbonization strategies for MSP are as follows:

1. **Electrification of the private vehicle fleet.** The most critical factors in determining life-cycle GHG emissions in the coming decades are the ICE turnover rate and rate of change in vehicle size and power. Vehicle electrification represents the most effective and feasible means of decarbonization transportation in a region with the modal mix of MSP. Anticipated changes in the electricity grid of Minnesota will decrease the GHG emissions of EVs. However, it is important to ensure these changes occur and to push for further decarbonization of the electricity grid. Regardless of changes in the electricity grid or whether the EV mix is dominated by PHEVs or BEVs, a shift towards EVs is the most significant driver of cumulative emission reductions (Craglia & Cullen, 2020). The introduction of DCFCs (level 3 chargers) throughout the region would be a major catalyst for EV adoption. It is also recommended that level 2 chargers be a requirement in all new dwellings and parking structures to reduce barriers to adoption.
2. **Electrification of the public transit vehicle fleet.** Public transit buses should be electrified as soon as feasibly possible. However, a dramatic expansion of public transit service is not anticipated to provide any benefit from the perspective of GHG emissions reductions. While recognizing there is a range of factors considered when establishing public transit investment, it was concluded that public transit only provides a decarbonization benefit when there is sufficient demand to fill vehicles (more than about 13 passengers for a standard bus). Right-sizing of vehicles and dynamic vehicle routing should be considered in the decarbonization strategy to increase the average vehicle occupancy.
3. **Shared fleets of vehicles.** While the timeline for automation of road transportation remains uncertain, it is prudent to plan for its eventual arrival. In the short-term, shared fleets of ride-hailing vehicles offer a means of FMLM transit where expected vehicle occupancies are below the necessary threshold to make bus and rail modes effective decarbonization strategies. In the long-

term, SAEVs will increase operational efficiency (and therefore reduce GHG emissions), reduce vehicle ownership, and likely decrease the size of vehicles. In addition, there is the potential to reduce requirements for parking structures. All these factors have been found to reduce the GHG emissions of transportation (Craglia & Cullen, 2020; Lawal et al., 2020). We recommend regulatory limits on empty VMT of 0% for private AVs and 15% for fleets of SAVs. Such limits would both reduce VMT and encourage the use of SAVs over private vehicles.

4. **Development along transit corridors.** Land use change is a slow process, and it is unlikely that a sufficient density to induce significant decarbonization is possible for the MSP region as a single strategy. However, there is clear support for densification and increased land use diversity along existing and planned transit corridors. Coupling land use densification with locations of frequent transit service is expected to provide strong benefits and increase destination accessibility.

While many technology and policy strategies represent marginal changes in GHG emissions, shifts in the electricity grid will produce step changes in the GHG emissions of transportation. Each additional EV purchased, or dollar increase in decongestion pricing, has an associated incremental decrease in emissions. However, replacing the generation capacity of a single coal-fired power plant with renewables will have a positive impact on the emissions of all EVs on the road, rail stock on the track, and buildings in the region.

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