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16. Abstract

Greenhouse gas (GHG) emissions continue to be an important focus area for state, local, and federal agencies. The transportation sector is the second biggest contributor to GHG emissions in the U.S., and Texas contributes the highest emissions among states in the country. Many transportation agencies are moving toward tackling the issue of GHG emissions on a voluntary or state-level policy basis. It is also expected that in the future, federal regulations could require transportation agencies to address GHG reductions in long-range transportation planning. This report presents a framework to link GHG emissions mitigation strategies with long-range transportation plans. The intent of the framework was to be flexible, practical, and equip Texas transportation practitioners with tools needed to address GHG emissions in the long-range transportation planning process. Each step of the framework involves different stakeholders, processes, and challenges that can occur and need to be taken into consideration. The framework can be used to supplement federal-level guidance or policy, or serve as a starting point for TxDOT and its partner agencies in the absence of federal guidance on the subject of transportation GHG emissions reductions. The framework includes guidance on incorporating control strategies, performance measures, and evaluation tools into long-range planning process to reduce GHG emissions.

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INCORPORATING GREENHOUSE GAS (GHG) EMISSIONS IN LONG RANGE TRANSPORTATION PLANNING – FINAL REPORT

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation. This report is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Josias Zietsman, P.E. # 90506.

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LIST OF ACRONYMS

ADAPT	Adaptation Database for Planning Tool
ARB	ARB Air Resource Board
NH3	Ammonia
AFCI	Average Fuel Carbon Intensity
BCS	Bryan – College Station
BRT	Bus Rapid Transit
CAMPO	Capital Area MPO
CO_2	Carbon Dioxide
CO	Carbon Monoxide
CACP	Clean Air and Climate Protection
CAPs	Climate Action Plans
CCATF	Climate Change Advisory Task Force
CDMF	Collaborative Decision-Making Framework
CRiSTAL	Community-based Risk Screening Tool – Adaptation and Livelihoods
DRCOG	Denver Regional Council of Governments
DCHC	Durham-Chapel Hill-Carrboro
EMFAC	Emissions Factor
EIIP	Emission Inventory Improvement Program
EIA	Energy Information Administration
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
FCVs	Fuel Cell Vehicles
GIS	Geographic Information System
GHG	Greenhouse Gas
GRIP	Greenhouse Gas Regional Inventory Protocol
GreenSTEP	Greenhouse Gas Statewide Transportation Emissions Planning
HAP	Hazardous Air Pollutants
HAZUS-MH	Hazards U.S, Multi-Hazard
HGAC	Houston Galveston Area Council
HPMS	Highway Performance Monitoring System
HOV	High Occupancy Vehicle
HC	Hydrocarbon
ITS	Intelligent Transportation Systems
LUPM	Land Use Portfolio Model

LRTP	Long-Range Transportation Planning
LCFS	Low-Carbon Fuel Standard
MPO	Metropolitan Planning Organizations
MTP	Metropolitan Transportation Plans
MOTOR	Midland – Odessa Transportation Organization
MOVES2010b	Motor Vehicle Emissions Simulator
MAP-21	Moving Ahead for Progress in the 21st Century
NAAQS	National Ambient Air Quality Standards
NCHRP	National Cooperative Highway Research Program
NEPA	National Environmental Policy Act
NCTCOG	North Central Texas Council of Governments
ODOT	Oregon Department of Transportation
NO_x	Oxides of Nitrogen
PHEVs	Plug-in Hybrid Electric Vehicles
PMC	Project Monitoring Committee
PM	Particulate Matter
PSRC	Puget Sound Regional Council
RGGI	Regional Greenhouse Gas Initiative
RFS	Renewable Fuel Standard
RDD&D	Research, Development, Demonstration, and Deployment
SA-BC	San Antonio – Bexar County
SLAMM	Sea Level Rise Affecting Marshes Model
SHRP 2	Second Strategic Highway Research Program
SOV	Single-Occupancy Vehicle
SCAG	Southern California Association of Governments
SoVi	Social Vulnerability Index
STICS	Spatial Trends in Coastal Socioeconomics
DOTs	State Departments of Transportation
SED	State Energy Data
SIPs	State Implementation Plans
SLRTP	Statewide Long Range Transportation Plan
SO_2	Sulfur Dioxide
TAC	Transportation Advisory Committee
TCAPP	Transportation for Communities-Advancing Projects through Partnerships
TCC	Technical Coordinating Committee
TCEQ	Texas Commission on Environmental Quality
TDM	Travel Demand Model
TIF	Tax Increment Financing
TOD	Transit-Oriented Development

TPAs	Transportation Planning Areas
TPP	Transportation Planning and Programming
TRB	Transportation Research Board
TRM	Triangle Regional Model
TWG	Texas Working Group
TxDOT	Texas Department of Transportation
VMT	Vehicle Miles Traveled

EXECUTIVE SUMMARY

The transportation sector is a major contributor to greenhouse gas (GHG) emissions in the U.S., and Texas contributes the highest GHG emissions among states in the country. While transportation agencies are not currently facing any federal-level regulations regarding transportation GHG emissions, there are indications that the federal government is making strides toward incorporating transportation GHG considerations into long-range transportation planning and climate mitigation policies. Also, many state governments and transportation agencies in the U.S. are moving toward tackling the issue of GHG emissions on a voluntary or state-level policy basis.

Many state transportation agencies are working to incorporate GHG reduction measures into their long-range planning (LRTP) process. The Metropolitan Transportation Plan (MTP) is an important vehicle for integrating GHG emissions reduction measures during this process for addressing GHG reductions from a long-term perspective. Many state agencies are also working with Metropolitan Planning Organizations (MPOs) to incorporate GHG mitigation strategies into their long-range planning process.

As federal and state governments move forward to address GHG emissions in long-range planning, there is the potential for the Texas Department of Transportation (TxDOT) and the Texas MPOs to do the same. Therefore, it is important to develop specific guidance and a framework to link GHG emissions mitigation strategies with the long-range transportation plans in the Texas context. This research project developed a mitigation-focused framework to link GHG emissions mitigation strategies with long-range transportation plans. The intent of the framework was to be flexible, practical, and equip Texas transportation practitioners with tools needed to address GHG emissions in the LRTP process. The framework can be used to supplement federal-level guidance or policy, or serve as a starting point for TxDOT and its partner agencies in the absence of federal guidance on the subject of transportation GHG emissions reductions.

As part of this project, the research team first conducted surveys and interviews with various MPOs and state departments of transportation (DOTs) in Texas and throughout the country to develop an understanding of incorporating GHG emissions mitigation strategies into long-range planning. The knowledge obtained from the surveys of transportation practitioners and a review of published literature was used to develop an approach and framework customized to TxDOT's specific needs.

The framework is structured to help guide MPOs on how to best implement control strategies and performance measures into their long-range planning process to reduce GHG emissions. The developed framework consists of six steps for MPOs to implement GHG emissions strategies into their long-range planning process so that planners can simultaneously develop control strategies, inventory processes, and performance measures for reducing or measuring GHG emissions as they develop their MTP. The framework's six-step process was identified as an effective means of integrating GHG emissions into the transportation planning process and is consistent with a GHG planning framework developed by the Federal Highway Administration. The framework developed in this research, however, is more detailed with a three-phase approach and step-by-step guidance geared towards TxDOT and its partner agencies. Each step has a detailed graphic noting key processes, opportunities for integration into the planning process, possible challenges and solutions, and relevant stakeholders. This framework provides practitioners in Texas with guidance on GHG mitigation strategies as they develop their long-range planning documents. It can also form the basis for workshops and training to prepare TxDOT and Texas MPOs for addressing GHG emissions either on a voluntary basis or to address future federal regulations.

CHAPTER 1:
INTRODUCTION

SIGNIFICANCE

The transportation sector is the second biggest contributor to greenhouse gas emissions in U.S. (*1*) and Texas contributes the highest GHG emissions among states in the country. Many states have implemented policies and programs targeting GHG emissions reductions through climate action plans and other initiatives, which cover a range of sectors including transportation. Some states are working to incorporate GHG reductions measures into their long-range transportation planning process, and several MPOs are also incorporating GHG mitigation strategies into their MTP. At the federal level, while there are currently no policies specifically affecting transportation GHG emissions, such regulations are expected in the future. The Obama Administration has made GHG emission reductions and climate change policy a second term priority, and federal-level actions in this regard are forthcoming. As the federal and state governments move forward to address GHG emissions in the transportation sector, specifically in long-range planning, TxDOT and the Texas MPOs will need guidance to address these topics in the Texas context.

RESEARCH GOALS AND SCOPE

This research project developed a framework to link GHG emissions mitigation strategies with long-range transportation plans. The intent of the framework was to be flexible, practical, and equip Texas transportation practitioners with tools needed to address GHG emissions in the long-range transportation planning process. The framework can be used to supplement federal-level guidance or policy, or serve as a starting point for TxDOT and its partner agencies in the absence of federal guidance on the subject of transportation GHG emissions reductions.

The MTP is an important vehicle for integrating GHG emissions reduction measures during the long-range planning process for addressing GHG reductions from a long-term perspective. This research equipped TxDOT and its partner agencies with necessary tools and guidance to incorporate GHG emissions into the state's LRTP process, specifically in MTPs produced by MPOs. The research efforts addressed the following goals:

- Develop a framework that TxDOT and TxDOT's partner agencies can incorporate GHG emissions into the LRTP process.
- Provide detailed practical information regarding GHG control strategies that can be incorporated in the MTP s developed by Texas MPOs.
- Develop performance measures that Texas MPOs could use to measure the selected control strategies.
- Provide practical information regarding enhanced methodologies, and inventory and evaluation tools, which can be used to quantify the effectiveness of the GHG control strategies.

In terms of study scope, given the focus on LRTP, this project is primarily concerned with GHG emissions reduction (i.e., mitigation of GHG emissions) from on-road mobile sources. This represents the majority of emissions from the transportation sector and this is also the primary element within the general sphere of TxDOT's control and influence. Also, carbon dioxide (CO_2), as the most common transportation GHG is the focus of this research, and the two terms used interchangeably in this report. While climate adaptation is also an aspect that is addressed by transportation agencies, this was not explicitly addressed in the study, except where relevant within the long-range transportation planning cycle.

RESEARCH TASKS AND APPROACH

As part of this project, the research team conducted a comprehensive state-of-practice assessment and also examined various existing frameworks linking transportation planning and emission mitigation strategies, in order to develop a specific framework suitable for TxDOT and its partner agencies. The tasks conducted as part of this research project are listed below:

- Conduct and extensive literature synthesis and develop an understanding of the subject.
- Use a survey-based approach to develop a further understanding of TxDOT's practices and the practices of other agencies that are currently incorporating GHG considerations into their LRTP process.
- Identify strategies and performance measures for TxDOT and its partner agencies to include in the LRTPs.

- Identify evaluation methodologies and inventory processes of relevance to apply in the LRTP process.
- Develop a finalized framework, guidance, and recommendations for TxDOT after conducting a case study analysis.

In order to develop a thorough understanding of incorporating GHG emission reduction into long-range planning, the research team first conducted surveys and interviews with various MPOs and DOTs throughout Texas and the country. The knowledge obtained from the surveys of transportation practitioners and a review of published literature was used to develop an approach and framework customized to TxDOT's specific needs. Interviews were conducted with one DOT and five MPOs that are incorporating GHG emissions inventory procedures and control strategies into the MTPs. Selected staff from Texas MPOs (Houston Galveston Area Council [HGAC], Capital Area MPO [CAMPO], North Central Texas Council of Governments [NCTCOG], and Corpus Christi MPO) were also interviewed. The research team also identified states similar to Texas from a socio-political standpoint, and interviewed three MPOs within these states (Georgia, Tennessee, and Oregon) to complement the findings.

REPORT OUTLINE

This final report provides a review of the project's final findings. Chapter 2 outlines the state of the practice based on survey responses, interviews with transportation practitioners, and a literature review. Chapter 3 provides context and description of the framework developed for TxDOT and MPOs. Chapter 4 describes the case study evaluating the control strategies recommended for the implementation of the framework. The final chapter offers concluding remarks and describes a possible implementation plan.

CHAPTER 2:
BACKGROUND AND STATE-OF-PRACTICE

The research team reviewed available literature and conducted a state-of-practice assessment on topics related to integration of GHG emissions into transportation planning. Frameworks established by other states for GHG emissions in the transportation were investigated, and the research team studied how transportation agencies in Texas and elsewhere incorporate GHG emissions into their transportation planning activities (including reviews of mitigation strategies, inventory methods, and performance measures). The findings from the state-of-practice assessment described in this chapter are based on the following activities conducted by the research team:

- ***Literature synthesis***: Published literature and other sources were reviewed for background information relating to GHG emissions and transportation. Transportation planning documents available online from state DOTs and MPOs were reviewed and summarized to report relevant findings concerning GHG procedures and regulations. After an extensive review of procedures being adopted by MPOs and DOTs in the country, researchers focused on several MPOs and DOTs that appeared to be quite aggressive in terms of incorporating GHG considerations in their LRTP processes. As part of this effort, both LRTPs and related documents for integration of climate change were studied. Federal regulations and statutes that govern transportation planning were also reviewed.
- ***Survey of transportation practitioners outside Texas***: Interviews were conducted with one DOT and five MPOs that are already incorporating GHG emissions inventory procedures and/or control strategies into their LRTPs. The survey questions were designed to discuss experiences, barriers and solutions, and typical GHG inventory development and control strategy evaluation approaches. Based on the results of the survey, trends across agencies' experiences with GHG incorporation into the LRTP were identified.
- ***Survey of transportation practitioners in Texas***: Based on the information obtained from the literature synthesis, selected staff from Texas MPOs (HGAC, CAMPO, NCTCOG, and Corpus Christi MPO) were interviewed. The survey was designed to gain a better understanding from Texas practitioners about current practices, concerns, and ideas

regarding the incorporation of GHG emission into LRTPs. Further, the research team identified states similar to Texas from a socio-political standpoint, and interviewed three MPOs within these states (Georgia, Oregon, and Tennessee). This last set of surveys was undertaken to complement the information provided by the Texas MPOs.

The remainder of this chapter describes the findings from the literature synthesis and practitioner interviews.

GHG EMISSIONS AND TRANSPORTATION

GHGs exist naturally in the atmosphere and help maintain the global temperature suitable for life. However, the concentrations of these gases have increased beyond natural amounts due to human activities such as burning fossil fuels, which releases large amounts of CO_2, the predominant GHG emitted by human sources. In fact, according to the Environmental Protection Agency EPA (*2*), CO_2 represents approximately 83 percent of total GHG emissions in the U.S. Because the largest source of CO_2, and of overall GHG emissions, is fossil fuel combustion, the transportation sector is a major source of GHG emissions. Transportation activities accounted for 27 percent of GHG emissions in the U.S. in 2009, which represents an increase of 16 percent since 1990. Based on historic data, it is expected that the contribution of transportation to GHG emissions will increase in the coming years. For this research project, as explained previously, GHG emissions are considered synonymous with CO_2 emissions as the pollutant is a major source of GHG emissions for the transportation sector. However, transportation also results in other GHG emissions such as methane, black carbon, etc. but none of these are at the scale and magnitude of CO_2 emissions associated with transportation (*2*). There are currently no U.S. national regulations on GHG emissions from transportation activities, but several state DOTs and MPOs are beginning to implement or consider GHG emissions control strategies in their MTPs. In particular, many transportation agencies are taking a more active role in developing inventories of transportation-related GHG emissions and evaluating GHG mitigation strategies. These strategies include switching to alternative fuels, using more fuel efficient vehicles, and reducing the total number of motorized vehicle miles driven.

Within the U.S., Texas is estimated to produce more GHG emissions than any other state. In fact, if Texas were a separate nation, it would rank seventh in the world in GHG emissions. Further, according to the Texas State Demographer, the state population is projected to grow at about twice the U.S. rate. This significant projected growth in the Texas population is likely to result in the continued increase in total motorized vehicle miles traveled (VMT) and overall freight transportation.

FEDERAL AND STATE REGULATIONS

The federal government and several states have begun to take steps to address GHG emissions. On December 7, 2009, the EPA issued two findings on GHG emissions under the Clean Air Act: first, the "endangerment finding" that noted that GHG emissions are found to be a threat to human health, and secondly, that motor vehicle emissions are a contributor to GHG pollution (*3*).

At the state level, many states have introduced actions and legislation relating to GHG emissions. For example, California's Assembly Bill 32 (Global Warming Solutions Act) and Senate Bill 375 (Regional Targets) (*4*), introduced targets for passenger vehicle emissions, promoted sustainable communities and enhanced MPO transportation planning effort. The California Environmental Protection Agency is required to manage GHG emissions inventory and mandatory reporting and verification of GHG emissions (*5*). Although Texas does not have mandatory GHG reporting and reductions regulations, the Texas Commission on Environmental Quality established an inventory of voluntary actions to reduce CO2 emissions (*6*).

During the initial stages of this research project (prior to some of the stages described above), the research team identified the following possible policy directions with implications for GHG emissions in LRTP at the federal or state level:

- Transportation GHG Performance Standard Incentives – This policy direction would include the establishment of GHG reduction targets and incentives for states the meet their goals such as additional transportation funding.
- Transportation GHG Budget with Penalties – Under this scenario, the federal government would establish maximum levels of allowable GHG emissions from the transportation sector with penalties for non-compliance.
- VMT Performance Standards with Incentives – States and/or MPOs that meet or exceed their VMT reduction goals would receive additional transportation funds.

- Climate Change Action Plan Requirement – This policy would require states and/or MPOs to develop a GHG reduction plan for all transportation sources and other sectors of the economy.
- Interagency Consultation Requirements – This measure would require all stakeholder agencies at the federal, state, and local to be consulted in efforts to reduce GHG emissions of either the state or MPO.
- Requirement for Emissions Reduction Strategy Implementation or Prioritization – This scenario would require implementation of emissions reduction/mitigation strategies or best management practices (BMPs) within LRTPs.
- Project-Level GHG Analysis with Penalties– This measure would require GHG analysis for individual projects or certain types of projects as specified by the National Environmental Policy Act (NEPA).
- Market-based Mechanisms – This includes market-based approaches such as carbon emissions trading and carbon taxes.

Currently there is no federal regulatory requirement for state DOTs and MPOs to reduce GHG emissions from the transportation system. However, federal policy is quickly moving forward to address the implications of climate change and reduce carbon pollution.

- In 2011, President Obama pledged that the federal government will reduce its GHG emissions by 28 percent by 2020.
- In 2013, President Obama noted in his State of the Union and Inauguration Speech that his administration will focus on climate change policy, which environmental groups hope will be regulation on GHG emissions.
- On June 25, 2013, President Obama gave a speech outlining his plan to cut carbon pollution. The Obama Administration will begin working with the EPA to impose mandates on cutting carbon pollution.

Therefore, it is important for MPOs and TxDOT to prepare for the eventuality of federal regulations on reducing carbon and GHG emissions. President Obama outlined the following steps as part of his plan in his Climate Action Plan:

- Deploying clean energy.
- Building a 21st century transportation sector.
- Cutting energy waste in homes, businesses, and factories.

- Reducing other GHG emissions.
- Leading at the federal level (*7*).

Several of the above areas are directly related to the transportation sector. Given that federal regulation on GHG emissions is forthcoming, MPOs and TxDOT can prepare for the regulations by implementing a framework that incorporates GHG emissions in the planning process. This will allow TxDOT and its partner agencies not only to be prepared for the regulations but the emissions mitigation strategies, but also achieve co-benefits from GHG reduction activities. These include potential benefits from congestion mitigation and increased public transportation use, other (criteria pollutant) emissions reductions, addressing energy security goals, and cost savings from energy reduction.

LONG-RANGE TRANSPORTATION PLANNING

Long-range transportation planning plays a fundamental role in the state, region, or community's vision for its future. It includes a comprehensive consideration of possible strategies—an evaluation process that encompasses diverse viewpoints, the collaborative participation of relevant transportation-related agencies and organizations, and open, timely, and meaningful public involvement. LRTP is a "cooperative process designed to foster involvement by all users of the system, such as the business community, community groups, environmental organizations, the traveling public, freight operators, and the general public, through a proactive public participation process conducted by state DOTs, MPOs, and transit operators" (*8*).

LRTP requires developing strategies for operating, managing, maintaining, and financing the area's transportation system aiming at advancing the area's long-term goals. The performance of the system affects public concerns, including air quality, environmental resource consumption, land use, urban growth, economic development, safety, and security (*8*).

According to Federal Highway Administration (FHWA) planning process, transportation planning includes a number of steps shown as below: (*8*)

- Monitoring existing conditions.
- Forecasting future population and employment growth, including assessing projected land uses in the region and identifying major growth corridors.

- Identifying current and projected future transportation problems and needs and analyzing, through detailed planning studies, various transportation improvement strategies to address those needs.
- Developing long-range plans and short-range programs of alternative capital improvement and operational strategies for moving people and goods.
- Estimating the impact of recommended future improvements to the transportation system on environmental features, including air quality.
- Developing a financial plan for securing sufficient revenues to cover the costs of implementing strategies.

CURRENT PLANNING PRACTICE IN TEXAS

The state of Texas has a large and extensive transportation system that serves about 25 million residents over an area that of 268,000 square miles. With over 310,000 miles of public roads, Texas has more roadway miles than any other state, with the closest being California at 171,000 miles (*9*). About 60 percent of Texas' roadway network consists of rural roads. TxDOT is responsible for the maintenance of the existing roadway infrastructure, in addition to working with local entities to plan, construct, and maintain new transportation infrastructure. Texas' transportation systems are integral to the state's economic and functional success, providing accessibility for the daily travel needs of residents and tourists, freight shipments, and commuting trips. While both roadways and public transportation systems are important to providing services for all residents, over 98 percent of Texas commuters use a personal automobile or carpool to get to work (*10*). This high dependence on the automobile and the large number of VMT contribute significantly to traffic delays, air quality issues, and high GHG emissions.

The Texas Statewide Long Range Transportation Plan (SLRTP) does not list policies directly focused on mitigating GHG emissions or adapting to the possible effects of climate change. Currently, planning regulations do incorporate policies that generally align with GHG mitigation, such as efficient management and operation of the transportation system and congestion mitigation. From an adaptation perspective, the plan recognizes inundation considerations as sea levels rise, flooding from storm activity, and temperature increase and extreme precipitation events as climate change effects that may have an impact on the transportation system.

While the state sets overall goals and handles federal funding, and TxDOT's Transportation Planning and Programming (TPP) Division is responsible for travel modeling at most MPOs, regional field planning and project implementations are coordinated by Texas' 25 MPOs. Texas' MPOs vary widely in both the spatial area and population (see Appendix A). Appendix A provides a table outlining Texas MPOs' specific characteristics. Many of the larger MPOs include both major metropolitan centers and smaller adjacent municipalities. Furthermore, the resources available to each MPO in terms of both staff and funding vary greatly across the state. While the largest MPOs (NCTCOG and HGAC) have experienced significant growth in the past decade, many smaller MPOs also have grown by similar, or even higher, rates (for example, Hidalgo County MPO and Laredo MPO). Thus, the 25 MPOs throughout the state of Texas have varying needs and resources, and many large and small MPOs are working to address rapid population growth and other local challenges.

STATE OF THE PRACTICE SURVEY

As noted earlier in the chapter, the research team conducted surveys with transportation practitioners to gain an understanding of the current practices used to reduce GHG emissions during the long-range planning process. The intention of conducting the surveys and literature review was to provide a foundation for the framework the research team developed, and included outlining the key components of the framework such as control strategies, performance measures, and tools for GHG emissions inventories/estimation.

Phone interviews were conducted with staff representatives from several MPOs in Texas and other MPOs in states that were deemed similar to Texas (from a socio-political structure standpoint). The results from the survey of MPOs outside of Texas can be found in the Appendix B. The focus of those interviews was to understand the concerns and current practices regarding the incorporation of GHG emissions into the long-range transportation planning process. As mentioned previously, the selected Texas MPOs interviewed were CAMPO, HGAC, NCTCOG, and the Corpus Christi MPO. Although currently there are no explicit GHG reduction targets, all MPOs agreed that GHG emissions should be incorporated into the LRTP, recognizing that GHG emissions are an issue that directly relates to transportation.

HGAC and NCTCOG, which represent Texas' larger urban areas are in air quality non-attainment for ozone, already have several GHG emissions reduction initiatives in their LRTP. HGAC, which is the largest MPO in Texas, is beginning to incorporate GHGs along with its air quality evaluation plans, and the next LRTP is expected specially to address GHG emissions. NCTCOG's most recent LRTP addresses GHG emissions using broad policy language regarding energy efficiency and the environment. General air quality conformity efforts at the MPO also reduce GHGs.

Both the medium-sized MPOs interviewed (CAMPO and Corpus Christi) are near non-attainment for ozone, and their efforts to reduce ozone, which is already incorporated in the LRTP, can be linked to GHG emissions control. In this context, Corpus Christi MPO has begun to quantify point and mobile sources of pollutants tied with ozone emissions. Moving beyond air quality requirements, CAMPO is actively proposing to quantify GHG emissions. In fact, the City of Austin is particularly interested in GHG mitigation and has been at the forefront of efforts to incorporate GHGs into the planning process.

In addition to the interviews, a broader review of practices and plans for other Texas MPOs was also conducted. Several MPOs have begun to address GHG emissions in their overall goals and LRTPs. While no MPO in Texas has completed a Climate Change Action Plan, many MPOs are in the early stages of incorporating GHG reduction goals into their planning visions, and several MPOs have incorporated the GHG mitigation strategies described in their LRTPs. The findings are discussed further in the adaptation and mitigation strategies section.

GHG Mitigation and Adaptation Strategies

Mitigation Strategies

During the state of the practice assessment researchers reviewed the GHG mitigation strategies included in the LRTPs of MPOs in the U.S. including recent LRTPs developed by MPOs who have expressly identified mitigation strategies aimed at reducing GHG emissions. Mitigation or control strategies are an important component incorporated into LRTPs or MTPs by MPOS to reduce GHG emissions. Mitigation/control strategies' main goal does not have to be to reduce GHG emissions exclusively but can also work to meet other goals of the long-range planning process such as VMT reductions, modal split shift, infrastructure improvements, management and operation improvements, and vehicle fuel efficiency improvements.

Table 1 provides an overview of the types of strategies included in selected Texas MPOs' plans (broadly categorized to describe the main intent/applicability of the strategy). Appendix C provides a summary of the findings from a survey of various LRTPs regarding mitigation strategies for specific regions around the country. The various mitigation strategies are not mutually exclusive, and some strategies may potentially fall into multiple categories. For example, improving transit service directly aims to cause a shift in the modal split, but may also lead to a reduction in VMT. Furthermore, various education and outreach efforts are tied to each of these categories, as MPOs inform the public of the numerous ways to reduce GHG emissions and the benefits of reduction efforts, such as improved health and air quality. Thus, each strategy may not exclusively contribute to one category of GHG emissions reduction, though it usually aims to target one of these areas directly.

Table 2 shows the various mitigation categories that are included in several non-Texas MPOs' long-range planning documents. In comparing Table 1, it is seen that similar to the strategies used by non-Texas MPOs, VMT reduction and modal split shift are the most common strategies even among Texas MPOs.

Table 1. Texas' MPOs Mitigation Strategies.

MPO	VMT Reduction	Mode Split Shift	Infrastructure	Management & Operations	ITS	Vehicle Fuel Efficiency	Alternative Fuels	Freight & Aviation
Bryan - College Station (BCS) MPO	X	X		X				
Capital Area MPO (CAMPO)	X	X		X	X	X	X	X
Corpus Christi MPO	X	X		X		X	X	X
Houston - Galveston Area Council (HGAC)	X	X	X	X	X			
Longview MPO	X	X		X				
Midland - Odessa Transportation Organization (MOTOR)	X	X			X		X	
North Central Texas Council of Governments (NCTCOG)	X	X						
San Antonio - Bexar County (SA-BC) MPO	X	X		X	X			
Wichita Falls MPO	X	X						

Table 2. Mitigation Strategies for GHG Emissions in LRTP Documents – Non-Texas MPOs.

MPO	State	VMT Reduction	Mode Split Shift	Infrastructure	Management & Operation	ITS	Vehicle Fuel Efficiency	Alternative Fuels	Freight & Aviation
Sacramento Area COG (SACOG)	CA	X	X		X				
Southern California Association of Governments (SCAG)	CA	X	X			X	X		
Denver Regional COG (DRCOG)	CO	X	X				X		
Housatonic Valley Council of Elected Officials	CT	X	X	X	X		X	X	
State of Connecticut	CT	X	X		X	X	X	X	
Miami-Dade County MPO	FL	X	X		X	X	X	X	X
Boston Region MPO	MA	X	X		X	X	X		X
Cape Cod Commission	MA	X	X		X	X			
Metropolitan Washington COG (Washington, DC)	MD	X	X		X	X			X
State of Maryland	MD	X	X				X	X	
Tri County RPC	MI	X	X					X	
Durham-Chapel Hill-Carrboro MPO	NC	X	X		X	X			
Tahoe RPO	NV	X	X					X	
Binghamton Metropolitan Transportation Study	NY	X	X			X			
Ithaca-Tompkins County Transportation Council	NY	X	X			X			
Lane COG	OR	X	X		X				
Puget Sound Regional Council (PCRC)	WA	X	X			X	X		

Adaptation Strategies

As discussed previously, the project's framework focuses on GHG mitigation strategies. However, adaptation is also an important component of GHG emissions planning. Adaptation measures such as improving infrastructure will reduce vulnerability of the transportation system to future climate change effects. A similar framework could also encourage or enforce implementation that focuses on adaptation issues, thereby complementing the current planning efforts on reducing GHG emissions during the long-range planning process. Therefore, due to the complementary planning efforts of adaptation and mitigation strategies, the research team also reviewed MPOs' adaptation plans.

Adaptation strategies can be defined as a general plan of action for addressing the impacts of climate change, including climate variability and extremes (*11*). Adaptation strategies decrease a transportation system's vulnerability (or increase its resilience) to severe weather change impacts. In certain circumstances, national-level strategies are required, which involve all the regions and vulnerable population groups, while, in other scenarios, the adaptation strategies may be focused on just one or two sectors or regions. Adaptation strategies are discussed in further detail in Appendix D, which includes focus areas for creating an adaptation plan and adaptation strategies in LRTPs and includes adaptation strategies from various MPOs in the country such as:

- Puget Sound Regional Council (PSRC), WA.
- Southern California Association of Governments (SCAG), CA.
- Roanoke Valley Area MPO, VA.
- South Western Region MPO, CT.
- Houston-Galveston Area Council (H-GAC), TX.
- Broward MPO, FL.

Texas MPOs – Implementation of Mitigation and Adaptation Strategies

The findings from the interviews revealed that Texas MPOs have not yet developed or analyzed strategies explicitly to reduce GHG emissions. Although there are no GHG-specific strategies mentioned in any of the LRTPs, the MPOs are considering many promising strategies. Among these strategies, local transportation improvements seem to be the most accepted policy, because it not only helps to reduce GHG emissions, but also reduces congestion and is relatively easy to implement. Strategies associated with air quality programs that decrease ozone and air toxics (such as a clean vehicles program, congestion mitigation, intersection improvements, working with ports to reduce diesel truck idling, and projects to electrify vehicles) are also identified by the MPOs as promising strategies to reduce GHG emissions.

The level of concern regarding potential threats that climate change poses to transportation systems is a function of MPO location and resources. The small MPOs (Corpus Christi MPO, which is located at the highest elevation along the Gulf of Mexico, and CAMPO, which is located inland) anticipate no effects from sea level changes or other climate change effects. However, the Corpus Christi MPO is looking at emergency evacuation preparations for tidal surges and hurricanes. The large MPOs, although they do not explicitly refer to the effects of climate change in their LRTP, include measures that can be considered as adaptation strategies. NCTCOG addresses in its most recent LRTP evacuation route planning, relocation of at-risk infrastructure and communities, and the impacts of potential extreme weather events on transportation infrastructure. Similarly, HGAC includes in its LRTP exposure to storm surges and emergency management. In particular, HGAC freeway design has been modified to handle contra-flow in the case of an emergency evacuation.

QUANTIFICATION AND REPORTING OF GHG EMISSIONS

A GHG emissions inventory is an accounting of the amount of GHGs emitted to or removed from the atmosphere over a specific period of time. GHG inventories provide useful information regarding emission trends over time, which can help to develop strategies to manage and reduce GHG emissions, to identify the main sources of GHGs, to quantify the benefits of mitigation strategies, and to set goals and targets for future reductions. Many transportation agencies currently attempting to quantify GHG emissions are taking different approaches, commensurate with their levels of resources and expertise in the area.

Currently, the Texas Commission on Environmental Quality (TCEQ) is required by the Texas Legislature to manage an inventory of voluntary actions by businesses and organizations within the state implemented to reduce GHG emissions. TCEQ has acknowledged that the inventory may be used in the future for credit from EPA for early actions the state has taken in case federal government imposes regulations relating to GHG emissions.

Any transportation planning framework to address GHG emissions reductions will require an emissions inventory component to establish a baseline in addition to methods to evaluate/quantify the amount of GHG emissions reduced and the effectiveness of the control strategies implemented. As discussed previously, CO_2 is by far the most significant GHG emitted by transportation sources, and in most practical applications, calculating the GHG emissions from transportation is based on estimating CO_2 emissions. Estimating CO_2 emissions can potentially be quite complex, since vehicle fuel consumption depends on a variety of factors, including vehicle type, model year, and fuel type; vehicle operating characteristics, such as speeds and accelerations; and vehicle maintenance, tire pressure, and other factors.

There are two approaches to develop GHG inventories: "top-down" and "bottom-up" (*12*). The top-down GHG inventory approach leverages existing institutional data at an aggregated level, basing its estimates on historical relationships. The bottom-up GHG inventory approach utilizes detailed site-specific data, compiling statistics or estimates from local or regional information.

Transportation agencies in the U.S. (MPOs and DOTs) that are working to quantify emissions are taking various analytic approaches, commensurate with their levels of resources and expertise in the area. MPOs reviewed for the research project that have created an inventory of GHG emissions only have information for the baseline year. However, some cities in the country have maintained their inventories for a number of periods (for example, the City of New York has developed GHG inventories for different economic sectors, including transportation, for years 2006 and 2010 [*13*]). Overall, the development of regional GHG inventories in the transportation sector is relatively new, and there are limitations in the ability of existing methods to estimate and forecast the emissions generated by transportation systems. Using the bottom-up approach to estimate GHG emissions with even a moderate level of accuracy and detail requires inputs including VMT, fleet composition, and average vehicle speeds.

Based on the review of over 50 planning documents and state Climate Action Plans (CAPs), it is seen that states, rather than MPOs, usually are the organizations responsible for developing inventories. In fact, a majority of states have developed statewide GHG inventories as a reporting tool to track annual emissions and inform policy development. However, statewide inventories do not report emissions at the MPO regional level, and therefore are of limited use for transportation planning activities that are usually undertaken by MPOs. Also, since the creation of a new network-based travel demand model (TDM) to forecast VMT at the state-level is not always feasible, particularly for large states such as Texas, MPOs are generally better positioned than DOTs to develop regional GHG inventories.

Evaluation Tools

There are a number of different tools for estimating GHG emissions and evaluating the possible effectiveness of mitigation strategies. This section provides a brief overview of the most commonly used tools and their associated implementations.

- **MOBILE6** (*14*): The MOBILE6 emissions factor model was released by the U.S. EPA in 2001. It estimates emissions rates of hydrocarbon (HC), carbon monoxide (CO), oxides of nitrogen (NOX), sulfur dioxide (SO_2), ammonia (NH_3), carbon dioxide (CO_2), hazardous air pollutants (HAP), and various types of particulate matter for a region. MOBILE6 outputs the rates of emissions of these pollutants per mile traveled. The model is available for free download at the EPA's website. MOBILE6 has been replaced by MOVES as the EPA's official model for estimating emissions from cars, trucks, and motorcycles.
- **MOVES** (*15*): MOVES2010b (for Motor Vehicle Emissions Simulator) is the EPA's latest emissions model. It calculates both emissions rates per mile as well as overall tons of emissions, including CO_2 equivalent. MOVES is more aligned with the Highway Performance Monitoring System (HPMS) vehicle type classifications than MOBILE6, and has reduced the number of vehicle types from 28 to 13. As described in more detail below, MOVES is a flexible model and is able to work at a variety of geographic and temporal scales.
- **EMFAC** (*16*): The EMFAC (for Emissions Factor) model has been developed by the California Air Resources Board. The 2007 version of the model has been approved for use in conformity analysis by the EPA. EMFAC calculates emissions factors and inventories for HC, CO, NOx, SO_2, CO_2, and particulate matter (PM). The software is specifically developed for California and is pre-loaded with California data parameters. It outputs both emissions rates and total emissions in tons. It can be used for air quality analysis at the project level.

- **GreenSTEP** (*17*): The GreenSTEP (for Greenhouse Gas Statewide Transportation Emissions Planning) model has been designed for scenario planning by the Oregon Department of Transportation (ODOT). The model includes not only emissions, but also other travel-related outputs such as household vehicle travel and walk trips, household spending on vehicle travel, and road tax revenues. However, GreenSTEP was originally designed as a tool for GHG reductions, and outputs tons of CO_2 equivalents to the emissions portion of its output. It is generally used internally by ODOT and Oregon-based transportation researchers.

Among the available methods, EPA's MOVES2010 software provides significant improvements over previous emissions models for the estimation of GHG emissions. Additionally, MOVES is currently used for Texas's State Implementation Plans (SIPs) and many areas' conformity analysis. Specifically, we will assess its application feasibility in Texas, investigating data needs, and the potential use of TDM outputs for scenario analysis and/or future GHG reduction effectiveness evaluation. MOVES data needs include VMT, vehicle speed distribution, fleet composition, fuel supply, roadway functional class, and metrology data.

Developing Inventories and Evaluating GHG Mitigation Strategies

This section focuses on the development of a GHG inventories and estimates in the context of Texas MPOs. At the metropolitan level, TDMs are inextricably linked to the transportation planning process. MPOs often utilize a TDM to assess the effectiveness of possible traffic control, operational strategies, and transportation demand management strategies and actions in response to public policy mandates, and to communicate the model results to policymakers and the public at large. Further, these modeling tools are used to demonstrate transportation projections relating to plan and updates. They are also used by MPOs, especially those in non-attainment of the National Ambient Air Quality Standards (NAAQs), to estimate mobile emissions and to develop appropriate reduction measures.

Texas has a total of 25 MPOs. Each of the Texas MPOs uses a TDM for the development and evaluation of its transportation plans. TxDOT's Transportation Planning and Programming Division (TxDOT-TPP) provides TDM development support to 23 MPOs in the state. NCTCOG and the H-GAC are responsible for the Dallas-Fort Worth and Houston regions, respectively.

Evaluating GHG Emissions Reductions Using TDM

The TDM serves as an ideal tool to evaluate, under alternative scenarios for the plan horizon year, the changes in travel patterns and VMT. As mentioned previously, MPOs are reasonably well-positioned to estimate potential GHG emissions reductions due to transportation control measures. Figure 1 provides a high level framework for such purpose. In this figure, MPOs currently use all the tools in the blue boxes for undertaking the transportation planning process for their region. In this regard, developing a GHG inventory and evaluating a GHG reduction strategy is very similar to developing a travel inventory and evaluating any other transportation policy. To estimate the effects of GHG reduction policies, the TDM has to be run for two scenarios—for the base case and the policy case scenario—to obtain VMT as an output from the traffic assignment step. This VMT, once disaggregated by vehicle type, is a direct indicator of a change in GHG emissions: as passenger vehicle travel miles increase, in general, GHG emissions also increase. To quantify a GHG emissions reduction, the TDM output has to be now routed into the emissions model. For MPOs with a mode split step, an analysis of the mode share shift toward non-motorized modes can also be considered and can contribute to GHG emissions reduction.

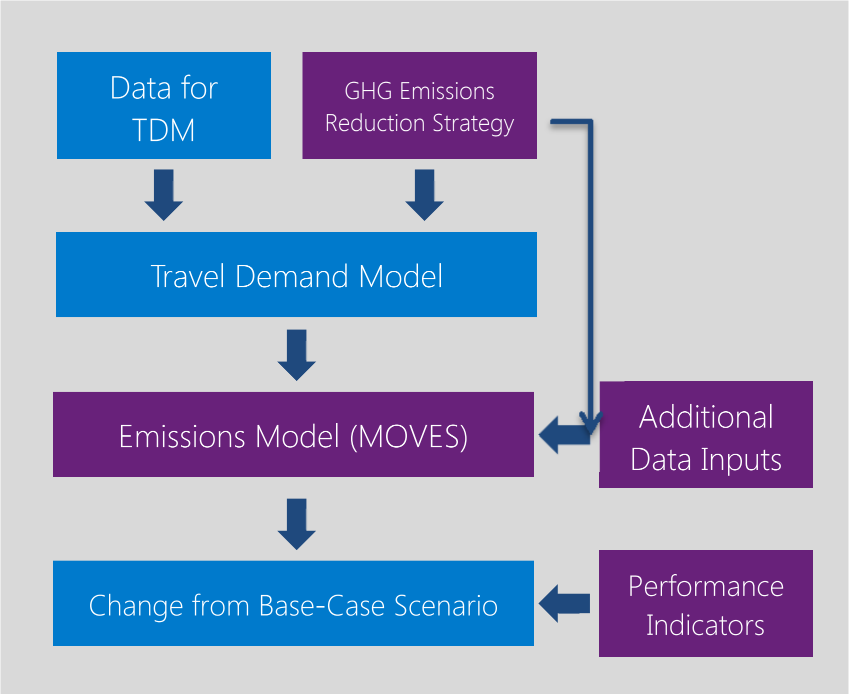


Figure 1. GHG Emissions Inventory Development and Reduction Evaluation Framework.

To estimate GHG emissions, the process begins with the MPO preparing relevant data to be fed in as the TDM input. This includes demographic data (such as population, household size, and car ownership) and road network data (such as link capacity and free flow speeds) for the study area. Additionally, if the MPO is using the framework for GHG reduction evaluation, it also needs to consider a set of carefully structured strategies that have the potential for mobile source GHG emissions reduction benefits. For this purpose, Texas MPOs can choose among the control strategies identified in the following section, which comprise pricing strategies, land use and smart growth strategies/non-motorized strategies, public transportation strategies, HOV/carpool/vanpool/commute strategies, system operations and management strategies, and multimodal freight strategies. Thus, for example, consider the GHG control strategy of *bicycle improvements*. Assume that improving the bicycle system will incentivize individuals to undertake more bicycle trips or increase the miles traveled by bicycles. As a result, the number of vehicle trips will decline. Then, this GHG control strategy can be incorporated into the TDM as a decrease of vehicle-trip production rates. Similarly, *signal control management* and *active traffic managemen*t can have the effect of increasing speeds or/and increasing the network capacity.

Typically, the TDM will predict VMT, vehicle trips, and average speed, among other variables, for the base year for which GHG inventory is to be developed and for alternative GHG reduction policy scenarios. These outputs have to be translated into actual GHG emission reductions using the emission model MOVES. Finally, MOVES outputs can be used to develop base year inventories, and this can be compared with alternative policy scenarios to evaluate the GHG reduction benefits. In order to undertake this comparison, the MPOs need to develop performance indicators. Performance indicators are metrics that quantify the performance of different strategies. They serve as relatively simple (to articulate) metrics of the effectiveness of alternative policies.

Off-Model Tools

Despite the benefits and versatility of the TDM to develop GHG inventories and/or evaluate GHG control strategies would need interface tools to translate TDM outputs into a form easily fed into the MOVES model. Creating customized TDM runs for multiple scenarios and strategies can also be time consuming and resource intensive. While this would appear to be a valuable investment, in the short term, an alternative is to develop quick-response off-model tools to develop GHG inventory and evaluate GHG emissions mitigation strategies. These tools take as input an aggregated version of the base scenario travel inventory from the TDM to estimate GHG inventory, as well as adjust the aggregate travel inventory in response to GHG mitgation strategies to estimate GHG reductions. The off-model tools can be broadly divided into two types: spreadsheet-based tools and sketch planning tools (*18*).

Spreadsheet tools are manual methods for estimating GHG emissions inventories, changes in travel demand, VMT, and GHG emissions in response to mitigation strategies. In particular, a variety of spreadsheet tools have been developed to forecast changes in VMT by applying appropriate elasticities to the four-step model outputs. An example is the *VMT Spreadsheet with 4D Smart Growth Adjustments*. The 4D stands for development density, diversity, design, and destination patterns that affect the VMT of a region. This tool can be used to compare travel demand for a policy scenario with a business-as-usual scenario. However, this tool is based on data from national surveys, may require extensive calibration to local conditions, and may not be directly transferable.

The second class of tools—the sketch planning tools—are primarily land uses planning tools that incorporate the TDM output data to estimate GHG emissions and assess impacts of various land use scenarios. They use geographic information system (GIS) data to visually display GHG inventories and the scenario effects. Examples include UBERMIS, IPLACE^{3}S, and INDEX. These tools also need to be calibrated for each metropolitan area.

ASSESSMENT AND SELECTION OF GHG MITIGATION STRATEGIES

Common GHG Mitigation Strategies in Long-Range Transportation Plans

As seen in the previous section discussion mitigation and adaptation strategies, GHG mitigation strategies vary considerably among MPOs. However, some of these strategies are more commonly included in LRTPs as being specifically for GHG reduction. The research team identified all the mitigation strategies discussed in the LRTP documents and highlighted the most common strategies that appear. Figure 2 shows the most common strategies included in LRTPs and the most common strategies implemented by MPOs (on the *x*-axis), the number of MPOs in the country whose LRTPs contain the strategy (explicitly as a GHG emissions reduction strategy), and the number of MPOs that have implemented the strategy (*y*-axis). Appendix E provides the list of MPOs employing the strategies.

Review of MPOs' long-range planning documents show that the most common GHG control strategies are land use and smart growth strategies/non-motorized strategies. In particular, "bicycle improvements" and "pedestrian improvements" are the most common as well as the most frequently implemented strategies. Almost every MPO aiming to mitigate GHG emissions has incorporated bicycle and pedestrian improvements into their LRTPs. Many MPOs are planning general improvements to bicycling conditions, such as adding bicycle lanes, building bicycle trails, adding bicycle racks to shopping centers, and installing bicycle racks on buses. Additionally, some MPOs are creating bikeshare programs and publishing regional bicycle maps to promote bicycling amongst residents. Improvements to pedestrian conditions are also common and may include adding sidewalks, crosswalks, median refuge islands, pedestrian cut-through paths in cul-de-sacs, and audible cues to pedestrian signals.

Traffic calming measures such as speed humps or chicanes are also being utilized to create a more pedestrian- and bicycle-friendly environment. In contrast to non-motorized mode oriented strategies, "mixed land use" is often included as a GHG reduction strategy in LRTPs, but not implemented very frequently. Mixed land use can reduce VMT through mixed-use development, transit-oriented development (TOD), densification, and smart growth strategies.

Public transportation improvements are also quite common LRTP-listed GHG control strategies. They are even more frequently implemented. A similar situation holds for HOV/carpool/ vanpool/commute strategies (in particular HOV lanes and car sharing) and system operations and management strategies. Pricing and multimodal freight strategies are the least common LRTP-listed GHG control strategies as well as among those that are least likely to be implemented.

MPOs all over the U.S. have varying needs and resources. In particular, small MPOs have fewer resources and less power to set policy precedents than the larger MPOs. To identify possible differences among MPOs in terms of the chosen strategies, the MPOs were categorized as small, medium, or large MPOs. Texas MPOs when implementing the proposed framework can choose strategies that are the commonly used by similar sized MPOs. Figure 3 shows the most common strategies included in LRTPs and the most common strategies implemented by MPOs by MPO size. Several insights can be obtained from this analysis and are briefly discussed below:

- **Small MPOs** (population 50,000 to 200,000), tend to include several GHG mitigation strategies into their LRTPs, but not all these strategies are implemented. In fact, multimodal freight strategies, system operations, and management strategies are mentioned in several LRTPs, but only implemented by one MPO (Ithaca-Tompkins County Transportation Council, New York). In general, land use and smart growth strategies/non-motorized strategies are more likely to be included in LRTPs and implemented by small MPOs.
- **Medium MPOs** (population 200,001 to 1,000,000) seem to divide their efforts among the categories of strategies. Despite the unpopularity of pricing strategies that increase the cost of driving, many medium MPOs have incorporated these GHG-mitigation strategies into their LRTPs. Further, HOV/carpool/vanpool/commute strategies, which require behavioral changes in travelers' daily patterns, have been commonly implemented by medium MPOs.
- **Large MPOs** (population more than 1,000,000) have been consistently implementing more strategies than small and medium MPOs. The figure shows that large MPOs implement more strategies aimed at reducing GHG emissions, although several of these strategies are not explicitly included in the LRTPs for this purpose. In particular, public transportation strategies and system operations and management strategies are mostly implemented by large MPOs for purposes different from GHG emission reductions.

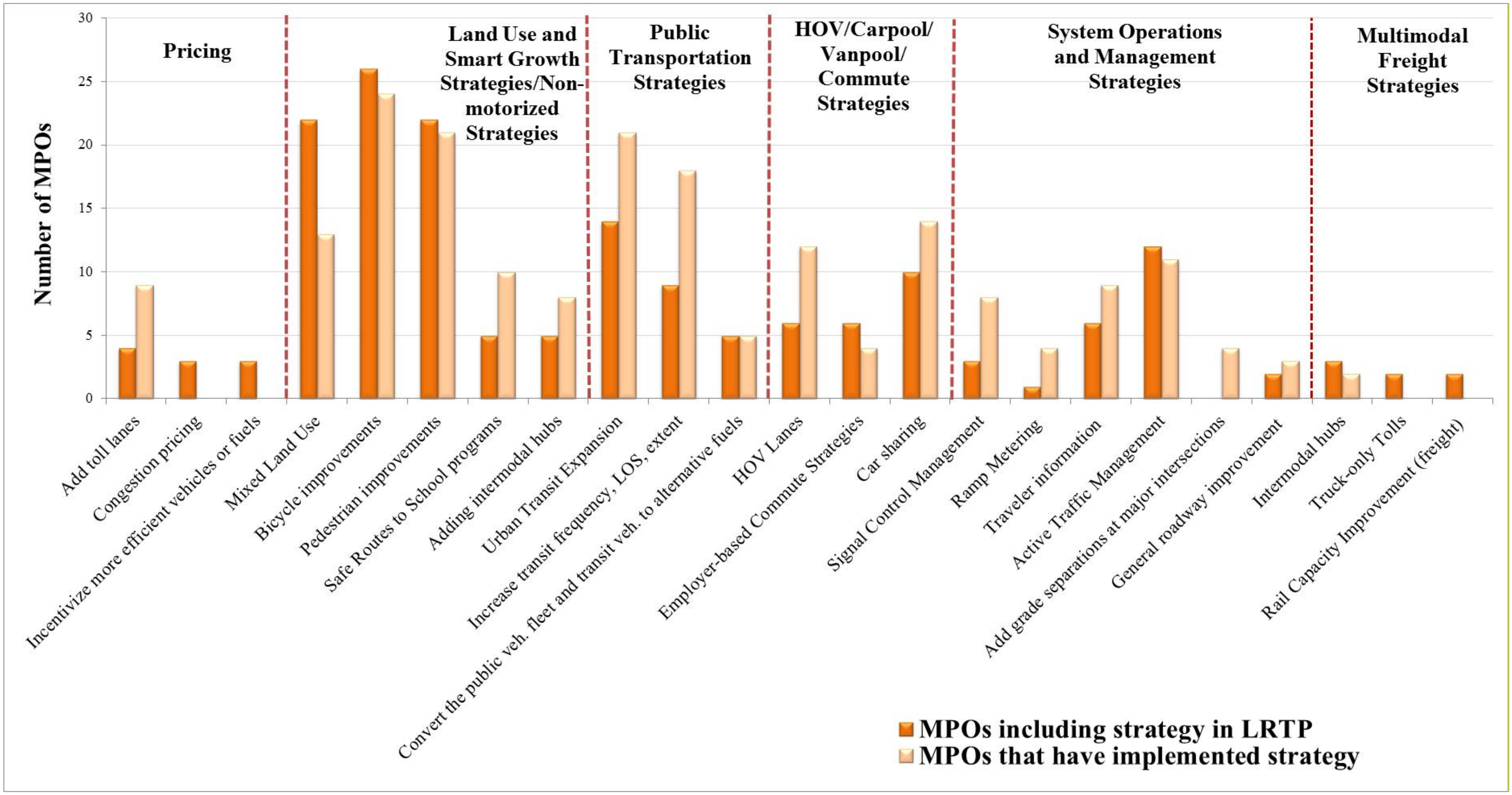


Figure 2. Most Common Mitigation Strategies.

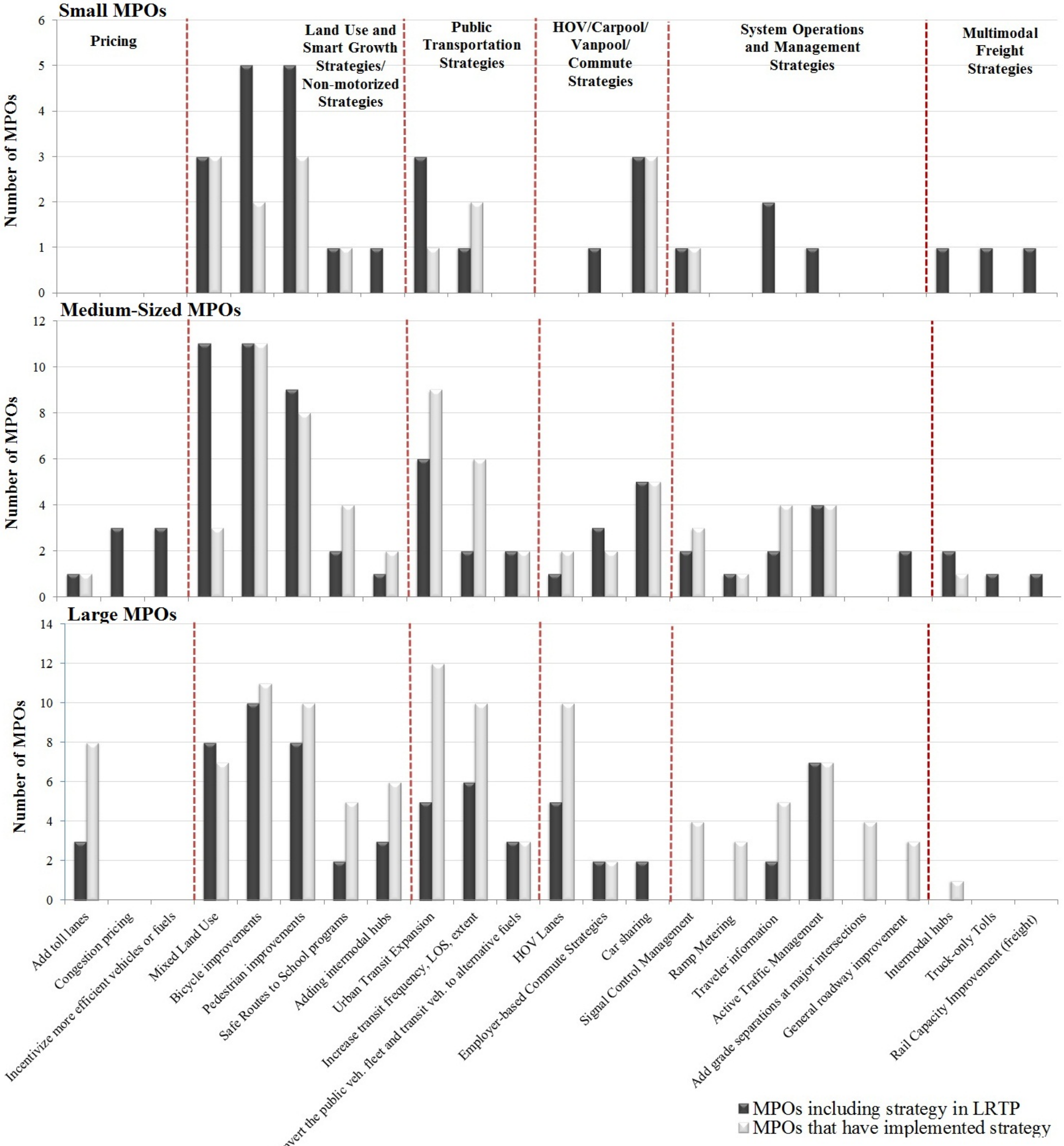


Figure 3. Most Common Mitigation Strategies by MPO Size.

Assessment of Feasibility of Implementation

In order to consistently evaluate strategies, several criteria need to be considered. These criteria include a wide range of economic, social, and political criteria, in addition to the identification of potential synergies and negative effects. MPOs should also be aware that there exists uncertainty in the process of evaluating GHG control strategies. For example, strategies can vary in their degree of effectiveness depending on how they are implemented, the estimates of effectiveness rely upon key economic and behavioral assumptions that are inherently somewhat uncertain, and the effectiveness of strategies varies over time. Therefore, the strategies' temporal scope is an important factor to consider. Mixed land use policies may provide good results in terms of reducing GHG emissions, but since these reductions are likely to be observed only in the long run, they are challenging to implement. MPOs should be aware that GHG mitigation strategies have associated positive impacts (or benefits) and the negative impacts (or challenges). Some general observations relating to the assessment of feasibility of implementing these strategies are provided below:

- Several strategies provide other benefits than GHG emissions reduction. Among these benefits are economic growth (or raising revenue), improvement of access and mobility, congestion reduction, and promotion of public health. The extent to which these synergies will be perceived by the population and the authorities depends on the manner in which they are presented to the public. Consequently, public outreach programs and stakeholder involvement are key instruments to emphasizing the positive effects of GHG control strategies.
- GHG control strategies may also have negative impacts on the transportation system or the metropolitan area in general. These negative impacts include funding requirements, jurisdictional limitations, and equity considerations, among others. In particular, equity considerations also play an important role in strategies' feasibility. A number of strategies can have a negative impact across population groups. For example, pricing strategies can be burdensome for households with low income that rely only on private transportation. Some of these negative impacts are particularly stressful for small MPOs, which may not have adequate resources to implement strategies such as adding toll lanes and expanding the public transportation system. Again, to some extent, the strategies' negative impacts can be overcome by involving the stakeholders in early stages of the planning process.

Feasibility Analysis for Common Strategies

To understand the feasibility and potential effectiveness of GHG control strategies, Table 3 presents an evaluation of the strategies identified in the previous section. In Table 3, the feasibility of each strategy was classified in a three-level scale:

- Feasible (√): strategies that are, in general, easy to include in LRTPs and should not be associated with any major implementation problems.
- Neutral (-): strategies that present no major applicability difficulties.
- Difficult (x): some problems may arise when trying to include the strategy into the planning process.

The strategies' feasibility was analyzed in terms of political constraints (such as political opposition of public unpopularity), legal constraints (related to statutory barriers and limited jurisdiction), and overall ease of implementation (costs and technology requirements). Table 3 shows that some strategies may have some implementation barriers. Politically speaking, pricing strategies are the most difficult to implement because of their public unpopularity. However, pricing strategies can become popular when travelers discover the benefits of the pricing programs in terms of congestion reduction and revenue. The most widely-cited example is the congestion pricing program in London that has become generally accepted by the public and interest groups (*19*). Legal barriers are significant for pricing, mixed land use, and freight strategies, mainly because the MPOs have no jurisdiction to modify current zoning regulations or laws. Regarding overall ease of implementation, those strategies that require funding, advanced technology, involvement of other actors (such as freight companies) and long implementation times, are more difficult to apply.

Table 3. Feasibility of GHG Mitigation Strategies.

Strategies	Strategy Feasibility		
	Political Constraints	Legal Constraints	Ease of Implementation
Pricing			
Add toll lanes	x	x	-
Congestion pricing	x	x	-
Incentivize more efficient vehicles or fuels	x	-	√
Land Use and Smart Growth Strategies/Non-motorized Strategies			
Combined land use	x	x	x
Bicycle improvements	√	√	√
Pedestrian improvements	√	√	√
Safe Routes to School programs	√	√	√
Adding intermodal hubs	x	√	x
Public Transportation Strategies			
Urban Transit Expansion	x	√	x
Increase transit frequency, LOS, extent	x	√	-
Convert the public vehicle fleet and transit vehicles to alternative fuels	-	√	-
HOV/Carpool/Vanpool/Commute Strategies			
HOV Lanes	-	√	-
Employer-based commute strategies	√	√	x
Car sharing	√	√	-
System Operations and Management Strategies			
Signal control management	√	√	x
Ramp metering	-	√	√
Traveler information	√	√	x
Active Traffic Management	√	√	x
Add grade separations at major intersections	x	√	x
General roadway improvement	√	√	√
Multimodal Freight Strategies			
Intermodal hubs	√	x	x
Truck-only tolls	x	√	√
Rail capacity improvement (freight)	√	x	x

ROLE OF PERFORMANCE MEASURES

Performance measures are commonly used by state and local governments to measure the effectiveness of various plans, programs, and for purposes such as internal and external communication. The use of performance measures can indicate strategies that are meeting goals and areas that need improvement. MPOs can identify the areas that they need additional expertise, funding, or resources. While MPOs will directly assess, evaluate, and implement performance measures for the developed framework, TxDOT can also benefit from this measurement approach. The performance measures will show TxDOT which MPOs need further assistance and areas that additional knowledge sharing or resources are needed during the framework implementation. This measurement analysis will provide a valuable tool to ensure that long-term planning goals are met. Also, the recently passed transportation legislation, MAP-21, emphasizes a performance-measurement based approach, increasing its importance in the transportation planning realm.

Performance measures are broadly defined as quantifiable criteria used to track and measure progress toward specific goals or objectives (*20*). Performance measures can help answer questions related to progress toward goals, how well an agency or program is doing compared to its peers, where improvements can be made, and to support decisions regarding the investment in more efficient and effective strategies and solutions.

A performance measurement approach can outline areas to improve efficiency, resource allocation, and communication challenges (*21*). Performance measures are identified as an important part of the long-range transportation planning process (*22*). Furthermore, many Texas MPOs have experience implementing performance measures and have found many benefits to incorporating the process into long-range transportation process. The possible benefits of performance measurement approach:

- Greater accountability about how funds are spent.
- Improved transparency to ensure public involvement and understanding.
- An assessment of "system" performance, rather than individual projects.
- A refocusing of decision making on outcomes (*21*).

In the context of a framework for GHG emissions in transportation planning, performance measures can assist MPOs and TxDOT officials to identify gaps or shortfalls in the control strategies chosen to mitigate GHG emissions, and to see whether progress is being made toward achieving GHG reduction goals. Therefore, performance measures are an important factor in the proposed framework developed to reduce GHG emissions in LRTP. In the context of the framework, performance measures are not only useful in evaluating progress toward set goals and targets, but are applicable for decision-making and management. Performance measures can be a tool to help MPOs decide which control strategies to implement. Performance measures can assess the possible control strategies and measure the economic benefits/deterrents of each strategy and help determine the best strategy.

Types of Performance Measures

There are many different ways of classifying performance measures, based on what the measure is used for, the type of measure, whether in is internal or external an agency implementing it, etc. A commonly-used typology for the classification of performance measures as relevant to public agencies such as DOTs or MPOs is to distinguish between "process" or "input" measures, "output" measures, or "outcome" measures. A process or input measure is one that relates directly to agency activities (for example, investment in a particular program), an output measure, in the transportation context, would be the effect of the transportation system, while an outcome measure would relate to the overall goal (for example, overall emissions reduced).

In general, process, output, and outcome measures can all be identified for the same goal and control strategy. For example, in the case of bike lanes being added to reduce GHG emissions, examples of process, output, and outcome measures are as follows:

- Process Measure – Miles of bike lanes added in a city to support VMT reduction goals.
- Output Measure – Increase in miles traveled by bicycles, increased bicycle trips.
- Outcome Measure – Automobile trips reduced/VMT reduced per year due to added bike facilities. Tons of GHG reduced per year due to added bike facilities.

Applicability to a Transportation Planning/GHG Framework

In the context of a framework for GHG emissions and transportation planning, the outcome/output/process measure classification can be applied as follows:

- The outcome measures considered would either relate to VMT reduced, or GHG emissions reduced. The outcome measures, therefore, can be used to assess progress toward overall goals by considering the overall GHG reduction or VMT reduction benefits of all the actions taken by an MPO or DOT in implementing the framework.

- The measures of effectiveness, in the context of this framework, will refer to output or process measures for individual control strategies, and can help not only in identifying and selecting appropriate measures but in assessing whether individual control strategies are being successfully implemented.

In addition to the basic performance measurement uses described above, there are many other applications for performance measures that relate to the framework as a part of the broader transportation planning process (for example, decision-making, communication, management applications). While these are touched upon in the next section of this report, the focus of the performance measures identified in this research are on measures that specifically support the evaluation of GHG control strategies.

Another aspect of performance measurement that is relevant to this framework is the topic of financial or cost-effectiveness analyses. Often, the cost-effectiveness, or overall cost of implementing a strategy is in itself used as a performance measure, most often for decision making (i.e., selecting control strategies for implementation). The research team recognizes the practical use of cost-effectiveness or other financial data as an implicit or explicit performance measures, but these are not discussed in detail, as the performance measures applicable will be the same for all control strategies.

Implementing a Performance Measurement Process

In general, performance measurement requires data, and in the context of this framework, most of the data will include data obtained from various planning and project functions, such as the number of VMT, availability of walkable streets, or the number of bus routes. The specific data that are collected or available may vary, depending on the region, project, or control strategy. The implementation of performance measures will also include setting of target reduction goals and designing appropriate performance measures. A report from the National Cooperative Highway Research Program (*23*) suggests that agencies using the performance measurement approach should:

- Begin with measures that are easy to implement.
- Have commitment from top-level leadership.

- Have the support of career-level managers.
- Coincide with creation of the performance measurement culture and employee accountability.
- Link measure results with decision making and actions.
- Include widespread responsibility for data collection, management, and analysis.
- Include cyclical reporting, especially to external stakeholders.

Suggested GHG Performance Measures

As discussed earlier, the research team recommends that the output measures used (to evaluate overall progress toward GHG reduction goals) be established as common to all control strategies, and evaluate overall GHG emissions reductions or VMT reductions. However, when it comes to output or process measures, the performance measures will vary depending on the individual programs or control strategies being implemented. This chapter identified popular GHG mitigation strategies and their feasibility in terms political constraints, legal constraints, and ease of implementation. Based on these strategies identified in previous section, the research team identified example performance measures for some of the control strategies identified as being most feasible to implement, as shown in Table 4.

Table 4. Performance Measures for GHG Control Strategies.

Category	Control Mitigation Strategy	Example Performance Measure (Output and Process Measures)
Commute Strategies	Employer-based commute strategies	-Increase in number of options for employees -Percentage of employee participants of organization
	Car sharing	-Change in number of commuters
Land Use and Smart Growth Strategies/Non-motorized Strategies	Bicycle improvements	-Percentage of increase bike lanes -Change in multimodal LOS due to project -Percentage of new riders -Change in street connectivity for bicyclists
	Pedestrian improvements	-Percentage of new urban routes -Change in multimodal LOS due to project -Change in street connectivity for pedestrians -Change in pedestrian facilities
	Land-use planning	-Number of mixed-use developments -Automobile trips reduced due to mixed and uses
System Operations and Management Strategies	Signal control management	-Change in travel time index -Change in travel time/commute times
	Active traffic management	-Change in travel time index by mode -Change in person hours of recurring delay, by mode -Change in V/C ratio (congestion reduction per unit (lane-mile)) due to project
Public Transportation Strategies	Increase transit frequency, LOS	-Change in number of transit users -Change in transit level of service
	Convert the public vehicle fleet and transit vehicles to alternative fuels	-Change in number of alternative-fuel vehicles

CONCLUDING REMARKS – COMPONENTS OF A FRAMEWORK

The research findings summarized in this chapter were based on survey responses, literature review on GHG emissions incorporation into long-range planning, and a review of various frameworks and guidebooks currently being used by other states or agencies. There are several existing publications and resources including guidebooks from the Transportation Research Board, Georgia Institute of Technology's Transportation Center and the Center for Clean Air Policy. A detailed summary of these guidebooks can be found in Appendix F.

The foundational knowledge developed in this chapter allowed the research team to structure a framework for Texas transportation practitioners, covering components such as GHG emissions inventory/evaluation, mitigation strategies (termed as control strategies), and performance measures. The framework, which is described in the next chapter also took into account GHG co-benefits, i.e., reducing GHG emissions can yield many benefits for TxDOT and MPOs. Addressing GHG emissions through mitigation (control) strategies can prepare agencies for future federal regulations on GHG emissions. For this project the term control and mitigation strategy will be used interchangeably. The application can also help address MAP21 performance measurement requirements and control strategies can also help meet other transportation goals.

CHAPTER 3:
FRAMEWORK FOR INTEGRATING GHG EMISSIONS INTO LONG-RANGE TRANSPORTATION PLANNING

This chapter presents the framework developed as part of this research project. As mentioned previously, the goal was to develop a framework to link GHG emissions mitigation strategies with long-range transportation plans. The intent of the framework was to be flexible, practical, and equip Texas transportation practitioners with tools needed to address GHG emissions in the long-range transportation planning process. The framework can be used to supplement federal-level guidance or policy, or serve as a starting point for TxDOT and its partner agencies in the absence of federal guidance on the subject of transportation GHG emissions reductions.

The framework is structured to help guide MPOs on how to best implement strategies, control measures, and performance measures into their long-range planning process to reduce GHG emissions. Each step involves different stakeholders, processes, and challenges that can occur and need to be taken into consideration. Some important guiding principles taken into account in the development of the framework were to:

- Have a framework that overlays the existing planning process, allowing it to be easily integrated into current transportation planning practice.
- Provide guidance on specific steps/actions for how GHG emissions can be incorporated into each step of the process.
- Take into consideration the Texas context and address the likelihood of federal government regulations for reducing GHG emissions as part of the framework, rather than considering a framework that addresses state-level GHG regulation.

This chapter provides context for the framework by describing how the framework is flexible for federal, state, and local changes including the issue of climate adaptation. It also explains how GHG reduction can provide co-benefits and explains TxDOT's role for implementing the framework. The framework is structured to help guide MPOs on how to best implement strategies, control measures, and performance measures into their long-range planning process to reduce GHG emissions. Each step involves different stakeholders, processes, and challenges that can occur and need to be taken into consideration. Some key terms as discussed in the remainder of this report are explained below:

- The MPO is a transportation policy-making organization composed of representatives from various regional stakeholder groups, including local government and transportation implementers. First authorized in 1962 as part of the Federal Aid Highway Act, MPOs were established to ensure that future expenditures for transportation were based on a comprehensive, cooperative, and continuing planning process (*24*). All MPOs in Texas are required to follow federal requirements and mandates to ensure that planning processes and procedures are followed.
- The purpose of the LRTP is to serve as a 24-year blueprint for the transportation planning process that will guide the collaborative efforts between TxDOT, local and regional decision makers, and all transportation stakeholders (*25*). In Texas, LRTPs are synonymous with MTPs. MTPs are long-range (typically 20–25-year period) transportation plans for urban areas that exceed 50,000 people. These plans are developed by the MPO in cooperation with TxDOT and publicly-owned transit services. MTPs identify policies, programs, transportation needs, and projects by travel mode, including roadways, public transit, bicycle, pedestrian, air rail, and freight facilities necessary to meet a region's transportation needs. It may also include information on the socio-economic profile of the area and environmental considerations. In the remainder for this report, the terms LRTP and MTP are sometimes used interchangeably.
- The Transportation Planning Process is seen as a much wider process of decision making and planning, which includes issues such as land use, stakeholder involvement, and requires an integrated approach to analysis and a clear vision for the future (*26*). In the framework described in this document, the LRTP is considered a component of the transportation planning process.

Figure 4 shows the steps identified in the framework developed in this research. This framework is intended to correspond to the general transportation planning process that TxDOT identifies in its transportation planning manual, so that GHG considerations can be directly incorporated into the process. As MPOs determine their long-term transportation plans, planners can simultaneously develop control strategies, inventory processes, or performance measures for reducing or measuring GHG emissions. This six-step process was considered the most effective framework for integrating GHG emissions into the transportation planning process and is consistent with a framework developed by a consultant as part of a project for the FHWA (*27*).

However, when compared to the framework developed for the FHWA, the research team's framework is streamlined with six steps outlined and categorized into three key phases: planning, evaluation, and implementation. This framework and the components including performance measures, inventory tools, and control strategies are chosen and evaluated to be Texas-specific. The framework is intended for use by TxDOT and Texas MPOs to be prepared for future federal regulations on GHG emissions and can also be applied for other pollutants.

Figure 4. Framework for Integrating GHG into Existing MPO Planning Process.

Table 5 summarizes the framework and outlines key elements that the research team identified as those that should be considered during each step, such as possible stakeholder groups, land use, and funding. Table 5 describes the following for each step of the framework:

- *Integration of GHG Considerations*: Identifies how to incorporate GHG reductions into the existing planning process.
- *Land Use*: Identifies where future land use patterns should be given explicit consideration.
- *Link Funding*: Identifies where linking the framework to funding for projects should be considered to ensure the GHG strategies can be pursued.
- *Possible Stakeholders to Engage*: Provides a list of possible groups that will play an important role during that step.
- *Implementation Components and Factors to Consider*: Identifies specific elements within the framework step to consider and notes specific activities to carry out during the implementation of that framework step.

Table 5. Summary of Framework for Incorporating GHG Emissions into the Transportation Planning Process.

Framework Step		Integration of GHG Considerations	Integrate Land Use	Link Funding	Possible Stakeholders to Engage	Implementation Components	Factors to Consider
Step 1	Identify GHG Reduction Goals	Establish GHG Emission Reduction Goals			USDOT/FHWA, EPA, TxDOT, TCEQ, regional and local environmental groups, industry leaders, community leaders, public	Outreach, Consensus Building	• Explain importance of GHG emissions/climate change through public involvement and other mediums through public education. • Utilize outside information to provide valuable input for guiding informed public discussion. • Survey effective strategies by MPOs in Texas and around United States.
Step 2	Establish the Performance Criteria	Define GHG Performance Criteria and Strategies	√		TxDOT, local government, local transportation agencies	Inclusion of GHG Reduction in Vision, Goals, and Tracking Trends	• Bring in all collaboration and coordination with interested stakeholders.
Step 3	Determine Strategies and Alternative Plans	Develop Strategies and Alternative Plan with GHG Reduction Goals in Mind	√	√	USDOT/FHWA, TxDOT, EPA, other MPOs in Texas	Performance Measures, Control Strategies, Analysis Process	• Explore and integrate best practices from around the state and choose to implement performance measures, control strategies, or analysis processes.
Step 4	Assess the Chosen Strategies	Evaluate GHG Deficiencies of Chosen Strategies	√		TxDOT, other MPOs	Control Strategies, Inventory Processes, Trends and Challenges	• Consider costs and benefits of all strategies. • Consider political, social, and economic impacts of chosen strategies.
Step 5	Assess the Alternative Strategies	Evaluate the GHG Reduction Alternative strategies	√	√	City planning officials, transit agency leaders, City Council, TxDOT	Control Strategies, Performance Measures, Analysis Tools and Improvement Projects	• Consider and weigh the benefits and costs of all strategies to reduce GHG emissions. • Review alternate strategy options that could produce desired results.
Step 6	Select Preferred Strategies	Select Preferred Alternatives	√	√	City planning officials, transit agency leaders, City Council, TxDOT	Performance Measures, Inventory Process, or Control Strategies	• Contact other MPOs and DOTs for input on alternatives.

The remainder of this chapter includes further details on each step of the existing planning process, with a graphic outlining the main components of each step. The detailed elements of the steps are outlined in charts with information on whom to involve in the process, opportunities to integrate into the current planning process, challenges, and possible solutions.

FRAMEWORK AND STEPS FOR GHG INCORPORATION

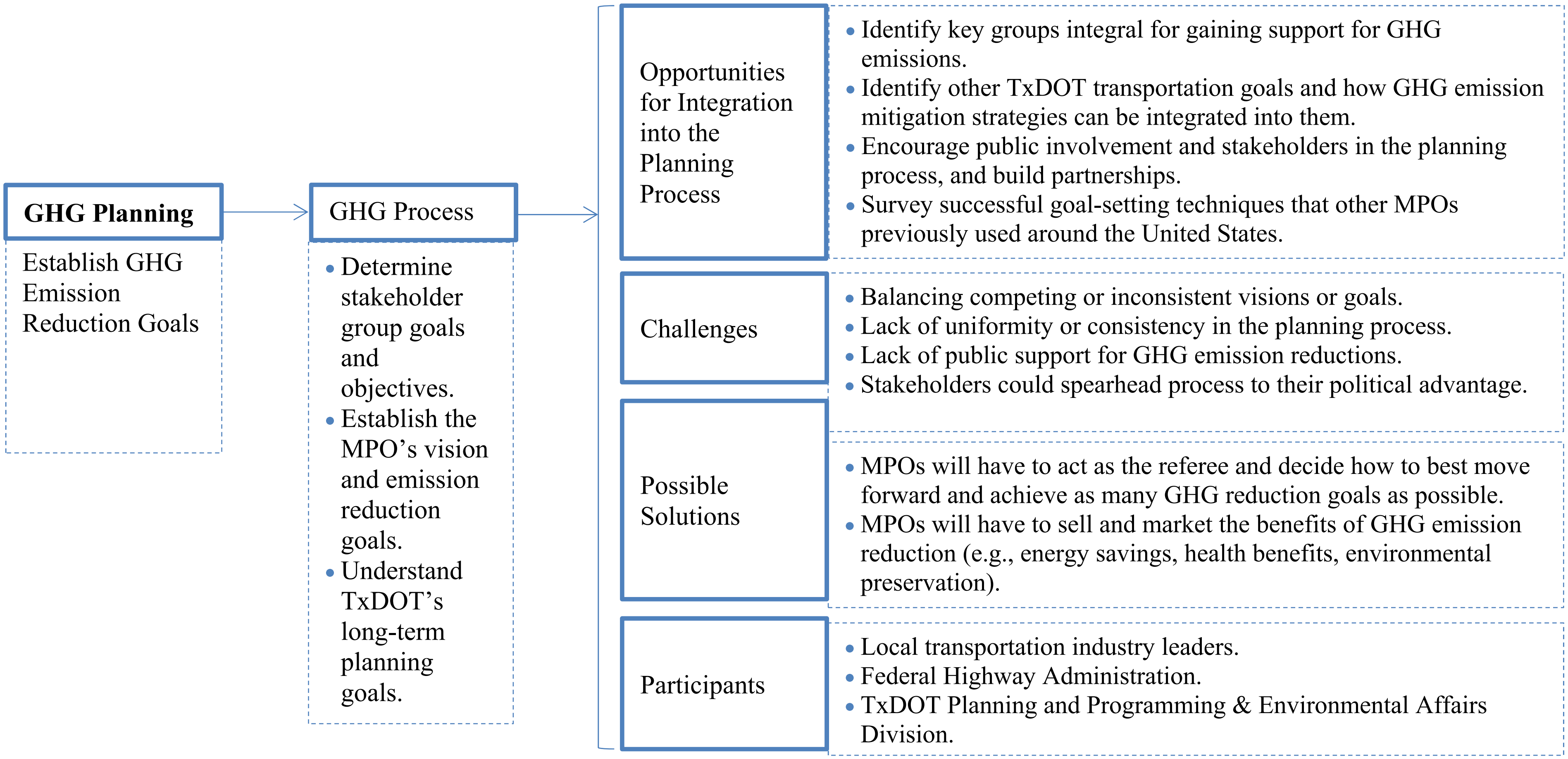
Phase 1: Plan

Framework Step 1: Identify the GHG Reduction Goals

There are several opportunities for Texas MPOs to integrate GHG emissions reduction into the first step of the transportation planning process. This step presents an opportunity to begin the conversation on GHG emissions and their long-range impacts in Texas and to set broad goals related to these. The overall planning for planning and publicizing a framework for further steps in the planning process is initiated during this step. Therefore, this is perhaps one of the most important places to build a GHG emissions reduction vision and goals, and elicit public support for such a vision.

There are several opportunities for Texas MPOs to integrate GHG emissions into the visioning and goal-setting step of the transportation planning process. This is the first opportunity to help influence the development of a vision for the region that includes sustainability and GHG emissions reduction. An MPO vision can be structured to emphasize mitigating the system's impact on contributing to GHG emissions. Effective goals and objectives cannot be developed without a vision that at least recognizes the potential impact from GHG emissions and seeks to somehow address those concerns. As Texas MPOs consider different stakeholders to incorporate into the process, public interest groups, the Texas Commission on Environmental Quality (TCEQ), regional coalitions, etc. could help to provide strong input on how best to steer the development of a vision that includes sustainability and addresses GHG emissions (*28*, *29*). Depending on the status of federal-level action with regard to GHG emissions in transportation, these may also be a factor that comes into play during this stage of applying the framework.

Ultimately, the visioning and goal-setting step of the planning process is an excellent opportunity to bring together stakeholders to the Table 5 and help come up with clear, measurable goals for ensuring long-term environmental sustainability and GHG emissions reduction. Figure 5 summarizes the key points in Step 1 of the framework.



GHG Planning

Establish GHG Emission Reduction Goals

GHG Process

- Determine stakeholder group goals and objectives.
- Establish the MPO's vision and emission reduction goals.
- Understand TxDOT's long-term planning goals.

Opportunities for Integration into the Planning Process

- Identify key groups integral for gaining support for GHG emissions.
- Identify other TxDOT transportation goals and how GHG emission mitigation strategies can be integrated into them.
- Encourage public involvement and stakeholders in the planning process, and build partnerships.
- Survey successful goal-setting techniques that other MPOs previously used around the United States.

Challenges

- Balancing competing or inconsistent visions or goals.
- Lack of uniformity or consistency in the planning process.
- Lack of public support for GHG emission reductions.
- Stakeholders could spearhead process to their political advantage.

Possible Solutions

- MPOs will have to act as the referee and decide how to best move forward and achieve as many GHG reduction goals as possible.
- MPOs will have to sell and market the benefits of GHG emission reduction (e.g., energy savings, health benefits, environmental preservation).

Participants

- Local transportation industry leaders.
- Federal Highway Administration.
- TxDOT Planning and Programming & Environmental Affairs Division.

Figure 5. Summary of Framework Step 1.

Framework Step 2: Establish the Performance Criteria and Data Needs

As in the previous step, there are significant opportunities available for incorporating GHG emissions planning into the transportation planning process. Several methods ensure that performance criteria align appropriately with transportation vision and goals, specifically as they relate to GHG emissions reduction.

This step requires MPOs to establish consistent data standards for quantifying GHG emissions in the planning process. Guidance on the appropriate quantification techniques of various planning agencies and planning departments is needed, especially when evaluating for effectiveness. Chapter 2 describes various estimation methods and evaluation tools for quantifying GHG emissions. MPO should also establish performance measure criteria to evaluate chosen control strategies and measure reduction effectiveness. The appropriate performance measures chosen will also depend on the control strategies selected. Therefore, the step of establishing performance criteria will need to be revisited as control strategies are changed. Chapter 2 provided a recommended list of performance measures that can be considered.

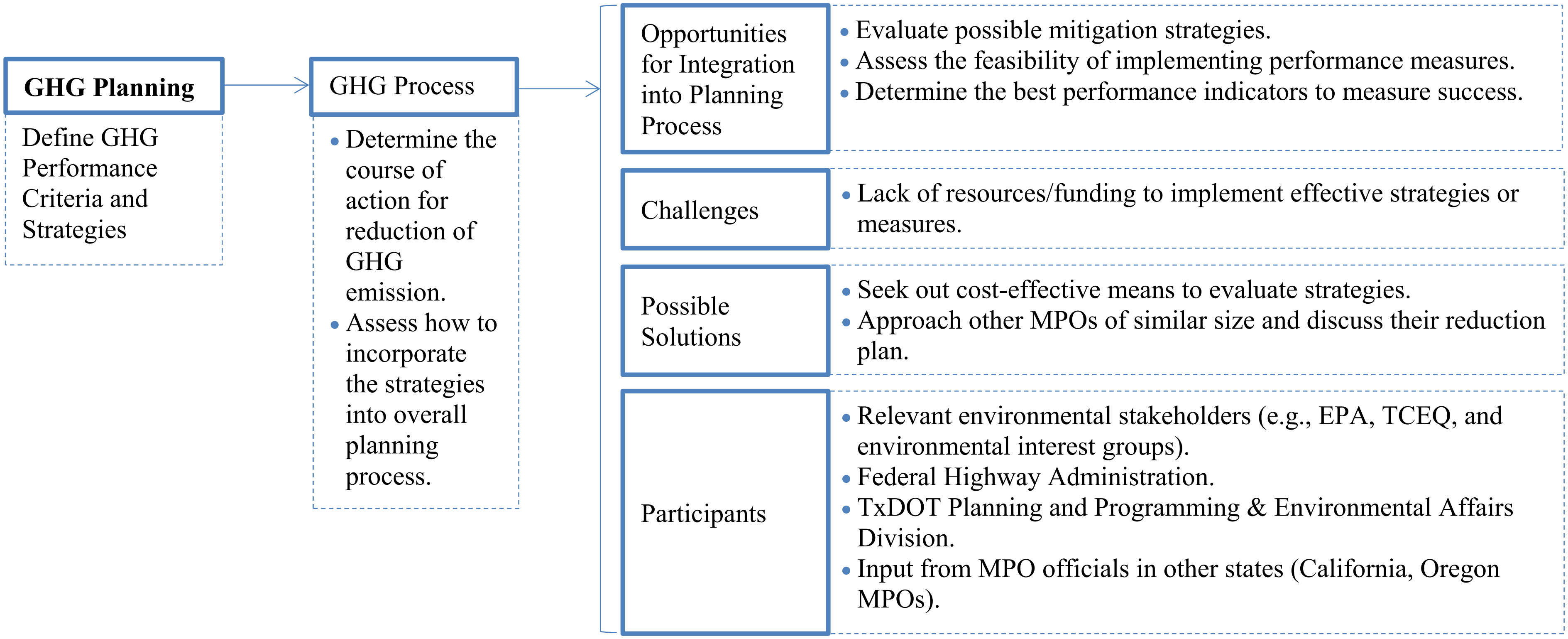
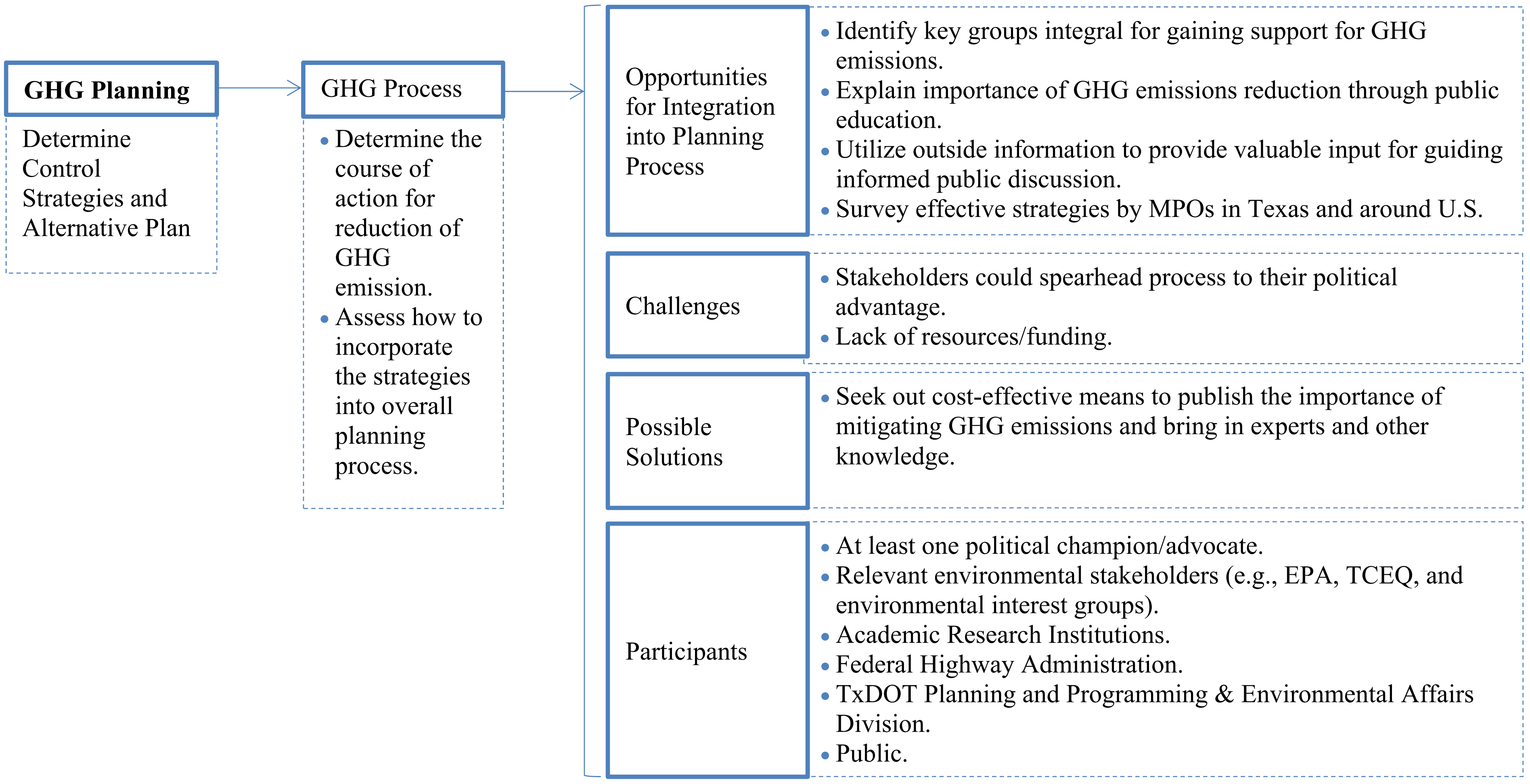


Figure 6. Summary of Framework Step 2.

Framework Step 3: Determine Strategies and Alternative Plans

This step requires the MPO to determine and choose which control strategies to implement for GHG emissions reduction. The MPO can choose strategies based on various criteria such being the easiest to implement, providing the most reduction or strategies with various co-benefits. Chapter 2 provides a list of the most common mitigation strategies chosen by MPOs including bicycle improvements, mixed land use, pedestrian improvements and urban transit expansion. After choosing strategies to implement, the MPO should also develop a list of alternative control strategies in case the chosen strategies are not feasible or do not provide the desired results.



GHG Planning

Determine Control Strategies and Alternative Plan

GHG Process

- Determine the course of action for reduction of GHG emission.
- Assess how to incorporate the strategies into overall planning process.

Opportunities for Integration into Planning Process

- Identify key groups integral for gaining support for GHG emissions.
- Explain importance of GHG emissions reduction through public education.
- Utilize outside information to provide valuable input for guiding informed public discussion.
- Survey effective strategies by MPOs in Texas and around U.S.

Challenges

- Stakeholders could spearhead process to their political advantage.
- Lack of resources/funding.

Possible Solutions

- Seek out cost-effective means to publish the importance of mitigating GHG emissions and bring in experts and other knowledge.

Participants

- At least one political champion/advocate.
- Relevant environmental stakeholders (e.g., EPA, TCEQ, and environmental interest groups).
- Academic Research Institutions.
- Federal Highway Administration.
- TxDOT Planning and Programming & Environmental Affairs Division.
- Public.

Figure 7. Summary of Framework Step 3.

Phase 2: Evaluate

Framework Step 4: Assess the Chosen Strategies and Evaluate the Deficiencies

In this step MPOs should assess and evaluate the effectiveness of their reduction targets or goals. It is important for MPOs to know and evaluate what are the most viable and effective strategies for meeting their emissions goals, and ensure that the GHG emissions strategies are not causing an undue burden on stakeholders or economic growth. MPOs want to evaluate to make sure the course of action is within the political will for their area and has support from stakeholder groups to secure a successful GHG emissions reduction plan.

This step involves refining any performance measures or indicators that were chosen previously. MPOs should establish indicators that accurately evaluate the GHG emissions reduction goals. Furthermore, this is also the step where viable control strategies, evaluation methods, and analysis tools can be refined, reworked, and refined again to fit their most appropriate role in the planning process.

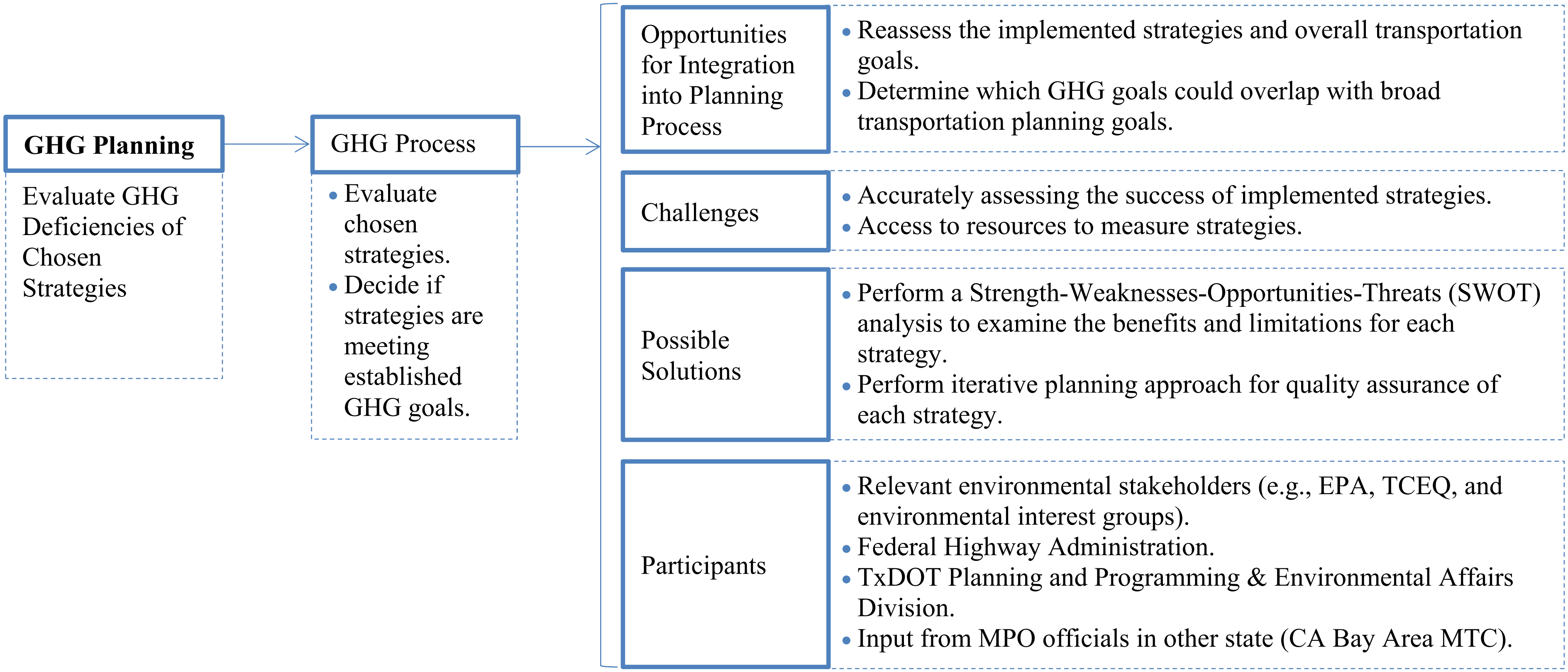
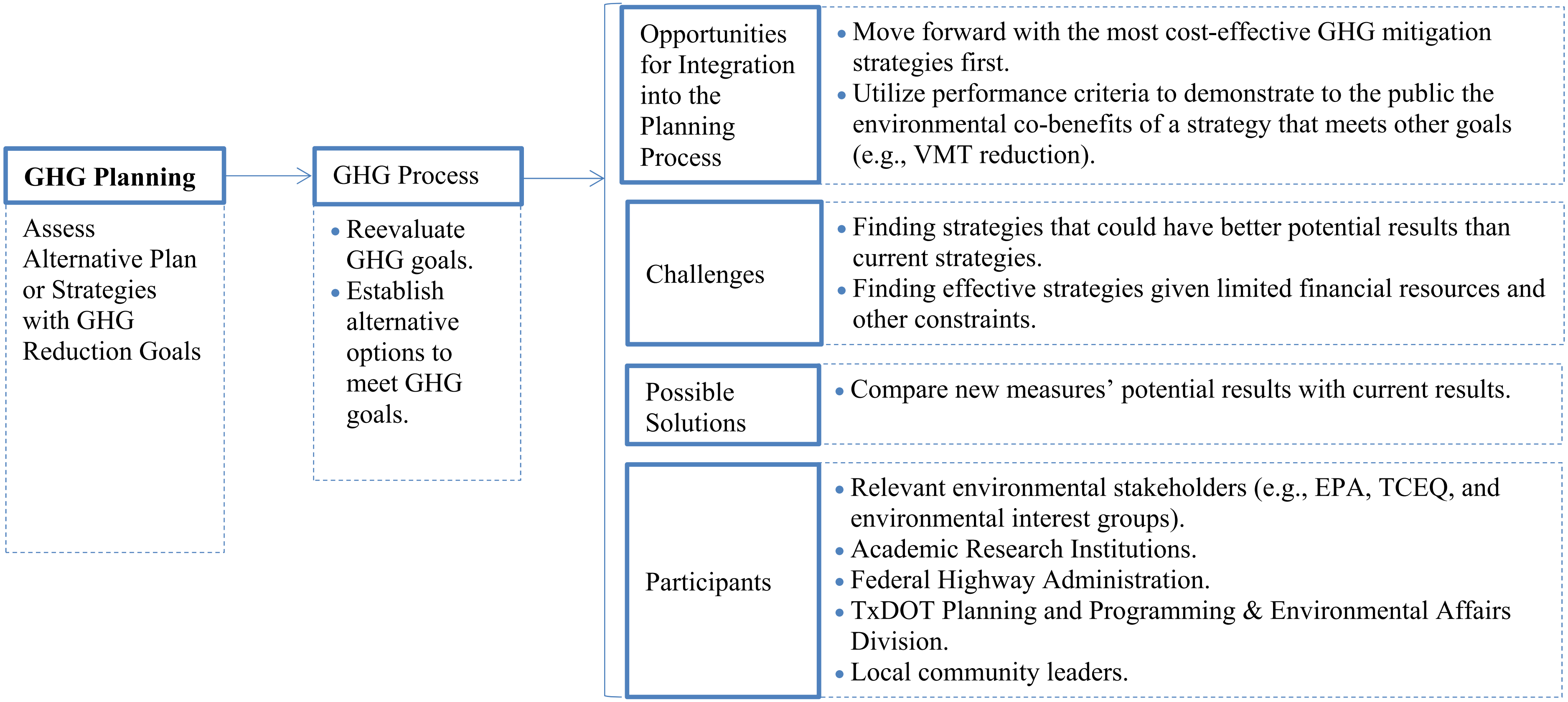


Figure 8. Summary of Framework Step 4.

Framework Step 5: Assess Alternative Plan Scenarios

There are several steps available for incorporating GHG emissions planning into the long-range transportation planning process. This step can identify alternatives available to help mitigate GHG emissions. Chapter 4 discussed possible control strategies that MPOs can implement, and they can use the recommended list for alternative strategies and reconsider strategies that they did not previously choose to implement. If MPOs did not incorporate measurements or evaluation methods, this would be a time to decide whether to add methods to the emissions reduction plans.



GHG Planning

Assess Alternative Plan or Strategies with GHG Reduction Goals

GHG Process

- Reevaluate GHG goals.
- Establish alternative options to meet GHG goals.

Opportunities for Integration into the Planning Process

- Move forward with the most cost-effective GHG mitigation strategies first.
- Utilize performance criteria to demonstrate to the public the environmental co-benefits of a strategy that meets other goals (e.g., VMT reduction).

Challenges

- Finding strategies that could have better potential results than current strategies.
- Finding effective strategies given limited financial resources and other constraints.

Possible Solutions

- Compare new measures’ potential results with current results.

Participants

- Relevant environmental stakeholders (e.g., EPA, TCEQ, and environmental interest groups).
- Academic Research Institutions.
- Federal Highway Administration.
- TxDOT Planning and Programming & Environmental Affairs Division.
- Local community leaders.

Figure 9. Summary of Framework Step 5.

Phase 3: Implement

Framework Step 6: Select Preferred Alternative

During this stage of the process, transportation agencies can examine different GHG mitigation strategies and select the most appropriate option to consider from the previously formulated project list. The project list is organized as a tiered structure of the best strategies for GHG reductions. As agencies consider a different approach, they can easily identify the next best option from the list. Stakeholder outreach and coordination is still highly important component to ensuring that GHG emissions can be included in these sections of the transportation planning process. This stage of the process is probably best suited for examining which proposal might have the most opportunity for transportation co-benefits. Ultimately, competing priorities might cause GHG mitigation to fall low on the priority list when making project selections. To keep GHG mitigation as high priority, it is important that alternatives that ensure GHG co-benefits are weighted higher than others. Chapter 2 noted co-benefits of many control strategies and a list of recommended control strategies. Furthermore, if MPOs decide to change the plan that was established earlier in the framework, they will want to revisit some of the earlier steps to ensure the new alternate plan meets all their goals and also will have stakeholder support.

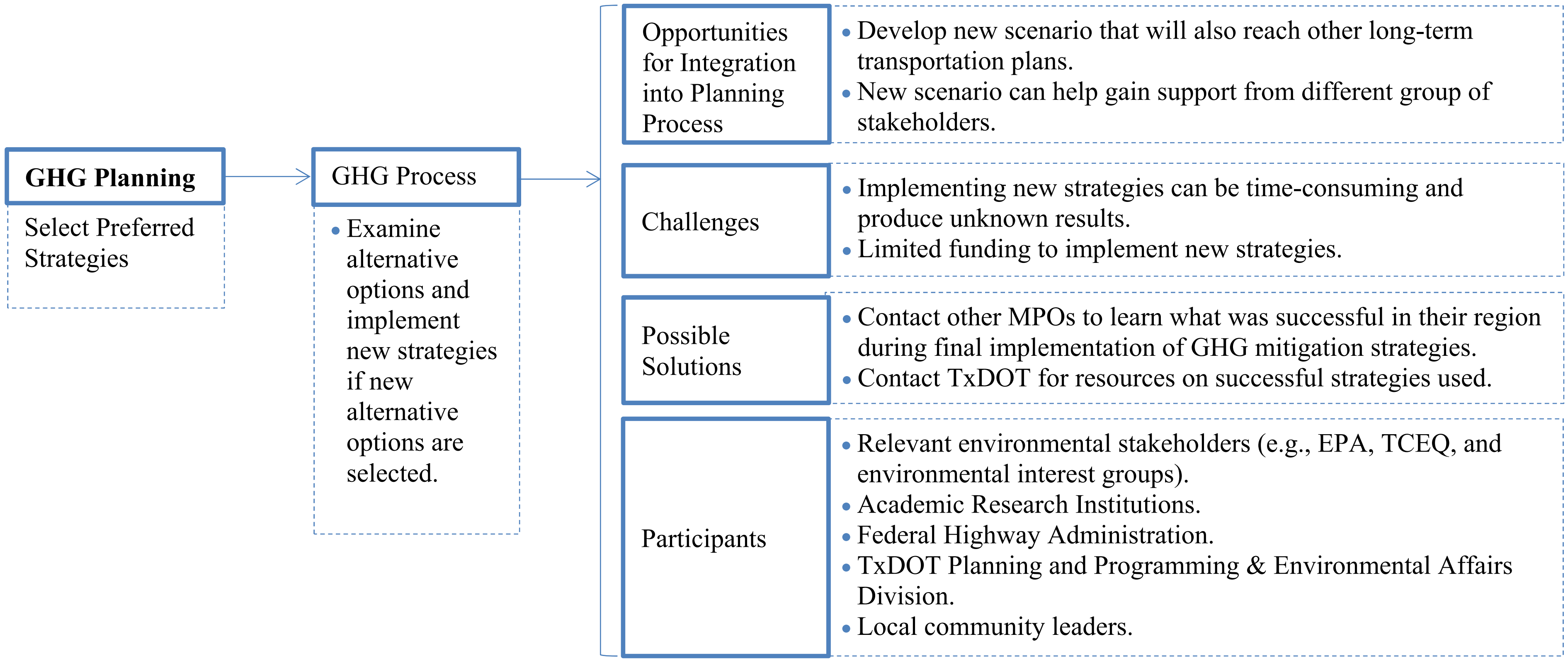


Figure 10. Summary of Framework Step 6.

CHAPTER 4:
CASE STUDY

The case study is to apply the developed framework to a selected area in Texas to validate the framework's usefulness and make final refinements before implementation by TxDOT and partner agencies. The application of the case study can be used as reference by metropolitan areas who wish to incorporate GHG emissions into their long-range plans. The Austin area was selected as a case study, and the research team worked with the Capital Area Metropolitan Planning Organization (CAMPO) to obtain data relevant to the case study. Due to resource constraints at CAMPO, the case study focused on evaluation of control strategies without modifying parameters in the existing TDM. That is, no modeling runs were performed exclusively for this case study. This is expected to be a common constraint for planning agencies and thus the limitations discussed here are what they will potentially face when applying this type of planning-level framework. If agencies have the resources, they can also use most of the approaches presented in this section by including them directly into their TDM instead.

CASE STUDY APPROACH

A total of five case studies were performed as pilot applications for the proposed framework. The aim of these case studies was to illustrate how data are to be assembled and GHG reductions estimated for selected control strategies. Conducting the pilot tests allowed examination of different methodologies, in terms of both analysis scope and estimation approach. The pilot tests also illustrated how the data requirements can be approached and how reasonable assumptions may be made in cases where complete data are not available. A subset of Austin's road network was selected as the pilot network. Link level information for this network was extracted from the results of the TDM provided by CAMPO. Major considerations in the selection of pilot strategies included overall applicability to the pilot area, availability of quantitative methods, and data requirement.

The following sections discuss the setup and results from each of these case studies. On completion of the three case studies, it was observed that the planning level information can be used to perform a quantitative impact analysis for different GHG mitigation strategies; however, the level of details and assumptions needed for the analysis was different for each strategy.

The overall approach for the case study analysis consists of the following three major steps:

1. Use the link-level data from the assignment step of TDM for years 2010, 2015, 2025, and 2035. Calculate the total baseline emissions for the pilot network with the value of traffic flow and travel time for each analysis year.
2. Use appropriate methods to estimate the traffic volume under the selected GHG reduction/mitigation strategies.
3. Estimate GHG emissions under each strategy scenario for all analysis years.

Determining the appropriate methodologies to estimate the impact of selected strategies on traffic flow and speed (step 2 above) is the most resource- and time-intensive step. The main reasons for this issue are: 1) there are not standard procedures for many of the GHG strategies, and 2) sometimes available procedures need data that are beyond the scope of a planning level analysis or not available to the research team at the time of analysis, e.g., requiring a new run of the TDM model. The research team made appropriate assumptions based on the literature where required information was not available. To keep the consistency between case studies, a kg/day of CO_2 emissions reduction used for all the strategies.

Because CO_2 constitutes the majority of GHG emissions, only CO_2 emissions are included in the case study analysis. All emission rates were extracted from the most recent official release of MOVES model (MOVES 2010b) at the time of analysis. The proposed procedure to calculate the total GHG/CO_2 emissions in the study area:

1. Determine the analysis years; in this case study, 2010 was used as the base year, and 2015, 2025, and 2035 were the other years for the analysis. These analysis years represented those that CAMPO had available TDM data.
2. Extract the following information from the TDM for all the links in the target network and all analysis years:
    a. Average daily traffic volume (if available by mode).
    b. Travel time (if available by mode).
    c. Length of each link.
3. Calculate the average travel speed on each link based on link length and travel time.

4. Run MOVES for the analysis years and develop speed-based emissions rates lookup tables. This step requires using appropriate assumptions regarding vehicle fleet distribution and other MOVES input parameters.
5. Calculate VMT for all links based on link length and daily traffic volume.
6. Apply appropriate emissions rate to VMT from each link. A linear interpolation equation can be used if the link average speed is not in the lookup tables.
7. Calculate the total daily emissions of the study area by summing up all the links.

STUDY AREA

A sub-area from Austin's TDM network obtained from CAMPO was selected as the pilot network. Figure 11 shows the pilot network. This area includes an interstate freeway section, a highway, and a mix of arterial roads connecting different land uses such as commercial, residential, and retail. Only major roadways are included in the TDM network. Travel demand modeling level of network was chosen for the purpose of this case study analysis because it is the main source of data at the planning level, i.e., MPOs will realistically have access to this information.

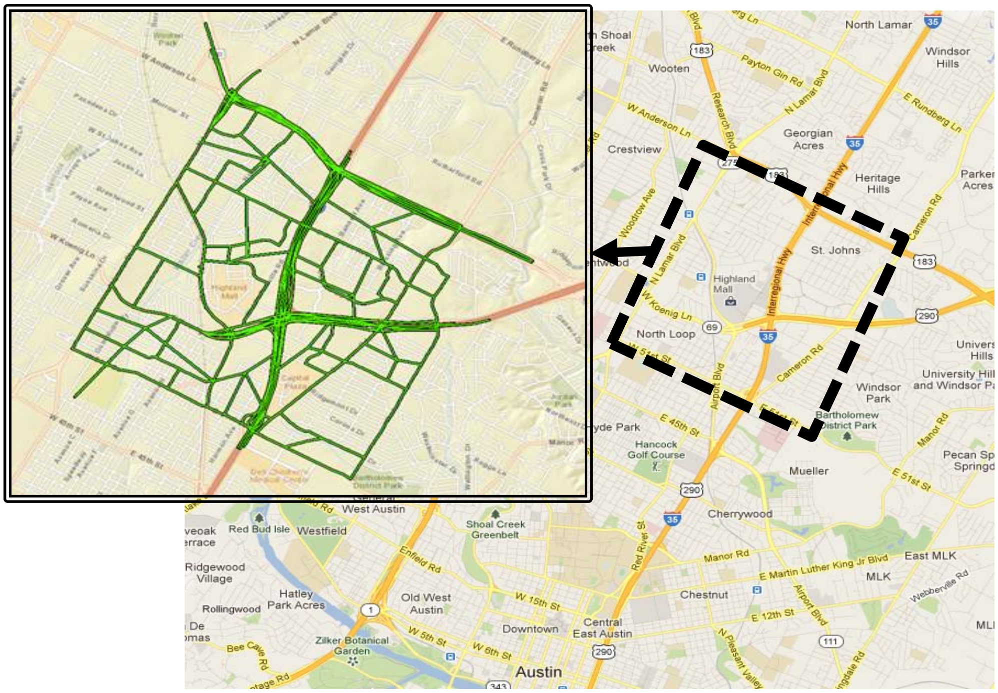


Figure 11. Layout of the Pilot Network.

SELECTED GHG MITIGATION STRATEGIES

The research team selected five GHG mitigation strategies for the case study analysis—one from each category of mitigations covering non-freight modes. No freight strategy was selected for the case study because none of the freight strategies was determined to be suitable for the target network. The baseline for all the strategies is the original results from the CAMPO TDM. To make the estimation process and comparisons simple, it is assumed that the no GHG reduction strategy exists in the baseline. The selected GHG mitigation strategies are as follows:

1) Incentivize more efficient vehicles or fuels – in the form of a feebate program incentivizing high fuel efficiency vehicles and penalizing low fuel efficient ones.

A feebate program is "a market-based policy for encouraging GHG emission reductions from new passenger vehicles by levying fees on relatively high-emitting vehicles and providing rebates to lower-emitting vehicles" (*30*). The feebate program aims to incentivize manufacturers to produce, and consumers to buy, vehicles with reduced carbon emissions. In a full feebate program, a rebate is rewarded for vehicles with emissions below a selected level of fuel efficiency or GHG rate level, and a fee is added to vehicles emitting above that level. Feebate programs usually target only light vehicles and with proper design can be revenue-neutral, i.e., fees cover rebates.

A feebate program is usually defined according to the change in surcharge or rebate for each additional amount of pollution a vehicle produces. There are three major types of feebate program designs: linear, piecewise linear, and step function. The example in Figure 12 shows a variation of step function design based on an $18 per gram of CO_2-equivalent emissions per mile. This is known as the slope of the feebate schedule. The pivot point, another element defining a program, is the point on the schedule where it crosses the horizontal (emissions) axis. For the program shown in Figure 12, the pivot point is 250 grams per mile. Additionally, this example uses three constraints: 1) surcharges and rebates are limited to $2,500; 2) the program is self-financing; and 3) the zero-band, where vehicles neither incur a surcharge nor earn a rebate, includes 20–25 percent of the fleet.

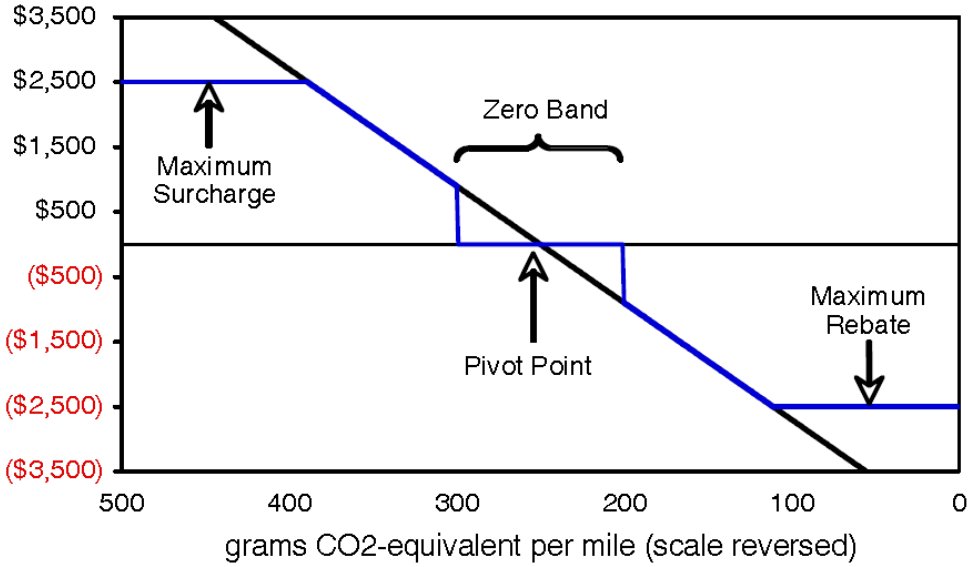


Figure 12. Hypothetical Feebates Program with Slope of $18/g/mi (*31*).

Determining the impact of a feebate program on GHG emissions from a specific system (e.g., a state) requires an analysis of the consumer behavior and car manufacturers' response. Because these analyses are beyond the scope of this case study, the research team adopted the results of a study investigating such program for California (*31*). The study investigated different system design and assumption. The following summarized the feebate design for that was adopted from the California study for the purpose of this case study analysis:

- A linear feebate program with a $20/g/mi rate and a single benchmark of 274 (g/mi).
- A proposed national standard for light duty vehicles GHG was applied to 2011–2016. This proposed standard is expected to result in a new vehicle fleet-wide average of 250 gCO_2E/mi.
- A 2 percent reduction per year was assumed for years 2017–2025.
- The feebate program is effective only in California; i.e., other states will not implement such program and therefore the majority of GHG reduction is the result of changing consumers' purchasing behavior and technology has only marginal impact.

Figure 13 shows the results from the different cases investigated in the California study. The *single benchmark* results are the ones used in this case study analysis. The estimation of the GHG reduction resulted from the California study followed the following steps:

1. For analysis year 2015 and 2025, determine the reduction percentage for that year and all preceding years.
2. Use a flat function for years between 2025 and 2035, i.e., 7.5 percent reduction.
3. Apply these reductions to emissions rates of the corresponding model year vehicles for each analysis year.
4. Estimate the total GHG for all the links using these new emissions rates and calculate the reduction percentage.

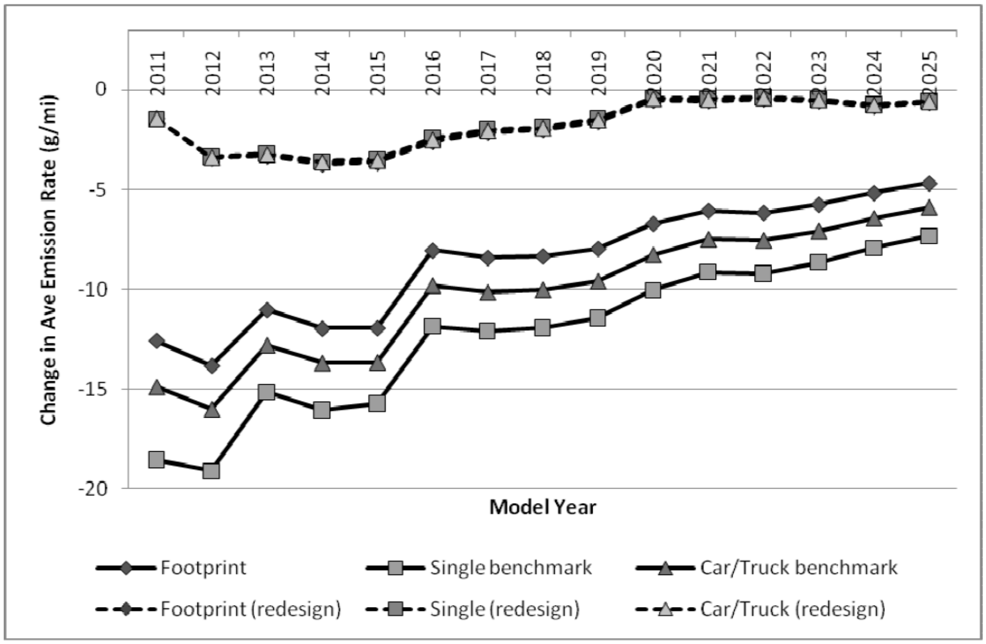


Figure 13. Change in Average New Vehicle Emission Rates from Feebates for Three Benchmark Systems (*30*).

2) Bicycle improvement – in the form of an extensive bike route construction along the major roads in the target network.

It was assumed that an extensive bike network will be implemented in three phases. Each phase covers roughly one-third of the network and will be completed 10 years apart, i.e., phase 1 in 2015, phase 2 in 2025, and phase 3 in 2035.

The underlying assumption for this strategy is that a new bicycle facility can attract more cyclists. Based on this increasing number of cyclists, the reduction of VMT and emissions are estimated. The estimation methodology for increased bicycle trips is from the National

Cooperative Highway Research Program Report, NCHRP 552 (*32*) assuming a moderate estimate of new bicyclists. The main inputs to this methodology are population density around the proposed bike facility and regional values for car ridership and average trip lengths. The results show 3303, 5091, and 6294 new commuter bicyclists for 2015, 2025, and 2035, respectively.

3) Convert transit vehicles to alternative fuels – in the form of annual conversion of a portion of the transit fleet to hybrid buses.

To demonstrate how the GHG impact of converting buses to alternative fuel can be calculated, the research team adopted a simple conversion program; that is starting from 2011, 5 percent of the transit bus fleet will be converted to hybrid vehicles. It was assumed that this 5 percent conversion rate translates directly to the same amount of VMT, i.e., all buses drive approximately the same distance during the day.

An average value of expected GHG reduction of 27 percent compared to conventional diesel buses, the equivalent of 37 percent increase of fuel economy, was adopted from a study report by Environmental and Energy Study Institute (*33*). For each analysis year, this reduction was applied to all converted buses till that year, e.g., for AY2015 a 25 percent reduction covering all buses that were converted during 2011–2015 period.

4) Employer-based commute strategies – in the form of a set of phased-in employer-sponsored carpool, vanpool, and bicycle programs.

This strategy associates the offering of a particular employer support measure with an incremental change in the mode share of the mode to which the program is applied. The calculation approach follows the methodology of EPA's COMMUTER model (*34*). The COMMUTER model approach includes different levels of program level support for each individual mode.

Table 6 lists the expected changes in mode share for each mode for different program levels. Employer support programs are divided into four different levels, ranging from Level 1, representing the minimum level of effort, to Level 4, reflecting the maximum. The details of the methodology including the identification of what measures have been assumed to make up each level can be found in the COMMUTER model documentation (*33*).

Table 6. Increase in Percent Using Model by Support Program Level (*34*).

		Program Level			
Program	Type of Workplace	1	2	3	4
Carpool	Office	0.40%	1.00%	2.00%	4.00%
	Non-Office	0.20%	0.40%	1.40%	2.00%
Vanpool	Office	0.40%	1.00%	2.00%	4.00%
	Non-Office	0.20%	0.40%	1.40%	2.00%
Transit	Office	0.20%	0.50%	1.50%	2.00%
	Non-Office	0.20%	0.50%	1.50%	2.00%
Bicycle	Office	0.20%	0.50%	1.50%	2.00%
	Non-Office	0.10%	0.25%	0.75%	1.00

For the purpose of this case study analysis, a three-phase program including carpool, vanpool, and bicycle modes considered to be implemented in the pilot area:

- Phase 1 – 2011 to 2015: resulting in an average level 1 support program for all the commuters in the pilot area.
- Phase 2 – 2016 to 2025: resulting in an average level 2 for the area.
- Phase 3 – 2026 to 2035: resulting in an average level 3 support program for the commuters in the pilot area.

The first step of the calculations involves determining the baseline (pre-implementation) mode share for commuting trips. Since this information was not available, the default mode shares of the COMMUTER model as well as some simplified assumptions were adopted as the baseline for this strategy. The above information was used to calculate the new mode share and total VMT for each of the target modes. Finally, appropriate emissions rates were applied to these VMT values and total GHG reductions were calculated for the analysis years.

5) Signal control management – in the form of signal timing optimization every five years.

This strategy consists of the potential improvement of signal timing at intersections that can reduce emissions by reducing vehicle delay. This strategy can be applied on a project basis, for example for an arterial or corridor, or for a region. The quantification methodologies are based on the Texas Guide to Accepted Mobile Source Emission Reduction Strategies.

The detail estimation of the impact of this strategy requires knowledge of traffic conditions before and after signal retiming, including parameters such as total delay before and after retiming, cruise speeds before and after retiming, volumes of peak and off-peak periods (veh/hour). Because most of this information is not usually available at the planning and travel demand modeling level, a simplified analysis using average regional impacts can be used for the analysis. Based on the information found in the literature (*35*), the research team adopted a regional average of 1 percent GHG reduction for the impact of signal optimization on GHG emissions from vehicles.

It is assumed that all the signals on the pilot network will be optimally retimed during the analysis years 2015, 2025, and 2035. All the traffic signals in the network were identified and VMT on all the approaches were summed up to represent the traffic affected by traffic signal retiming. The 1 percent reduction was applied to the total GHG representing this signal-affected VMT.

DATA NEEDS

Quantification of the impact of the proposed GHG mitigation strategies for the pilot network requires information from different data sources. Table 7 shows the list of the required input data along with their value for the study section. The intention of this case study analysis was to demonstrate how the proposed framework works, and thus many simplifying assumptions made when required data were not readily available at the time of analysis. Many of these assumptions are based on well-established models and literature and therefore are potentially sufficient for a planning level analysis. If more accuracy is desired, these assumptions can be simply substituted if local information is available. The following lists some of these assumptions:

- MOVES default values for Travis County were used to extract CO_2 emission rates for the pilot area.
- Only moving tailpipe emissions are included.
- Mode share of commute trips are based on default values of the COMMUTER model.
- No GHG mitigation strategy exists in the baseline case.
- Average length of car and bike trips was assumed to be 1 mile based on the size of the area.
- An average population density for the entire area was used. A separate population density for each link can increase the accuracy of the analysis.
- All existing transit buses are conventional diesel buses.

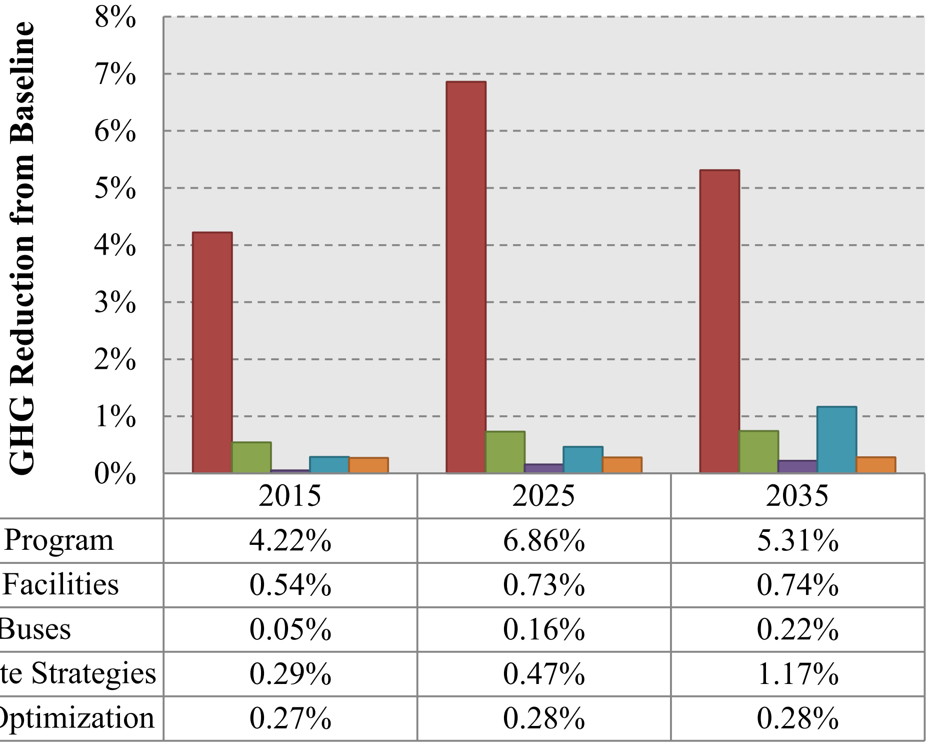
Table 7. Key Input Data for Case Study Analysis.

Strategy	Parameter	Value and/or Source
All Strategies	Pilot Network/Roadway Sections	Approximately 1-mile on each side of IH-35 between Hwy183 and 51st street, Austin, Texas
	Average Daily Traffic Volume for All Links (vehicles/day)	CAMPO Travel Demand Model Results for 2010, 2015, 2025, and 2035
	Average Traffic Speed by Mode (mph)	CAMPO Travel Demand Model Results for 2010, 2015, 2025, and 2035
	CO_2 Emissions Rates by Road Type, Vehicle Class, and Average Speed (g/mi)	MOVES 2010b
Feebate Program	Vehicle Age Distribution for All Analysis Years	MOVES 2010b
	Impact of Feebate Program on New Cars' GHG Emissions (percent reduction)	16% in 2015, 7.5% in 2025, 7.5% in 2035 Based on Literature
Bike Rout	Population Density for the Pilot Area (person per sq. mile)	Approximately 4000 Based on ESRI Demographics Database
	Average Length of Car and Bike Trip (mi)	1 mile Based on the size of the Pilot Network
Hybrid Buses	Percent of Buses Converted to Hybrid Electric Drive Annually starting from 2011	5%
	Average Percent Difference of Hybrid Buses' CO_2 Emissions from Conventional Diesel Buses	27% (equivalent to 37% MPG increase) Based on Literature (*33*)
Employer-Based	Current Mode Share for Commuting Trips	COMMUTER Model
	Percent Change in Mode Shares as a Result of a phased-in Employer-Based Carpool, Vanpool, and Bike Program	COMMUTER Model Documentation (*34*)
Signal Optimization	Average Impact of Traffic Signal Optimization (percent reduction)	1% Based on Literature (*35*)

RESULTS

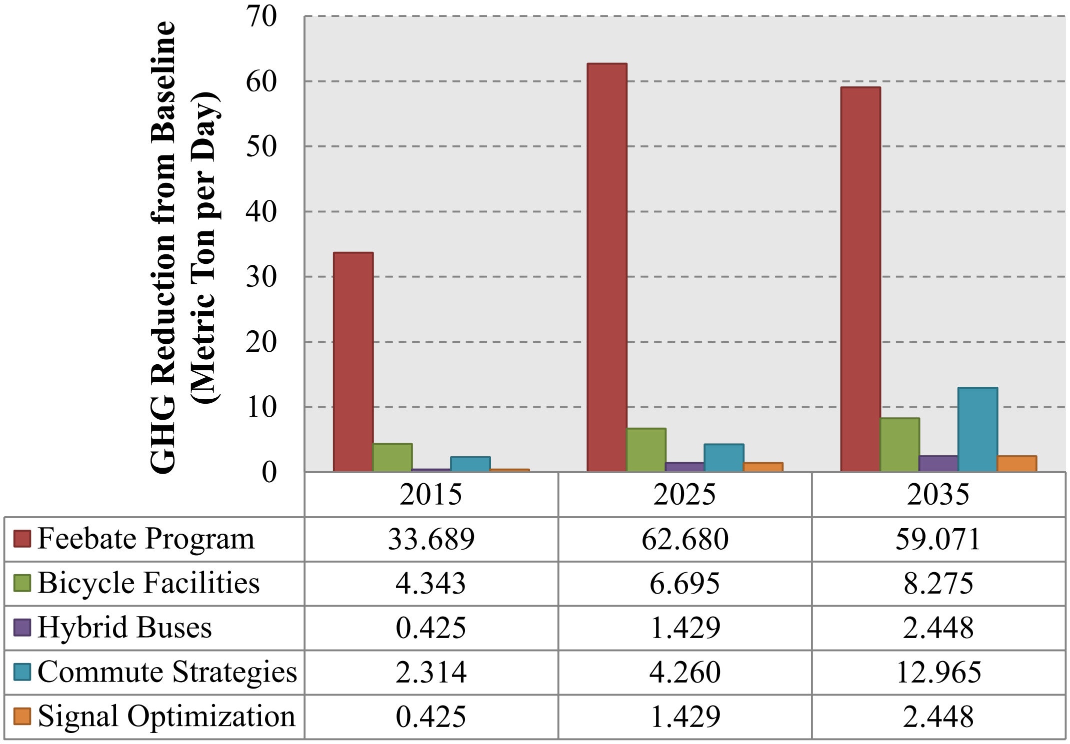
After assembling the required data, a spreadsheet-based analysis was established for the pilot network. For each case study, including the baseline, the total daily CO_2 emissions were estimated for all the target analysis years and then the corresponding reduction percentages were calculated. Figure 14 through Figure 16 show the final results of this analysis effort.

All the reductions shown in Figure 14 and Figure 15 are calculated from the baseline case, i.e., no mitigation strategy, for the entire pilot network. The results show how the impact of different strategies changes over the analysis period; some growing through 2035 and some show reach a maximum impact around 2025. Figure 16 shows the total amount of CO_2 from the pilot network under each case scenario conditions. The total amount of the emissions increases over the analysis period with a slightly concave behavior. This is mostly because the TDM shows lower link speeds as the result of higher traffic flow which in turn results in higher emissions rates.



	2015	2025	2035
🟥 Feebate Program	4.22%	6.86%	5.31%
🟩 Bicycle Facilities	0.54%	0.73%	0.74%
🟪 Hybrid Buses	0.05%	0.16%	0.22%
🟦 Commute Strategies	0.29%	0.47%	1.17%
🟧 Signal Optimization	0.27%	0.28%	0.28%

Figure 14. GHG Reduction Percentages for the Selected Mitigation Strategies.



	2015	2025	2035
🟥 Feebate Program	33.689	62.680	59.071
🟩 Bicycle Facilities	4.343	6.695	8.275
🟪 Hybrid Buses	0.425	1.429	2.448
🟦 Commute Strategies	2.314	4.260	12.965
🟧 Signal Optimization	0.425	1.429	2.448

Figure 15. GHG Reduction (Metric Ton per Day) for the Selected Mitigation Strategies.

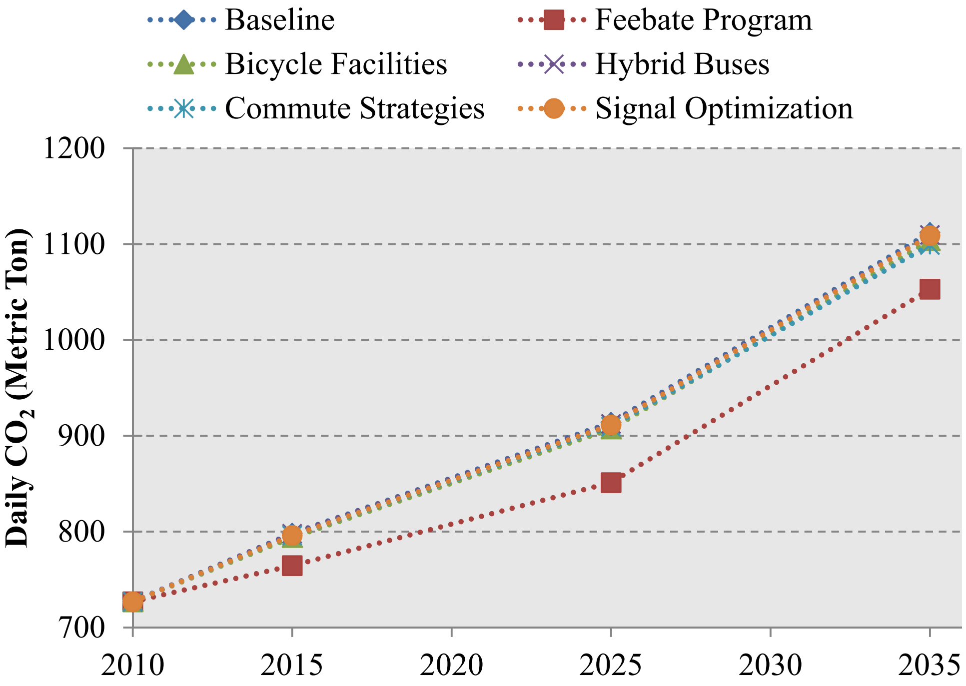


Figure 16. Total Amount of the GHG for Different Case Studies.

FINDINGS

The case studies demonstrated how the mitigation strategies of the framework can be accounted for at a planning level GHG analysis. A subsection of the Austin network around IH-35 was selected as the pilot network for this purpose, and the relevant TDM data obtained from CAMPO for this purpose. Analysis years used in this analysis were 2010, 2015, 2025, and 2035. The following summarizes the activities and findings from the completion of the case study:

- Five GHG mitigation strategies were selected and applied to the pilot network resulting in five case studies. The total daily CO_2 emissions for each case study were estimated using appropriate methods. In the case of this hypothetical example with specific set of assumption, it is seen that the feebate program would provide the highest magnitude of GHG reductions, while strategies such as hybrid buses and signal optimization are relatively less effective.
- All the GHG estimation calculations were based on a link-based methodology, i.e., speed and traffic flow information of each individual link were used to estimate the total daily emissions from that link.

- The research team performed an extensive literature review to find and establish appropriate methods for the case studies. The research team implemented the quantification process for each case study in an Excel spreadsheet and calculated the total daily emissions and as well as resulted reductions from the baseline.
- The calculation for each case study requires a different set of input parameters and assumptions. The level of analysis varies also depending on the data requirement and estimation methodologies, from a very aggregate analysis for signal optimization to a semi-link-based analysis for bike facilities.
- Where available, real-world data were obtained for the study section from different data sources including the CAMPO TDM and ESRI Demographics database.
- When local data were not available, appropriate assumptions were made based on the literature and the experience of the research team.
- Through this case study analysis effort, the research team was able to show how the proposed GHG mitigation strategies can be included in a GHG analysis at the long-range planning level. The key factor in performing such analysis is that all the estimation methodologies, data sources, and assumptions must be selected based on available planning-level resources.

CHAPTER 5: CONCLUSIONS

The research team developed a framework to link GHG emissions mitigation strategies with long-range transportation plans. The framework presented in this report is flexible, practical, and equips Texas transportation practitioners with tools needed to address GHG emissions in the long-range transportation planning process. The framework will prepare TxDOT and MPOs for any future GHG reduction legislation and can also serve as a starting point for TxDOT and its partner agencies in the absence of federal guidance on the subject of transportation GHG emissions reductions. The framework is structured to help guide MPOs on how to best implement control strategies and performance measures into their long-range planning process to reduce GHG emissions. Each step involves different stakeholders, processes, and challenges that can occur and need to be taken into consideration.

This concluding chapter identifies opportunities to keep the framework current and ensure its continued relevance. It discusses implementation of the framework, updating the framework and ensuring its continued use, recommended implementation workshops, and future related research.

IMPLEMENTATION OF FRAMEWORK

Three important guiding principles embodied by the framework include 1) the framework can be easily integrated into current transportation planning practice, 2) it provides guidance on specific steps and actions for how GHG emissions can be incorporated into each step of the process, and 3) the framework takes into consideration the Texas context, and addresses the likelihood of federal government regulations for reducing GHG emissions as part of the framework, rather than considering a framework that addresses state-level GHG regulation. Further suggestions for implementation of each of the framework steps are provided below.

Step 1: Identify the GHG Reduction Goals

Texas MPOs can begin to integrate GHG emissions reduction in the first step of the transportation planning process. This step presents an opportunity to begin the conversation on GHG emissions and their long-range impacts in Texas. This is perhaps one of the most important places to build a GHG emissions reduction vision and goals, and elicit public support for such a vision.

Step 2: Establish the Performance Criteria

Several methods ensure that performance criteria align appropriately with transportation vision and goals, specifically as they relate to GHG emissions reduction. The MPO can establish consistent data standards for quantifying GHG emissions in the planning process.

Step 3: Determine Strategies and Alternative Plans

This step requires the MPO to determine and choose which control strategies to implement for GHG emissions reduction. The MPO can choose strategies based on various criteria such being the easiest to implement, providing the most reduction or strategies with various co-benefits.

Step 4: Assess the Chosen Strategies

MPOs should assess and evaluate the effectiveness of their reduction targets or goals. It is important for MPOs to know and evaluate what are the most viable and effective strategies for meeting their emissions goals, and ensure that the GHG emissions strategies are not causing an undue burden on stakeholders or economic growth. MPOs want to evaluate to make sure the course of action is within the political will for their area and has support from stakeholder groups to secure a successful GHG emissions reduction plan.

Step 5: Assess the Alternative Strategies

This step can assess alternatives available to help mitigate GHG emissions. If MPOs did not incorporate measurements or evaluation methods, this would be a time to decide whether to add methods to the emissions reduction plans.

Step 6: Select Preferred Strategies

During this stage of the process, transportation agencies can examine different GHG mitigation strategies and select the most appropriate option. Stakeholder outreach and coordination is still a highly important component to ensuring that GHG emissions can be included in the transportation planning process. This stage of the process is best suited for examining which proposal might have the most opportunity for transportation co-benefits.

UPDATING THE FRAMEWORK AND ENSURING CONTINUED USE

Considering the findings from the investigations presented in this report, researchers offer the following recommendations on TxDOT continuing implementation of incorporating GHG emissions in long-range transportation planning in the Texas. In order to ensure continuing relevance of the framework, periodic updates, including a review of the state-of-the-practice and discussions with key TxDOT and MPO personnel is recommended. The Technical Working Group on Mobile Source Emissions (TWG) can also be used as a platform for discussion of GHG emissions implications to the state and provide a method for development of tools and resources to address them.

The main focus of the framework is MPOs as they are responsible for developing LRTPs for their regions and are best positioned to implement the framework. Texas MPOs can incorporate the framework during the development of their MTP. In the absence of federal or state direction, Texas MPOs could consider establishing reduction targets at the MPO level. Several MPOs in other states have proven successful at developing local GHG emissions reduction targets. For some of the state's larger MPOs, such as HGAC and NCTCOG, this could be a viable option to consider. These larger MPOs have the resources available to involve the public in a discussion about long-term GHG mitigation.

TxDOT can provide guidance and assistance to MPOs to work to reduce GHG emissions in their regions. TxDOT should consider the following as it pertains to MPOs incorporating GHG emissions into long-range transportation plans:

- Develop/incorporate complementary strategies that can support other transportation goals.
- Monitor federal legislation and possible future policies concerning GHG emissions regulation.
- Consider enhancing or revisiting state transportation goals, interagency and intermodal collaboration.

RECOMMENDED IMPLEMENTATION FOR MPOS

The research team recommends developing a half-day workshop, guidebook, and/or web-based information system for technology transfer that will promote the research findings and disseminate information to TxDOT and its partners. The target audience is MPO air quality staff, TxDOT TPP staff, and the staff of interested partnering agencies. The objective of developing educational supplementary information/training will be to introduce participants to the framework, helping participants understand the organization and contents of the framework so they can take full advantage of implementing the structure when opportunities are available or when the need arises.

SCOPE FOR FUTURE RESEARCH

Adaptation

This framework focuses on GHG mitigation/control strategies. However, adaptation is also an important component of GHG emissions planning. Adaptation measures such as improving infrastructure will reduce vulnerability of the transportation system to future climate change effects. A similar framework could also encourage or enforce implementation that focuses on adaptation issues, thereby complementing the current planning efforts on reducing GHG emissions during the long-range planning process. TxDOT can sponsor additional research that addresses the potential effectiveness of GHG adaptation strategies. Previous work has been performed on GHG adaptation in the state including the USDOT's *Gulf Coast Study.* While most adaptation studies have focused on coastal communities, adaptation strategies could benefit all regions of the state.

Transportation and Land Use

Research can also begin focusing on transportation, land use, and climate change scenario planning. This would attempt to inform transportation and land use decision-making, initially in selected study areas, by using scenario planning to analyze strategies to reduce GHG emissions and adapt to climate change impacts. Similar to this project, the goals of the research would be to advance climate analysis in scenario planning, develop a transferrable process, build partnerships, and impact decision making.

Additional Case Studies

Case studies would contain additional GHG mitigation strategies and evaluation methods. This would lead to an improved framework along with practical applications of GHG analysis for MPOs.

Performance Measurement

As mentioned in Chapter 2, the MAP-21 transportation authorization bill contains requirements for planning performance measures to be developed and adopted by states and MPOs. While performance measures are part of the framework developed in this research, further research can be performed to better align with MAP-21 requirements based on the outcome of the rulemaking process and other changes at the federal level.

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APPENDIX A. MPO CHARACTERISTICS

This table lists all Texas' MPOs specific characteristics including area of square miles, 2000 and 2010 population, population growth and number of staff members.

Table A1. Texas' MPOs Characteristics.

MPO	Area (Sq. Miles)	2000 Population	2010 Population	% Population Growth	Number of Staff Members
Abilene MPO	266	121,606	125,229	3.0	3
Amarillo MPO	348	196,133	216,490	10.4	3
Brownsville MPO	279	176,490	226,282	28.2	4
Bryan - College Station MPO	591	152,415	194,851	27.8	5
Capital Area MPO (Austin)	2840	1,159,836	1,603,952	38.3	17
Corpus Christi MPO	538	300,979	328,116	9.0	6
El Paso MPO	1240	721,562	853,190	18.2	14
Harlingen/San Benito MPO	343	133,971	153,819	14.8	2
Hidalgo County MPO	993	566,634	772,000	36.2	7
Houston-Galveston Area Council (HGAC)	8466	4,669,571	5,892,002	26.2	251
Killeen - Temple MPO	555	277,078	348,556	25.8	3
Laredo MPO	421	186,042	243,978	31.1	5
Longview MPO	178	94,830	103,406	9.0	3
Lubbock MPO	193	211,921	245,161	15.7	3
Midland-Odessa MPO (MOTOR)	528	230,489	267,927	16.2	4
NCTCOG (Dallas-Fort Worth)	4696	4,879,535	6,034,939	23.7	135
San Angelo MPO	96	91,470	96,283	5.3	3
San Antonio - Bexar County MPO	1287	1,415,906	1,763,463	24.5	13
Sherman - Denison MPO	320	80,736	86,830	7.5	2
South East Texas RPC (Beaumont - Port Arthur)	2229	385,090	388,746	0.9	4
Texarkana MPO	196	88,565	94,278	6.5	Not available
Tyler Area MPO	343	139,123	165,017	18.6	8
Victoria MPO	890	84,088	86,793	3.2	2
Waco MPO	1061	213,517	234,906	10.0	3
Wichita Falls MPO	153	108,074	108,311	0.2	3

Source: Transportation Planning Capacity Building, TEMPO

APPENDIX B. MTP SURVEY SUMMARY

This section provides a summary of MTPs from the surveyed Texas and non-Texas MPOs.

Bryan – College Station (BCS) MPO
In: BCS MPO MTP, 2010–2035 (latest update: February 2011)

BCS's most recent MTP makes an effort to consider climate change by identifying several programs that will reduce GHG emissions. Some of these programs, such as Texas A&M's ride share program, are already in place and contributing to GHG reduction. Others, such as telecommuting, operational improvements, and public transportation service improvements are suggested more broadly as possible options for reducing emissions.

Capital Area MPO (CAMPO)
In: CAMPO 2035 Regional MTP 2035 (latest update: October 2011)

CAMPO lists minimizing GHG emissions as one of the primary goals of its MTP. The City of Austin works with regional entities, including CAMPO, to reduce GHGs through reducing VMT, spreading anti-idling awareness, increasing the accessibility of alternative fuels, and replacing older vehicles with more efficient models.

Corpus Christi MPO
In: Corpus Christi MPO MTP 2035 (latest update: March 2011)

Under its goal relating to energy conservation and the environment, Corpus Christi's MTP recognizes transportation issues related to GHG emissions and climate change. It also acknowledges the transportation sector as the second largest contributor to GHG emissions. The MPO is currently discussing, with local governments, the possibility of land use changes and road pricing as possible mitigation strategies. In its transportation plans, the Corpus Christi MPO plans to use public transportation improvements and the promotion of non-motorized modes as policy tools for congestion management and GHG mitigation.

Houston – Galveston Area Council (HGAC)
In: Bridging Our Communities 2035 (latest update: January 2011)

HGAC acknowledges the area is a major contributor of on-road transportation sources to overall GHG emissions, as well as a contribution to Texas' total GHG emissions. In the most recent MTP, HGAC enumerates the anticipated effects of climate change on the area's transportation infrastructure. HGAC is currently working with TxDOT, TTI, and the Houston Advanced Research Center to estimate the area's GHG emissions and identify mitigation strategies for on-road sources. This research is expected to allow the agency to track mitigation efforts and reduction goals over time.

Longview MPO
In: Transportation 2035 (latest update: January 2009)

Longview MPO's most recent MTP acknowledges the causal relationship between fossil fuel combustion (largely from transportation) and GHG emissions, and subsequent climate change effects. The MTP discusses a number of possible physical and economic effects of climate change, and lists various strategies for GHG mitigation. More specifically, it points out that incorporating climate change and GHG transportation plans is a relatively new idea, but that VMT and congestion reduction strategies, land use patterns and policies, fuel-efficient vehicle and fuel technologies, and temperature and sea level effects on transportation systems are important issues to consider. The MTP lists possible mitigation strategies.

Midland – Odessa Transportation Organization (MOTOR)
In: Midland-Odessa 2035 Transportation Plan (latest update: November 2009)

MOTOR recognizes the national trend toward addressing GHGs in transportation planning and lists a number of general FHWA recommended mitigation strategies. The most recent MTP includes GHG emissions reduction as part of its air quality project evaluation guidelines.

North Central Texas Council of Governments (NCTCOG)
In: Mobility 2035 (latest update: March 2011)

NCTCOG's most recent MTP includes GHG reduction as a component of one of its air quality policies. It recognizes the transportation sector as the second largest contributor to GHG emissions, and the possible effects of climate change on transportation infrastructure and local communities. NCTCOG plans to begin incorporating CO_2 reduction as part of its multi-pollutant evaluation of projects and anticipates further guidance in this area from federal and state agencies. GHG reduction is also incorporated into the MTP's livability and quality of life improvement goals.

San Antonio – Bexar County (SA-BC) MPO
In: Mobility 2035 (latest update: December 2009)

SA-BC MPO references, in its most recent MTP, the scientific consensus regarding the greenhouse effect's contribution to climate change. It identifies mitigation strategies, as recommended by the FHWA. In 2009, SA-BC MPO conducted an analysis of development patterns, emphasizing the environmental effects of land use decisions. Looking forward, the MPO expects to incorporate GHG mitigation efforts into its existing goals, including in measures of quality of life, energy conservation, economic vitality, safety and mobility, and enhancing the environment.

Wichita Falls MPO
In: Wichita Falls 2010–2035 MTP (latest update: November 2010)

In its latest MTP, the Wichita Falls MPO lists GHG emissions reduction as one of the benefits of a number of its proposed programs. GHG mitigation is specifically emphasized as an effect of efforts through the Livable Communities Act, a program designed to help local communities create better and more affordable places to live, work, and raise families.

Review of Surveyed Non-Texas MPOs' MTPs

Denver Regional Council of Governments (DRCOG)

DRCOG was founded in 1955 as a nonprofit, public agency dedicated to serving local governments. DRCOG's planning area consists of Adams, Arapahoe, Boulder, Clear Creek, Douglas, Gilpin, and Jefferson counties, the City and County of Broomfield and the City and County of Denver, and southwest Weld County. DRCOG is the federally designated MPO for transportation in the region. The Board of Directors works with the Colorado Department of Transportation, the Regional Transportation District, the Regional Air Quality Council, and others to prepare transportation plans and programs. DRCOG is responsible for both long-range and short-range roadway and public transit plans.

Vision and Goals:

- The Colorado Climate Action Plan sets the goals of lowering statewide emissions from all sectors to 20 percent below 2005 levels by 2020 and to 80 percent below 2005 levels by 2050.
- DRCOG's MTP aims to reduce annual per capita GHG emissions from the transportation sector by 60 percent by 2035.
- The MTP also aims to reduce the per capita VMT by 10 percent from the 2010 value by 2035, and to reduce the percent of trips to work by single occupancy vehicles to 65 percent by 2035 (existing 2009 value = 74 percent).

The state of Colorado's GHG Inventory uses the EPA's State GHG Inventory Tool (SGIT) and follows the Emission Inventory Improvement Program (EIIP) guidelines to calculate emissions from the transportation sector. Transportation-related emissions were based on data from:

- US Department of Energy's Energy Information Administration (EIA) State Energy Data (SED) projections for gasoline, diesel, natural gas, LPG, and jet fuel and aviation.
- FHWA, Colorado DOT, Colorado Department of Public Health and Environment, and various MPO's projections for VMT.

Mitigation and Adaptation Strategies:

- Operational improvements.
- Adding lane-miles to reduce congestion.
- Transit improvements.
- Bicycle and pedestrian improvements.

Durham-Chapel Hill-Carrboro (DCHC) MPO

DCHC-MPO is the regional organization responsible for transportation planning for the western part of the Research Triangle area in North Carolina. The DCHC-MPO is an umbrella organization comprised of the Transportation Advisory Committee (TAC), the Technical Coordinating Committee (TCC), local governments, and the state. As with the other MPOs DCHC-MPO is expected to maintain and update an MTP, TIP, and UPWP.

One of the main goals of the MTP is to have a multimodal transportation system that provides access and mobility to all residents, while protecting the public health, natural environment, cultural resources, and social systems. However, the effort to reduce GHG emissions is currently a local effort. The City of Durham and Durham County completed an emissions inventory and defined their emissions reduction target by 30 percent from 2005 levels by 2035 from the community at-large, including emissions from the transportation sector.

The Durham County GHG Emissions Inventory and Local Action Plan consists of an inventory of GHG in the county, a forecast of 2030 emissions, an evaluation of measures to reduce emissions, and an implementation plan to achieve emission targets. This plan is a joint effort of the City of Durham, Durham County, and the DCHC MPO.

- The VMT are obtained from the TDM Triangle Regional Model (TRM).
- ICLEI used the Clean Air and Climate Protection (CACP) software to develop a GHG emission inventory, forecast, target, and local action plan.
- The CACP software uses a set of equations to describe the impact of a particular measure or strategy for the transportation and vehicle fleet sectors, as follows:

$$Emissions = VMT \times Emissions\ per\ VMT$$

$$VMT = (Person\text{-}Trips/Persons\ per\ Vehicle) \times Trip\ Length\ (miles)$$

$$Emissions\ per\ VMT = Fuel\ Efficiency \times Emissions\ per\ Unit\ of\ Fuel\ (emission\ coefficient)$$

$$CO2\ Emissions = (A/B) \times C \times D \times E$$

where A is the number of person trips made using the vehicle type, B is the number of people per vehicle (occupancy factor), C is the trip length, D is the fuel consumption (in Gal/100miles), E is the emissions per unit of fuel (i.e., the fuel type factor).

Mitigation Strategies:

- Increase Park and Ride Lots and Parking Fare.
- Bike Lanes.
- High Capacity Transit.
- High Occupancy Vehicle (HOV) Lanes.

- Transportation Improvement Projects.

Miami-Dade County MPO

The Miami-Dade County MPO is the federally designated transportation planning authority serving the mobility needs of the Miami urbanized area. The MPO divided Miami-Dade County into six distinct geographic units identified as Transportation Planning Areas (TPAs). The TPAs that comprise the county's geographic area are: Beach/Central Business District (CBD), Central, North, Northwest, South, and West. They are responsible for MTP (20-year strategic plan for roads, highways, pedestrians, cyclists, transit, and rideshare), TIP (the 3-year and 5-year priority list of funded projects that are going directly to construction crews), and UPWP (outlines studies that help to define future projects).

Vision and Goals:

Miami-Dade County's Climate Change Advisory Task Force (CCATF) coordinated with the MPO toward GHG reduction goals in its MTP. Miami-Dade County MPO has set the goal of reducing GHG emissions by 80 percent from 2005 levels by 2050.

The City of Miami's Climate Action Plan aims to reduce GHG emissions from the transportation sector by 565,000 metric tons by 2020.

The governor of Florida set by Executive Order the goal of reducing GHG emissions to 2000 levels by 2017, reducing GHG emissions to 1990 levels by 2025, and reducing GHG emissions to 80 percent 1990 levels by 2050.

Inventories:

The MTP includes an emissions inventory based on the EPA's Mobile 6.2 guidelines. CO_2 emissions were calculated using average fuel efficiencies from the Transportation Energy Data Bank, countywide VMT from the MPO's TDM (distinguishing between gasoline and diesel), and CO_2 emissions rates per gallon from RENEW Northfield.

The MTP includes the following GHG mitigation strategies:

- Managed lanes with priority given to hybrid and high-occupancy vehicles.
- Bicycle path and sidewalk projects.
- Express bus and bus rapid transit projects.
- Park-and-ride development and expansion.
- Congestion management and transportation demand management.

The State of Florida's Climate Change Action Plan includes the following adaptation strategies:

- Require Florida Building Code to incorporate climate change hazards into design criteria.
- Develop training provisions for professionals in relevant fields to incorporate climate change education into infrastructure design certification and licensing.

- Initiate a major public education and outreach campaign on climate change adaptation.
- Investigate the impact of possible climate change scenarios on water supplies.
- Promote the protection of vulnerable ecosystems along the coast.

Oregon GHG Emissions Taskforce

The Oregon DOT was established in 1969 to provide a safe, efficient transportation system that supports economic opportunity and livable communities for Oregonians. Oregon DOT develops programs related to Oregon's system of highways, roads, and bridges; railways; public transportation services; transportation safety programs; driver and vehicle licensing; and motor carrier regulation. Oregon DOT is a state-level organization and has control over the state MPOs. They are responsible for the state-level MTP as well as the implementation plans.

Vision and Goals:

The MPO GHG Emissions Task Force was formed to evaluate alternative land use and transportation scenarios that would meet community growth needs, while reducing GHG emissions and to recommend future legislative action to support such efforts. The state has set a GHG reduction target of 10 percent below 1990 levels by 2020 and 75 percent below 1990 values by 2050. This translates as 42.5 percent below 1990 levels by 2035 through linear interpolation.

Inventories:

The MPOs under the task force use GreenSTEP—a model that microsimulates households, vehicles, and travel characteristics to forecast emissions under different scenarios. GreenSTEP computes the GHG emissions based on county-level population projections of households, vehicle ownership, household VMT, truck VMT, bus and urban passenger rail VMT, speeds, and fuel consumption.

Mitigation Strategies from Oregon GHG Emissions Taskforce

Since the taskforce is a group of MPOs there is no single approach that every MPO is following. However most of the policies are based on the actions detailed in the Oregon Strategy for GHG Reductions. They are listed below:

- Adopt Low Emission Vehicle (LEV II) Emission Vehicle Standards.
- Adopt GHG Tailpipe Emission Standards (per California AB 1493 "Pavley" standards).
- Integrate land use and transportation decisions with GHG consequences.
- Review and enhance state tax credits and local incentives for citizens purchasing high efficiency vehicles.
- Incorporate GHG emission impacts into transportation planning decisions.
- Reduce GHG emissions from government fleet purchase and vehicle use.
- State and local governments should switch to clean diesel fuel, vehicle purchases, and retrofits.
- Set and meet goals for reduced truck idling at truck and safety stops.

- Establish consumer awareness education link to transportation choices.
- Improve mass transit and inter-city transit links.

Southern California Association of Governments (SCAG)

SCAG is the nation's largest metropolitan planning organization, representing six counties, 191 cities and more than 18 million residents. SCAG undertakes a variety of planning and policy initiatives to encourage a more sustainable Southern California. SCAG functions as the MPO for six counties: Los Angeles, Orange, San Bernardino, Riverside, Ventura, and Imperial. SCAG is responsible for the development of the MTP for the region.

Vision and Goals:

Among the goals that have been identified by SCAG for the 2008 MTP is to "protect the environment, improve air quality, and promote energy efficiency." The policies and the implementation strategies are expected to be detailed in the upcoming 2012 MTP.

- Though this goal does not explicitly state the reduction of GHGs, its measurement and mitigation have been detailed in the 2008 RTP. They have defined a 13 percent GHG reduction goal by 2035 (compared to 2005).
- Global Warming Solutions Act of California (AB 32) mandates California to reduce GHG emissions to 1990 levels by 2020.
- Executive Order S-3-05 sets long-term targets GHG emissions to 80 percent below 1990 levels by 2050.

Inventories:

The Draft SCAG GHG Inventory and Reference Case Projection prepared by The Center for Climate Strategies (CCS) for SCAG provides an initial comprehensive understanding of SCAG's current and possible future GHG emissions. The implementation plan based on this assessment is expected to be included in the 2012 RTP.

California Air Resource Board's (ARB) EMFAC Model is used for estimating emissions. Two different methodologies were employed depending on the vehicle fuel. The first is based on the amount of fuel combusted and emission factors, consistent with the Tier-2 IPCC methodology (applied for on-road vehicles combusting natural gas and all other transportation category). The second methodology uses an emission model based on tail pipe measurements and is consistent with the Tier-3 IPCC methodology (applied for on-road gasoline and diesel vehicles). The two primary information sources that are used the EMFAC model are:

- Activity data (VMT) from local and regional transportation surveys and models.
- Tailpipe emissions tests data from representative vehicle types.

Mitigation Strategies

- Increasing rideshare and work-at-home opportunities to reduce demand on the transportation system.

- Investments in non-motorized transportation and maximizing the benefits of the land use-transportation connection.
- TDM measures.
- Goods movement capacity enhancements.
- Key transportation investments targeted to reduce heavy-duty truck delay.

Sacramento Council of Governments (SACOG)

SACOG is an association of local governments in the six-county Sacramento region. Its members include the counties of El Dorado, Placer, Sacramento, Sutter, Yolo, and Yuba as well as 22 cities in the region. SACOG provides transportation planning and funding for the region, and serves as a forum for the study and resolution of regional issues. In addition to preparing the region's long-range transportation plan, SACOG approves the distribution of affordable housing in the region and assists in planning for transit, bicycle networks, clean air, and airport land uses.

Sacramento Preferred Blueprint Scenario is a plan that promotes compact mixed-use development and alternative transit choices, which was adopted by SACOG in December 2004. The 2035 MTP that was developed in 2008 builds upon the vision and strategies developed in the blueprint. The MTP explicitly states that *"SACOG intends to use the best information available to implement strategies and projects that lead to reduced GH) emissions."* The long-range planning is wholly based on scenarios developed in the Blueprint and travel forecasts estimates nearly 10 percent reduction in VMT per household by 2035, along with a reduction in average commute distance, and holds congested travel per household to less than a 5 percent increase.

The MTP adopted in 2008 does not measure the GHGs as a part of its emission inventory. It uses California Air Resource Board's (ARB) EMFAC Model for estimating emissions for air quality conformity. The two primary information sources that are used in the EMFAC model are:

- Activity data (VMT) from the SACMET TDM.
- Tailpipe emissions tests data from representative vehicle types.

The Sacramento Area Council of Governments has issued a GHG Regional Inventory Protocol (GRIP). The GRIP model allows formation of a regional emissions inventory using different sources and scales of available data. There are three main parts to the process, the first part is the inventory, the second part is the scenario process, and the final part is the formation of policy. This approach is expected to be implemented in the next MTP update due in 2012.

SACOG mitigation strategies focus on implementing the principles of Preferred Blueprint Scenario:

- Transportation choices.
- Housing diversity.
- Compact development.
- Mixed land uses.
- Use of existing assets.

- Natural resource protection.
- Quality design.

APPENDIX C. CURRENT GHG MITIGATION STRATEGIES

The following sections describe in detail each of the categories of GHG mitigations strategies currently adopted by various MPOs in their MTPs.

Vehicle Miles Traveled (VMT) Reduction

One of the primary strategies for reducing GHG emissions from transportation is to reduce the number of motorized VMT in the region. This approach aims to reduce emissions through a decrease in fossil fuel consumption caused by a decrease in roadway travel. As mentioned before, VMT-reduction strategies are being implemented by a large number of MPOs throughout the U.S. The VMT reduction strategies can be classified into categories of long-term and short-term VMT reductions.

Short-Term VMT Reduction

Short-term VMT-reduction strategies relate to reducing VMT by influencing individuals' daily travel decisions, including both incentive and disincentive approaches.

Incentive programs aim to add benefits to individual travel decisions that decrease the region's total VMT. One such method is to encourage a higher vehicle occupancy rate through:

- Promoting rideshare programs.
- Adding managed high-occupancy vehicle lanes.
- Specifying priority parking spaces for carpool vehicles.
- Encouraging employers to provide a guaranteed ride home from work in the case of a mid-day emergency for employees who do not drive their own personal vehicles to work.

Additionally, vehicle-sharing programs, such as Zip Car,[1] in which individuals pay to use a vehicle for short periods of time, allow people to use a private vehicle when essential without solely relying on alternative forms of transportation for daily travel needs.

In contrast to incentive programs, disincentive programs add a cost to private vehicle usage. Toll charges or congestion pricing are common disincentive programs. Other strategies include increased parking prices in central business districts, reducing parking requirements for buildings, and renting or selling parking spaces separately from building facilities.

Long-Term VMT Reduction

Unlike short-term strategies, long-term VMT-reduction strategies focus on modifying travel patterns in the long run. These strategies involve more fundamental changes in transportation-related systems and may be related to land use, employment, or other areas.

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[1] Technical Report 0-5541-1, Developing Sustainable Transportation Performance Measures for TxDOT's Strategic Plan.

Land-use planning can reduce VMT through:

- Mixed-use development.
- Transit-oriented development (TOD).
- Densification.
- Smart growth strategies.

Several policies may be enacted to promote the types of land development listed above. For instance, tax increment financing (TIF) can be used to encourage mixed-use and dense development. Additionally, location-efficient mortgages may facilitate TOD by facilitating mortgage financing along transit lines where household transportation costs are expected to be lower. Employment-related VMT-reduction strategies include encouraging telecommuting, alternative or off-peak work schedules, and four-day workweeks. Each of these reduces the VMT associated with commuting. Finally, another long-term strategy is pay-as-you-drive insurance, which directly associates a cost with VMT.

Mode Split

Many MPOs are incorporating strategies (within their MTP) aimed at shifting the mode split of a region away from private automobiles in their MTPs. Public transportation generally makes more efficient use of fuel and reduces GHG emissions relative to private automobiles,[2] and non-motorized transportation produces no emissions. Thus, policies and programs that encourage a shift from private automotive travel to public transit or non-motorized transportation reduce GHG emissions.

Public Transit

MPOs are using a number of different strategies to increase the mode split of public transit. The most common of these is to increase the service frequency or route coverage of transit services. In addition to these general transit improvements, the service provided by public transportation is also being improved by:

- Providing signal priority for transit vehicles.
- Adding intermodal hubs to provide seamless connectivity (including airports, passenger rail, and buses).
- Using a uniform fare collection system for all regional transit systems.
- Improving shelters or bus stops.
- Improving accessibility for persons with disabilities (according to Americans with Disabilities Act standards).
- Improving aesthetics surrounding transit stops.

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[2] Southwest Region University Transportation Center. Performance Measures for Metropolitan Planning Organizations.

In addition to these modifications to existing transit systems, some MPOs are considering adding bus rapid transit (BRT) services, which often utilize separated lanes to provide bus service comparable to light rail but at a fraction of the light rail cost.[3] Other MPOs are planning to add to park-and-ride services to increase the convenience of transit options in low-density areas. Beyond improving transit services, some MPOs are considering encouraging employers to provide a parking cash-out for employees who use transit to get to work and thus save the company the expense of building and maintaining additional parking space.

Transit, Rail, and Park-and-Ride Development

Arkansas is proposing a new program that will improve existing transit service and expansion of transit routes that can shift passenger transportation from single-occupant vehicles to public transit. This strategy will reduce GHG emissions by 7,000 tons of CO_2E by 2025. Maryland is pursuing enhanced connectivity of non-automobile transportation modes between cities through infrastructure and technology investments. This strategy will reduce GHG emissions by 300,000 tons of CO_2E by 2025. Minnesota is seeking to expand infrastructure and programs to increase transit ridership, carpooling, bicycling, and walking. This strategy will reduce GHG emissions by 300,000 tons of CO_2E by 2025. Iowa is seeking to achieve an annual ridership increase of 100 percent by the year 2020. This strategy will reduce GHG emissions by 206,000 tons of CO_2E by 2020. Arkansas is encouraging the reduction of transportation sector GHG emissions when transporting students to schools, colleges, and universities. This strategy will reduce GHG emissions by 13,000 tons of CO_2E by 2020. Iowa is reducing VMT associated with commuters traveling to and from work. This strategy will reduce GHG emissions by 13,000 tons of CO_2E by 2020.

The City of Pittsburgh, PA, is introducing new transit management programs, such as encouraging rideshare programs and telecommuting. The City of Alameda, CA, is seeking to develop transit-oriented streets. These streets will provide transit and shuttles with signal priority lanes and queue jumpers to make transit a more attractive alternative to the automobile. The City of San Rafael, CA, is considering providing transit and car pool incentives to city employees, including alternate work schedules and telecommuting opportunities to all its employees. This strategy will reduce GHG emissions by 155 tons of CO_2E by 2013. Evanston, IL, is seeking to encourage businesses to adopt strong employee commuting and telecommuting programs, providing resources and incentives to reduce the number of single-occupancy vehicle (SOV) commuters. The city is also seeking to support car-share programs by expanding designated parking for car-share vehicles, high-density neighborhoods, at new developments, and along transit lines. This strategy will reduce GHG emissions by 6,684 tons of CO_2E by 2020.

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[3] "Connections 2035 – The Regional Plan for a Sustainable Future." Delaware Valley Regional Planning Commission. January 2008.

Non-Motorized Transportation

Non-motorized transportation improvements are also central to many MPOs GHG reduction strategies. Almost every MPO aiming to mitigate GHG emissions has incorporated bicycle and pedestrian improvements into their MTPs. Many MPOs are planning general improvements to bicycling conditions, such as adding bike lanes, building bike trails, adding bike racks to shopping centers, and installing bike racks on buses. Additionally, some MPOs are creating bikeshare programs and publishing regional bicycle maps to promote bicycling among residents. Improvements to pedestrian conditions are also common and may include adding sidewalks, crosswalks, median refuge islands, pedestrian cut-through paths in cul-de-sacs, and audible cues to pedestrian signals. Traffic calming measures such as speed humps or chicanes are also being utilized to create a more pedestrian- and bicycle-friendly environment. Safe Routes to School programs encourage schoolchildren to walk or bicycle to school.

Smart Growth/Efficient Land Use Patterns

Reversing the United States' longstanding trends toward lower density development by promoting compact, mixed-use development would reduce the growth of travel and yield other benefits. Compact development shortens trip lengths and promotes walking, bicycling, and public transit. A recent National Research Council study and two other recent studies conclude that GHG emissions could be reduced by 10 percent or more by 2050 if 75–90 percent of all new development were "compact."[4] Other researchers found the potential for both smart growth and technology change to measurably offset the growth in mobile source CO_2 emissions projected to occur within large metropolitan areas by 2050. Across 11 Midwestern cities used in a study, the more aggressive of the two smart growth scenarios was found to reduce emissions of CO_2 by 8 percent at the median.[5]

Several different land use and transportation demand strategies have been adopted by cities and regions in pursuit of GHG emission reductions. These include:

- Adopted comprehensive plan goals or objectives to manage growth, reduce sprawl, and/or focus development in existing urban areas.
- Adopted comprehensive plan goals or objectives to encourage mixed-use, pedestrian-oriented, and/or transit-oriented development.
- Updated zoning code to manage growth, reduce sprawl, or focus development in existing urban areas.
- Updated zoning code to encourage mixed-use, pedestrian-oriented, or transit-oriented development.

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[4] Southwest Region University Transportation Center. Performance Measures for Metropolitan Planning Organizations.

[5] Cambridge Systematics, Inc. *Guidelines for Environmental Performance Measurements, Final Report.* NCHRP 25-25, Task 23, National Cooperative Highway Research Program, Transportation Research Board, National Research Council, Washington, D.C., June 2008.

- Adopted additional growth management tools such as transfers of development rights or conservation easements.
- Collaborated with nearby jurisdictions and/or regional agencies on regional or metropolitan-area growth management plans.
- Increased mass transit service (e.g., increased service frequency, added new bus or rail lines).
- Built new bicycle lanes, multiuse paths, or other bicycle or pedestrian amenities.
- Provided carpool matching or "guaranteed ride home" programs for commuters.
- Worked with private sector to provide subsidized transit passes and/or other programs to encourage employees to use alternative transportation modes.
- Other policies to reduce VMT by encouraging the use of alternative transport modes.

For specific examples, Arizona is seeking GHG reductions by facilitating fewer vehicle trips and total VMT. This strategy will reduce GHG emissions by four $MMTCO_2E$ by 2020. The City of Camden, CT, is examining the promotion of urban infill and denser, mixed-use development built to a human scale, with an emphasis on walkability and a more humane architecture.

Infrastructure Improvements

Relatively few MPOs are currently considering infrastructure improvements to reduce GHG emissions. However, Texas' HGAC, Utah's Wasatch Front Regional Council, and Connecticut's Housatonic Valley Council of Elected Officials are all considering adding grade separations at major intersections or railway crossings. This decreases idling time for vehicles waiting to cross intersections, and thus reduces fuel consumption and GHG emissions. Massachusetts' Montachusett Regional Planning Commission is planning to direct funds to degraded sections of roads to improve vehicle operational efficiency.

Management/Operations

Many MTPs contain goals of management and operations improvement to reduce GHG emissions. These strategies aim to decrease excess fuel burned due to inefficiencies in the transportation network. Common operational improvements are re-evaluating signal timing and coordinating signals to improve traffic flow. Some MPOs are also planning to implement ramp metering programs to reduce highway congestion and thus decrease time spent idling in traffic. Furthermore, some MTPs include plans to improve incident management coordination so that accident sites may be cleared more quickly to allow traffic to continue its normal flow.

ITS

Many MPOs are using Intelligent Transportation Systems (ITS) technologies to reduce GHG emissions. These strategies also have indirect impacts on emissions by influencing travel behavior. ITS can generally be broken down into user information services and automation of processes.

User Information Services

One main application of ITS technologies is to improve user information. This information can be provided in a number of different forms, including:

- Travel time information displayed on Dynamic Message Signs for highway drivers.
- Real-time vehicle arrival information displayed on signs at transit stops.
- Real-time travel information distributed to cellphone users.
- Electronic way-finding stations at key transit stops.

Each of these strategies improves either the efficiency and/or reliability of the roadway system (a driver may choose an alternate route to avoid traffic and save fuel) or adds convenience to the public transit system.

Automation of Processes

ITS technologies can also be used to automate elements of transportation systems, improving efficiency and reducing fuel consumption. For instance, adding vehicle detectors at signals can reduce delay. Some MPOs are also considering installing incident detection systems to cut down on emergency response time and the associated congestion. Furthermore, a number of MPOs are planning to install automatic pedestrian detection systems at signals.

Vehicle Fuel Efficiency

MPOs are considering a number of different strategies aimed at increasing vehicle fuel efficiency to reduce GHG emissions. These may be initiatives aimed at the public fleet of vehicles or privately-owned fleet of vehicles. In fact, many MPOs are planning to upgrade the public fleet of government and transit vehicles to newer and more fuel-efficient models.

There are a number of different strategies for encouraging increased efficiency in privately-owned vehicles, including:

- Tax exemption programs for cleaner or more efficient vehicles.
- CO_2-based excise taxes.
- Reduced registration and licensing fees for cleaner or more efficient vehicles.
- Promoting low-rolling-resistance tires.
- Anti-idling awareness to increase the efficiency of private vehicle operations.

Technology Improvements

Incremental improvements in vehicle technology include:

- More efficient combustion, such as variable valve systems, gasoline direct injection, cylinder deactivation.
- More efficient transmissions such as 5- and 6-speed automatic, automated manual, and continuously variable.
- Overall vehicle advances, such as aerodynamics and light-weighting.

Researchers project GHG emissions rates can be reduced by 20–30 percent with these technologies in new vehicles. Studies show that fuel savings from these improvements more than outweigh the increased vehicle cost, often by a large amount. Similar technology packages yield substantial GHG reductions and net positive benefits for commercial freight trucks as well.[6]

Lutsey and Sperling found much greater GHG reductions are possible with electric drive propulsion technologies. These include:

- Hybrid gasoline-electric vehicles.
- Plug-in hybrids which use both electricity and petroleum fuels.
- Battery electric vehicles.
- Hydrogen powered fuel cell vehicles.

Such technologies can double vehicle fuel efficiency. The life cycle GHG emissions, considering the potential to use low carbon electricity and hydrogen, can be reduced by at least 80 percent. However, these advanced technologies involve either larger initial costs, for electricity and hydrogen storage, and/or have high development costs and uncertain post-implementation costs.[6]

University of Minnesota researchers found that commercial trucks can increase efficiency with an array of technological enhancements and operational measures including:

- Improved aerodynamics for both trailer and tractor.
- Lower rolling resistance tires.
- Properly inflated tires ensured through automatic inflation systems.
- Low-friction lubricants.
- Reduced vehicle weight.
- Reduced speed.
- Driver training.

For an initial estimate of how heavy-duty vehicle technology improvements would affect Minnesota, national heavy-duty diesel VMT projections were apportioned to Minnesota based on the state 2004 VMT percentage. An estimate of the number of vehicles each efficiency improvement could affect and the resulting decrease in fuel consumption was assumed from a previous study. Table C1 from the study tabulates the estimated reductions measured against the transportation sector's goals from each of these efficiency improvements. It indicates that, in aggregate, the technology improvements could contribute approximately 10–16 percent of state 2015 and 2025 GHG emission reduction targets.

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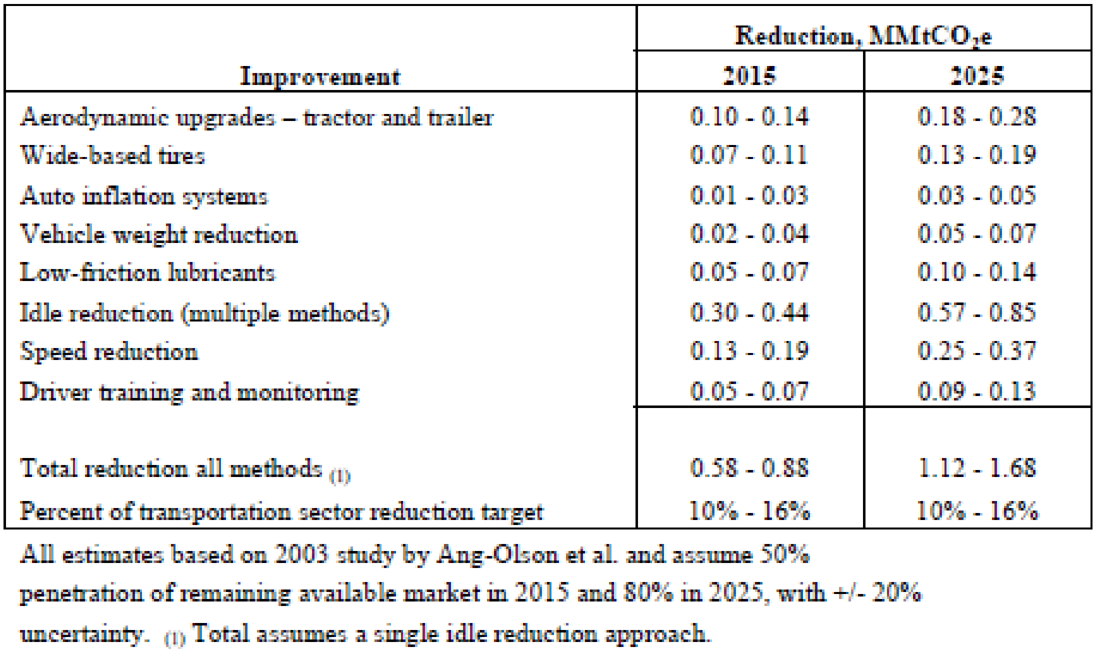
[6] U.S. Government Code, 23 USC Chapter 1 Federal-Aid Highways, 1962.
http://uscode.house.gov/download/pls/23C1.txt

Table C1. Estimated Contribution to Minnesota Total GHG Reduction Goals from Commercial On-Road Diesel Efficiency Improvements and Idle Reduction.



Improvement	Reduction, MMtCO$_2$e	
	2015	2025
Aerodynamic upgrades – tractor and trailer	0.10 - 0.14	0.18 - 0.28
Wide-based tires	0.07 - 0.11	0.13 - 0.19
Auto inflation systems	0.01 - 0.03	0.03 - 0.05
Vehicle weight reduction	0.02 - 0.04	0.05 - 0.07
Low-friction lubricants	0.05 - 0.07	0.10 - 0.14
Idle reduction (multiple methods)	0.30 - 0.44	0.57 - 0.85
Speed reduction	0.13 - 0.19	0.25 - 0.37
Driver training and monitoring	0.05 - 0.07	0.09 - 0.13
Total reduction all methods (1)	0.58 - 0.88	1.12 - 1.68
Percent of transportation sector reduction target	10% - 16%	10% - 16%

All estimates based on 2003 study by Ang-Olson et al. and assume 50% penetration of remaining available market in 2015 and 80% in 2025, with +/- 20% uncertainty. (1) Total assumes a single idle reduction approach.

Alternative Fuels

MPOs also are considering alternative fuel strategies for both the public and private vehicle fleets. Alternative fuels (such as ethanol, hydrogen, or natural gas) produce fewer GHG emissions than traditional gasoline.[7]

Many MPOs are planning to convert the public vehicle fleet and transit vehicles to models that run on alternative fuels. A number of MTPs also include plans for alternative fuel use in private vehicles. These strategies include providing a subsidy for a portion of the purchase cost of alternative fuel vehicles, allowing the use of managed lanes by alternative fuel vehicles, and providing free parking to vehicles that run on alternative fuels.

States also have an active role in defining fuel efficiency standards. The state-level regulations oriented to reduce GHG emissions are:

- Modify vehicle GHG emissions standards.
- Modify low carbon fuel standards.
- Incentivize/request the use of biofuels.
- Incentivize the use of plug-in vehicles.

Fuel Standards and Technology

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[7] http://ftp.dot.state.tx.us/pub/txdot-info/tpp/rural_2035/report/slrtp_final_summary.pdf p.6

Fuel standards and technologies refer to public strategies to mandate the use of low-carbon fuels or to develop alternative fuel technologies. Increased use of low carbon fuels, or fuels with lower life cycle GHGs, can greatly reduce overall transportation GHG emissions. Most alternative transportation fuels face a combination of infrastructural and economic barriers. The easiest action is to blend small proportions of biofuels into gasoline and diesel fuel. Biofuels are not necessarily less expensive, but the processes for converting abundant agricultural feedstock, such as corn and sugarcane, into ethanol are well known and ethanol is easily blended into gasoline for use in conventional vehicles. The GHG benefits of sugarcane conversion are substantial, compared to gasoline, but only about 10–20 percent for corn. Future biofuels, made from agricultural residue or cellulosic energy crops, could have life cycle GHG benefits of 90–100 percent. A similar array of biofuel feedstock can be used to produce biodiesel, which can be mixed into conventional diesel fuel.[6]

There are other transport fuel options systems involving wholly different fuels and fuel distribution systems that can greatly impact GHG emissions. Marginally lower GHG fossil fuels, such as compressed natural gas and liquefied petroleum gas have continued to make small contributions to transportation, mostly in fleet vehicles. On the other hand, next generation fossil fuels produced from oil shale, coal, and tar sands would have much higher GHG emissions than conventional petroleum, unless the carbon from such fuels was captured and stored underground.[6]

The alternative fuels most likely to have a larger role in the future are electricity, liquid fuels from biomass, and hydrogen. A report from the Argonne National Laboratory explains:

- Electricity has become a viable option, due to the development of lithium-ion batteries and plug-in hybrid electric vehicles (PHEVs). PHEVs with electric ranges of 10 to 40 miles overcome the range limitations of pure electric vehicles (by allowing the vehicle to shift to gasoline operation when the battery is depleted). Battery cost and lifetime remains an issue and the GHG benefits of PHEVs depend on the extent to which the electric grid is decarbonized.
- Liquid fuels from biomass offer another strong opportunity. Certain types of biomass fuels can virtually eliminate GHG emissions (on a lifecycle basis) from the vehicles in which they are used. Two key remaining issues are reducing biomass fuel costs and preventing adverse land use impacts.
- Hydrogen remains a prospect although earlier enthusiasm has waned. Hydrogen fuel cell vehicles (FCVs) emit no GHGs or other pollutants, although their lifecycle emissions depend on how the hydrogen is produced and distributed. FCVs have already demonstrated ranges of 300 miles, while refueling nearly as quickly as

gasoline vehicles. However, hydrogen requires a new refueling infrastructure and the vehicles remain very expensive.[8]

The Renewable Fuel Standard (RFS) program, as required by the Energy Independence and Security Act of 2007, currently ensures that transportation fuel sold in the U.S. contains a minimum volume of renewable fuel. The new renewable fuel standards increase the volume of renewable fuel blended into transportation fuel to 36 billion gallons by 2022. In June 2011, the EPA released a proposed rule that might increase the total amount of renewable fuel required in the nation's motor fuel supply in 2012. For 2012, the agency is proposing 15.2 billion gallons of renewable fuel, about 9.2 percent of all fuel used in the U.S., and up from 13.95 billion gallons in 2011.[9]

Several states are also pursuing low carbon fuel standards. Iowa is seeking to reduce GHG emissions by decreasing the carbon intensity of vehicles fuels sold in Iowa. This strategy will reduce GHG emissions by 5.1 $MMTCO_2E$ by 2020 at a cost of $62 per ton of CO_2E removed. South Carolina is also seeking to reduce GHG emissions by decreasing the carbon intensity of all passenger vehicle fuels sold in the state. This strategy will reduce GHG emissions by 3.7 $MMTCO_2E$ by 2020 at a cost of $183 per ton of CO_2E removed. Montana is seeking to increase the use and market penetration of low-carbon fuels to offset traditional fossil fuels. This strategy will reduce GHG emissions by 0.04 $MMTCO_2E$ by 2020. North Carolina is seeking to offset fossil fuel use (gasoline) with production and use of starch-based and cellulosic ethanol. This strategy will reduce 0.04 $MMTCO_2E$ by 2020. The City of Austin, Texas, is developing infrastructure for fueling stations and electric plugs. The City of Seattle, Washington, is examining the use of smaller, more fuel-efficient vehicles as taxicabs and offering incentives to taxicab owners to use gas-electric hybrid vehicles.

Agricultural production for biofuel offsets of up to 317 million tons of CO_2 can be generated from energy crops and waste residue at $37 per ton of CO_2 reduced. Due to the competitiveness for that agricultural feedstock between transportation and electricity generation sectors under a GHG mitigation scenario, and without available research to determine a more likely apportionment, half of the agricultural feedstock apportioned to each sector. The result is that at that cost-effectiveness value of $37 per ton, agriculture sector will generate 16 billion gge (from half of the overall expanded waste and energy crop production) after the shift is fully implemented in year 2030. Using the 85 percent life-cycle GHG reduction (per gge) gasoline displacement estimation, the resulting transportation sector GHG reduction in 2030 is

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[8] Meyer, Michael and Eric Miller. Urban Transportation Planning. Second Edition. 2001.

[9] http://www.fhwa.dot.gov/environment/climate_change/adaptation/resources_and_publications/integrating_climate_change/page02.cfm#section-2-1

approximately 124 million tone CO_2 per year for the displacement of this amount of motor gasoline.[10]

Researchers at the University of Minnesota modeled three alternative fuel scenarios in an attempt to meet a low-carbon fuel standard (LCFS) in an attempt to reduce the average fuel carbon intensity (AFCI) statewide by 10 percent by 2020 and 12 percent by 2025. An LCFS is a market-based mechanism that requires fuel providers within the state to reduce fuel carbon content at the pump by a specified percentage over a given period of time. Fuel providers are required to calculate the carbon intensity of their fuels. Carbon intensity includes total life-cycle emissions, incorporating GHG emissions associated with the production, transportation, and storage of the fuel as well as any land use changes that may have a climate-changing effect. Fuel providers are allowed to reduce the carbon intensity of their fuels by blending them with lower carbon fuels or by purchasing carbon credits from other providers. The result would be a lower statewide average carbon intensity of fuels, which would in turn lower total transportation GHG emissions.

To meet the AFCI targets, analysts studied two variables: the percentage (E10, E20) of ethanol in the fuel and the carbon footprint of the ethanol production process. E10 is currently mandated in Minnesota and E20 is mandated in 2013, but the latter's use requires EPA approval. It was assumed that diesel fuel would remain the same, with 2 percent by volume coming from biodiesel.[11] The three models consisted of:

1) An LCFS in which the entire Minnesota LDV fleet was fueled with E20 produced by the existing commercial method that produces ethanol from corn using natural-gas-fired distillers.
2) Assumes E20, but with all ethanol produced from corn using a dry-mill process in a refinery burning stover (leaves and stalks) to make process heat. This process reduces the ethanol portion of carbon emissions from 76 to 47 g CO_2e/MJ.
3) The ethanol feedstock is switched from corn to cellulosic material, and an E10 blend is assumed. Ethanol produced from cellulosic feedstock was phased in at an assumed rate.

Scenario 2 showed that a 10 percent AFCI reduction is achievable by 2020, but not the 12 percent goal. This is due to traditional gasoline vehicles not able to accept quantities of ethanol in excess of 20 percent. Minnesota produces enough corn to produce the E20 needed in the scenario, but using more corn to produce fuel may have adverse consequences, such as conversion of virgin land to cropland both domestically and abroad. In addition, the removal of corn stover from the cropland may contribute to soil degradation. Scenario 3 achieved the 2020 and 2025 targets even without changing from E10 to E20, demonstrating the importance of the fuel processing methods and source of biomass. The benefits from this conversion to cellulosic material from prairie grass are derived because there is a greater than 90 percent reduction in the

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[10] http://www.greenbuilder.com/general/txenvinfo.html

[11] http://www.tceq.state.tx.us/assets/public/implementation/air/rider8/Rider8-tceqContacts.pdf

AFCI from Midwest average corn ethanol (76 gCO_2-e/MJ) to cellulosic ethanol derived from Midwest prairie grass (7 gCO_2-e/MJ).[11]

Going forward, the success of alternative fuel vehicles, and the substitution of significant quantities of gasoline and diesel fuels, will depend on several factors:

- The new vehicles and fuels must become cost competitive.
- A research, development, demonstration, and deployment (RDD&D) program must be sustained and robust.
- Major mistakes (such as safety problems) on the part of vehicle designers and fuel providers must be avoided.
- Government and/or industry must subsidize elements of the new fuel system until it becomes self-sustaining.
- Gasoline and diesel prices must remain high due to sustained high world oil prices or government's willingness to use taxes or other pricing policies.[8]

Freight and Aviation

A small fraction of MPOs uses freight-related strategies to reduce GHG emissions. These strategies either target intermodal hubs or truck-based freight.

GHG emissions reduction at intermodal freight hubs is achieved through increased efficiency in cargo loading and unloading, which then decreases idling time and energy consumption at the hubs.

Reductions in truck-based-freight-related GHG emissions may be achieved in several ways. Many MPOs are planning to decrease fuel wastes through increasing the enforcement of heavy vehicle idling limits or to providing electric hook-ups at overnight truck parking facilities to prevent the need to run diesel generators. Others are considering the addition of a truck-only highway lane to avoid freight-related congestion issues. Furthermore, some MPOs are planning to issue loans for truck owners to buy new, more efficient, cleaner vehicles that will in turn produce lesser GHG emissions.

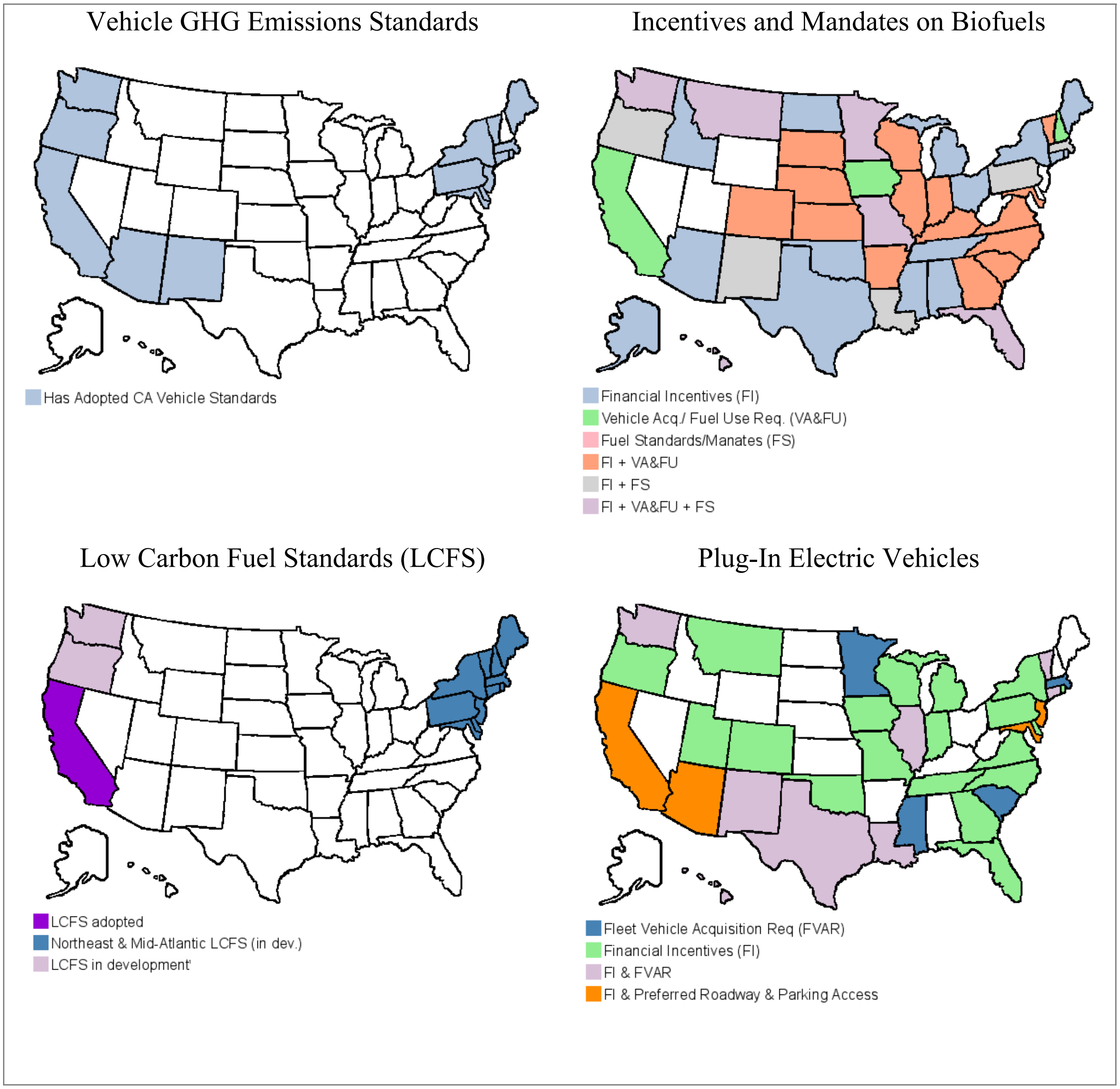

Figure C1. State Regulations on Vehicle Alternative Fuels.

Source: Center for Climate and Energy Solutions (18)

In terms of reducing aviation-related GHG emissions, the Massachusetts Port Authority (Massport) plans to improve the efficiency of aircraft movement through taxiway improvements, constructing a new runway, and demand management through peak period pricing. Additionally, the state plans to advocate for increased aviation efficiency in national stakeholders meetings for the aviation industry.

Implementation Challenges

Researchers have noted a number of important challenges to effective implementation of land use and transportation demand strategies:[11]

1. *Decentralized decision making* – Land use decision making is decentralized, typically requiring coordination at several levels of government. This can make effective implementation challenging, as competing interests within multiple layers of government strive for different goals.
2. *Insufficient funding* – Infrastructure development is capital intensive and often requires obtaining federal or state funds through competitive, lengthy, and expensive processes. The uncertainty surrounding future funding at any governmental level creates challenges in project planning and prioritization.
3. *Induced demand* – Efficiency improvements generally reduce travel times and costs. These improvements often stimulate induced demand, thereby reducing the improvement's effectiveness.
4. *Consumer preferences* – Citizens consider more than just transportation costs when choosing where to live and work and how to travel. Given the complexity of transportation and land use systems, it is often difficult to measure, estimate, or predict the impact of specific strategies, thereby making choices more difficult.

Education and Outreach Programs

Federal, state, and local officials can create policies based on the belief that incentives and voluntary strategies are viable solutions to reduce GHG emissions. Many who believe that most GHG standards and requirements are unlikely to achieve emissions reduction goals see merit in this approach. Incentive programs include passenger vehicle incentives and outreach programs directed at educating the public about effective GHG mitigation techniques. Federal, state, and local programs can encourage the purchase of more fuel-efficient vehicles or discourage the purchase of inefficient ones.

Passenger Vehicle Purchase Incentives

There are several strategies pursued by some states to encourage less driving. Arizona is pursuing a combination of public education and information and financial incentives to promote the sales of light-duty vehicles with a hybrid gasoline engine. Maine is imposing a fee on purchases of relatively high-emitting (more CO_2 per mile) vehicles and purchasers of low emitters would receive a rebate. This strategy will reduce 20,000 metric tons of CO_2E by 2020. New York is pursuing a vehicle sales tax incentive credit. This strategy will reduce 5,000 metric tons of CO_2E by 2020. Virginia is pursuing enacting state incentives for the purchase of fuel-efficient vehicles, regardless of energy source. This strategy will reduce four $MMTCO_2E$ by 2020.

Feebates are financial incentives for manufacturers to produce, and consumers to buy, vehicles with reduced carbon emissions. In a full feebate program, a rebate is offered for vehicles with emissions below a selected level, and a fee is added to vehicles emitting above that level. With proper design the policy can be revenue-neutral with fees covering rebates. No state has implemented a vehicle feebate policy. However, studies of a California feebate program show that it would be effective alone or in conjunction with the California standards. Studies indicate that the majority of the impact of a feebate program comes from manufacturers redirecting production rather than consumers shifting behavior. Manufacturers will add efficiency technology in response to the fee/rebate so long as the marginal value to consumers exceeds the marginal cost to the automakers.[11]

Driver Education

Several states and municipalities have also pursued GHG education and outreach programs aimed at educating and convincing travelers to make efforts to reduce emissions associated with their travel. Driver education programs aim to influence driver behavior/practice driving habits toward more fuel efficient practices. This could involve making fuel efficient driving practices part of driver training curriculum for both commercial and private licenses. The curriculum could include dissemination of information to discourage unnecessary idling and peak-time congested travel, encourage shifting to higher gears more quickly, and inform on the use of overdrive and cruise control on highways. Consumer and maintenance education programs would train on recommended maintenance schedules, tires (on maintaining inflation levels and on low rolling resistance tire purchases), alignment, oil changes (frequency and low friction oil purchase), and air filter replacement. Another alternative is for manufacturers to deploy technologies that aid in driver awareness of fuel economy, such as on-board indicator technologies like an instantaneous fuel economy meter, a tachometer with “efficiency rpm range,” shift indicator lights (for manual transmissions), and a tire inflation monitor.[10]

Texas has the longest running statewide program, “Drive Clean Across Texas.” This program encourages Texans to reduce emissions by maintaining vehicles according to manufacturer recommendations, driving less and combining trips, buying “cleaner” vehicles, driving within the speed limit, and not idling. Fort Worth also has an active outreach and education program that explains steps people can take to perform proper maintenance, conserve energy, and reduce emissions. [12] Houston’s “commute solutions” educational program encourages carpooling, vanpooling, and other ridesharing options.[13] In 2011, the Massachusetts DOT launched a new campaign with tips and advice to help drivers save money on fuel, improve fuel economy by up to 33 percent, and help reduce CO_2 and other GHG emissions. The state’s website includes tips

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[12] City of Fort Worth. Environmental Management, accessed August 23, 2011. *Available at:* http://fortworthtexas.gov/dem/info/default.aspx?id=7996.

[13] Commute Solutions Houston: A Smarter Way to Work, Accessed August 23, 2011. *Available at:* http://www.commutesolutionshouston.org/.

on driving less, driving slower, avoiding fast stops and starts, avoiding idling, and maintaining appropriate tire pressure.[14] The North Carolina DOT is currently pursuing a "Drive Green, Save Green" campaign. This campaign serves as a way to inform drivers how to reduce CO_2 emissions and save money.[15] The City of Denver, CO, is pursuing the first internet-based vehicular GHG management system. This program will empower organizations to reduce CO_2 emissions, increase vehicle mpg, and lower fuel costs.[16]

The most effective "in-use" technologies that are improved by education programs include:

- A shift indicator light for manual transmissions.
- Dual cooling circuits.
- Tire inflation monitor.
- Low rolling resistance tires.

Other relatively cost effective in-use technologies include the use of low friction oil and improved accessories use. In fact, the proposed California GHG regulation for light duty vehicles incorporated improved efficiency accessory use, including high efficiency variable displacement air conditioning compressors, in its establishing its GHG standards.[10]

The use of these "in-use" technologies and programs to improve the "on-road" fuel consumption could be considered somewhat more uncertain. For the use of any sort of education programs are less predictable and are less easily validated. Implementation of some in use improvements would also need a combination of support from government agencies, manufacturers, and dealerships to disseminate information as needed.[10]

Many of the education-related techniques involving driving behavior modification and proper vehicle maintenance are also applicable to efficiency improvements for the light-duty fleet. The EPA's SmartWay Transport Partnership program encourages implementation of many of the technologies and operational changes noted above.[11]

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[14] MassDrives: Families Drive Smart, accessed August 24, 2011. *Available at:* http://www.commute.com/.

[15] North Carolina Drive Green Save Green Campaign, accessed August 23, 2011. *Available at:* http://www.ncdot.gov/programs/drivegreen/.

[16] City of Denver. Driving Change, accessed August 22, 2011. *Available at:* https://www.drivingchange.org/home.aspx.

APPENDIX D. ADAPTATION PLANS AND STRATEGIES

Adaptation planning involves a process of identifying the systems that are most at-risk and the reasons for this heightened exposure. There are three focus areas that need to be investigated for creating an adaptation plan:

1) **Exposure** is related to the expected types of climate changes and their impacts on the transportation system. Exposure also considers the plausible range of severity, which includes the duration, frequency, and magnitude of changes in average climate and extreme climates.
2) **Sensitivity** relates to the extent to which the system is (or systems are) likely to be affected as a result of projected climate changes. Sensitivity considers whether the impacts may be irreversible (such as death, species extinction or ecosystem loss) or temporary, and examines the plausibility of other substantial impacts (such as extensive property damage or food or water shortages).
3) **Adaptive Capacity** relates to the extent to which the system can adapt to plausible scenarios of climate change and/or cope with projected impacts.

Because of the current and projected climate disruption precipitated by high levels of GHG emissions by the industrialized nations, adaptation is a necessary strategy at all scales to complement climate change mitigation efforts. However, this comes with a caveat, as "adaptation to climate change has the potential to substantially reduce many of the adverse impacts of climate change and enhance beneficial impacts, though neither without cost nor without leaving residual damage."[17]

There are two types of adaptation strategies to climate change—anticipatory and reactive, which are illustrated in Table D1. According to IPCC, anticipatory strategies are those that are made before impacts of climate change are observed. Thus, anticipatory strategies acknowledge possible impacts and plans are made in advance. Reactive strategies are those strategies that are undertaken after the impact is observed. The ecological, social, and economic costs of relying on reactive strategies are substantial, but many of these costs can be avoided through planned, anticipatory adaptation.

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[17] McCarthy, James J. (2002) Climate Change 2001: Impacts, Adaptation, and Vulnerability, IPCC. *Cambridge University Press, Cambridge.*

Table D1. Types of Adaptation to Climate Change.

		Anticipatory	**Reactive**
Natural Systems			• Changes in length of growing seasons • Wetland migration • Changes in ecosystem composition
Human Systems	*Private*	• Purchase of insurance • Construction of houses on stilts • Redesign of oil rigs	• Changes in farm practices • Changes in insurance premium • Purchase of air-conditioning
	Public	• Early warning systems • New building codes, design standards • Incentives for relocation	• Compensatory payment subsidies • Enforcement of building codes • Beach nourishment.

Source: IPCC 2001

The effects of a changing climate could have serious consequences on the safety and preservation of surface transportation systems. Potential impacts to the transportation sector may include:

- Accelerated deterioration of roadways.
- Flooding of roadways and increased storm-water issues.
- Storm surge damage to docks and other facilities.
- More frequent landslides.
- Bridge damage from storms, and structural degradation of bridge materials.
- Rail buckling from higher temperatures.
- Reduction in aircraft lift and efficiency due to higher temperatures.
- Reduced water levels affecting ships and barges.
- Increased load on the transportation system due to evacuation of adjacent zones.
- Sea level rise and increased flooding.

Adaptation Strategies in MTPs

Based on the review of several MTPs, four steps are usually followed to implement an adaptation strategy.

1) Step 1: The first stage of an adaptation planning process is to develop a detailed climate vulnerability assessment and an adaptation plan for the state's transportation infrastructure.

   Vulnerability assessment begins with the identification of existing stressors facing transportation systems, and projects how climate change will impact and/or introduce new stressors in the future. The findings of the assessment can then be ranked to assess, prioritize, and address vulnerabilities.

Risk assessment evaluates the likelihood and consequence of climate-related impacts on transportation systems, typically based on the product of the probabilities of exposure and vulnerability. This assessment provides transportation policymakers with guidance based on the quantitative analysis of the level of risk associated with changing climate conditions.

Adaptation assessment identifies plans and prioritizes, implements, and measures transportation management options available to effectively adapt to climate change impacts. This assessment may discuss ways to reduce transportation vulnerability, increase resilience, and/or highlight regions of retreat.

The assessments above may be undertaken for various alternative scenarios that may occur. A probabilistic chance of occurring is assigned to each scenario (scenarios may include flooding, earthquake, visibility issues, land use change due to environmental change and emergency evacuation traffic). The scenarios are then simulated using software that combines the spatial data with the scenario event, generally using GIS to output the final state of the infrastructure if the event occurs.

The vulnerability level of the system is primarily dependent on its resilience to change. Hence if a good adaptation plan is undertaken, the system resilience increases and its vulnerability decreases.

2) Step 2: Based on the vulnerabilities identified in the previous step, the climate change vulnerability assessment planning tools, policies, and strategies are incorporated into existing transportation and investment decisions.

   The tools may be categorized into three groups based on function:

   - **Process Tools** are those that help a community design and pursue a planning process that addresses the vulnerabilities, risks, and uncertainties inherent in climate-related transport planning. Examples of process tools include the Adaptation Database for Planning Tool (ADAPT), CRiSTAL (Community-based Risk Screening Tool – Adaptation and Livelihoods), NOAA CSC Coastal Inundation Toolkit, and CSC Roadmap.

   - **Visualization Tools** allow users to build unique tools and simulations that enable stakeholder engagement though the use of pictures or web-based tools. The tools in this group are generally simple to use, but can include web-based GIS visualization that require special software, hardware, and expertise. CanVis, Google MashUps, and NOAA Coastal County Snapshots are examples of visualization tools.

- **Socio-economic Tools** provide community level socio-economic data that allows planners and stakeholders to visualize, explore, and understand the social impacts that could result from future hazards and climate change. Spatial Trends in Coastal Socioeconomics (STICS) and SoVi (Social Vulnerability Index) are examples of tool under this category.

- **Analytical Tools** allow planners to investigate current conditions and ecosystem processes, determine the effects of potential future conditions, and explore scenarios to determine potential effects of planning decisions. These are the most technically challenging of the tools, often requiring GIS software, expertise, and training. HAZUS-MH (Hazards U.S., Multi-Hazard), Sea Level Rise Affecting Marshes Model (SLAMM), Land Use Portfolio Model (LUPM), and SimCLIM are examples of this type of tools.

At this stage the decision-maker must come up with a criterion that he/she feels should define the threshold for the impact of scenarios for categorization as *high risk* and *low risk*. Appropriate classes of policies and strategies should then be developed specific to these classes of events and to the nature of the scenario.

3) Step 3: The third stage of an adaptation planning process is to update the transportation design and engineering standards to minimize climate change risks to vulnerable transportation infrastructure.

4) Step 4: The final step is to incorporate climate change impact considerations into disaster preparedness planning for all transportation modes. Disaster preparedness is a process of ensuring that an organization (1) has complied with the preventive measures, (2) is in a state of readiness to contain the effects of a forecasted disastrous event to minimize loss of life, injury, and damage to property, (3) can provide rescue, relief, rehabilitation, and other services in the aftermath of the disaster, and (4) has the capability and resources to continue to sustain its essential functions without being overwhelmed by the demand placed on them. Preparedness for the first and immediate response is called emergency preparedness.

Few MPOs currently have full-fledged adaptation strategies for their transportation systems. The adaptation plan is, in most cases, a part of State Climate Action Plans (CAPs), which include strategies for each economic category: agriculture, commercial, electricity generation, industry, residential, and transportation. Consequently, the MPOs design their adaptation policies based on the CAP. States that have already incorporated adaptation plans into their CAPs are shown in Figure D1. An overview of the nature of adaptation plans at MPOs that currently include this element in their MTP is provided below.

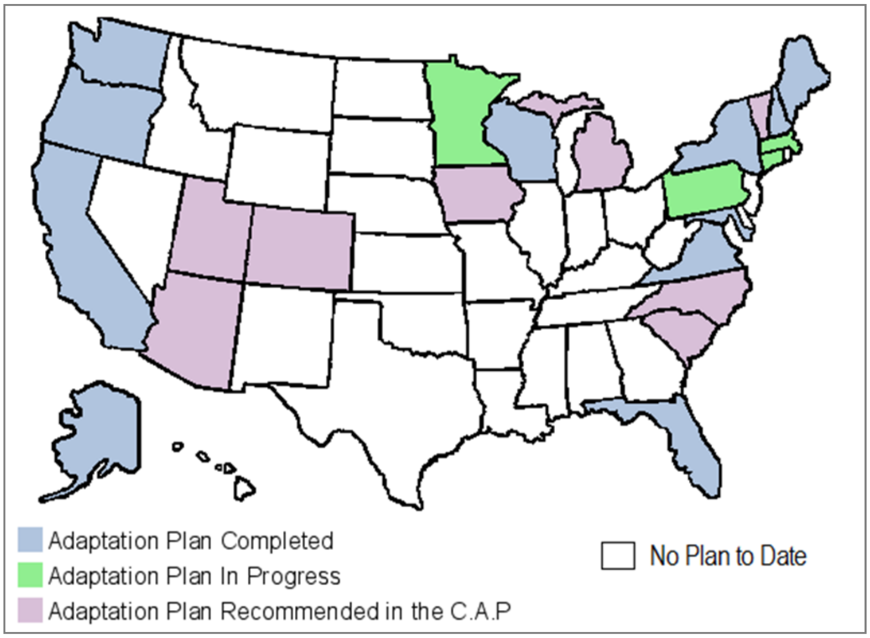

Figure D1. State Adaptation Plans.

Source: Center for Climate and Energy Solutions

Puget Sound Regional Council (PSRC), WA

The Puget Sound Regional Council is not currently taking action to adapt the transportation system to a changing climate. Deciding how to incorporate adaptation into the MTP is a particular challenge. As with many MPOs, PSRC is an agency that plans for and coordinates the efforts of local jurisdictions, but the agency has no implementing authority. The agency feels that it lacks clarity in terms of what role it should play in establishing protective measures.

However, PSRC has published a white paper on Climate Change Adaptation, which recognizes the need to include adaptation to climate change in the MTP. The agency anticipates impacts due to long term climate change; these include rising sea levels, increased flooding, and an increase in the frequency and severity of storms and other weather events, droughts, wildfires, impacts to water availability and quality, and impacts to crops. Specific to transportation, predicted impacts include the accelerated deterioration of roadways, issues related to flooding and increased storm water, bridge damage, rail buckling, and reduced water levels in some water bodies that could affect the passage of ships and barges. PSRC has evaluated these potential impacts to transportation infrastructure in the Puget Sound region, including the port areas, which would be most affected by rising sea levels.

Southern California Association of Governments (SCAG), CA

The SCAG 2012 Regional Transportation Plan (RTP) addresses climate change in its trends and challenges and performance measures. The plan's environmental document proposes GHG mitigation measures and identifies key impacts that will have adverse consequences for public health, economic livelihoods, the financial sector, the insurance industry, individual comfort, and recreation. They anticipate a need to cope with scenarios such as:

- Longer and hotter heat waves.
- Increased urban heat island impacts, such as heat-related illness and higher cooling demand and costs.
- More damaging storms and storm surges.
- Greater river flooding.
- Increased frequency and intensity of combined sewer overflows.
- More intense and extended duration of droughts.
- Longer water supply shortages.
- Declines in local ecosystem services, such as species loss or the loss of specific ecosystem types (e.g., forests or coastal wetlands).

The MPO has come to an understanding that climate and impact modeling can offer a scientific basis for more informed planning, including improved data gathering. However, it is imperative to have additional monitoring, development of improved management practices, and coordination among state and local agencies and the private sector. SCAG feels that adaptation to these new risks is possible through resilient resource and land-use choices.

Roanoke Valley Area MPO, VA

Roanoke valley has done extensive flooding scenario testing and has compiled a list of links and other infrastructure that may be adversely affected by flooding. The MPO has also analyzed population shifts due to the environmental conditions from one TAZ to another and the associated strain that these shifts might have on the transportation infrastructure.

South Western Region MPO, CT

The MPO has done a scenario evaluation of increased storms and identified culverts that may not be able to handle the storm-water surge. Additionally, they have tested the impacts on the transportation system caused by a mass evacuation from New York City.

Houston-Galveston Area Council (H-GAC), TX

The H-GAC acknowledges the need for climate change adaptation and mitigation in the trends and challenges of its long-range plan. The MTP includes a section on Transportation and Climate

Change, which describes the phenomenon of climate change and its potential impact on the transportation system of the Houston-Galveston region. It references joint research efforts with the U.S. DOT and other agencies to identify potential impacts of climate change on the system and ultimately to identify adaptation strategies.

Broward MPO, FL

The Broward 2035 MTP defines many approaches and policies to address issues related to climate change and to reduce GHG emissions. However, these are primarily mitigation-focused strategies. The Broward County Climate Change Action Plan published in May 2010 discussed in detail adaptation strategies and the possible ramifications these will have on transportation policies. The recommendations made in this document are expected to be recognized by the MPO in their next cycle of MTP update.

APPENDIX E. MPOS AND MITIGATION STRATEGIES IN MTPS

MPOs and Mitigation Strategies in MTPs

Mitigation Strategy	MPOs including strategy in MTP	Count	MPOs that have implemented strategy	Count
Pricing				
Add toll lanes	SANDAG, AMBAG, WashCOG, SACOG	4	MTC, BroMPO, SCAG, SANDAG, HGAC, DRCOG, DCHC, PSRC, WashCOG	9
Congestion pricing	HVCEO, CCC, TCRPC (LCOG - feasibility study vetoed this policy)	3		0
Incentivize cleaner/more efficient vehicles or fuels	HVCEO, TCRPC, LCOG	3		0
Land Use and Smart Growth Strategies/Non-Motorized Strategies				
Mixed Land Use	BroMPO, DCHC, BMTS, TCRPC, Bristol, METRO, DRCOG, AMBAG, RV, LCOG, SACOG, CCC, MRPC, PSRC, Tahoe, PPACG, HVCEO, SANDAG, CCRPC, SCAG, CHCRPC, BRMPO	22	RV, SCOG, LCOG, SACOG, MTC, SWRPA, SCAG, PSRC, METRO, WashCOG, Tahoe, HGAC, CCRPC	13
Bicycle improvements	PPACG, HVCEO, SWRPA, MTC, SCAG, DCHC, SANDAG, AMBAG, BMTS, ITCTC, RV, PSRC, Tahoe, Bristol, CHCRPC, KACTS, RISP, CCRPC, SCTPO, MRPC, WashCOG, SACOG, DRCOG, MDMPO, BRMPO, LCOG	26	BMTS, CHCRPC, PPACG, MTC, SCAG, DCHC, SANDAG, ITCTC, PSRC, WashCOG, TCRPC, Tahoe, LCOG, METRO, RISP, SACOG, RV, DRCOG, SWRPA, SCTPO, MRPC, HGAC, AMBAG, BroMPO	24
Pedestrian improvements	PPACG, HVCEO, SWRPA, MTC, SANDAG, AMBAG, BMTS, ITCTC, RV, PSRC, Tahoe, Bristol, CHCRPC, KACTS, RISP, CCRPC, SACOG, DRCOG, SCTPO, LCOG, MDMPO, WashCOG	22	SANDAG (nothing specific mentioned), PSRC, Tahoe, MTC, SCAG, ITCTC, BMTS, SACOG, DRCOG, PPACG, SWRPA, SCTPO, DCHC, TCRPC, Bristol, HGAC, LCOG, AMBAG, METRO, WashCOG, BroMPO	21
Safe Routes to School programs	MRPC, SANDAG, ITCTC, LCOG, SACOG	5	SWRPA, SCAG,DCHC, AMBAG, ITCTC, WashCOG, LCOG, METRO, RISP, SACOG	10
Adding intermodal hubs to provide seamless connectivity	SCOG, LCOG, METRO, SACOG, DRCOG	5	MTC, SCAG, SANDAG, AMBAG, PSRC, LCOG, SACOG, DRCOG	8
Public Transportation Strategies				
Urban Transit Expansion	DRCOG, AMBAG, ITCTC, SCOG, LCOG, SACOG, MDMPO, CCC, BMTS, HVCEO, BroMPO, WashCOG, DCHC, Bristol	14	MTC, SCAG, SANDAG, AMBAG, RV, PSRC, WashCOG, HGAC, LCOG, SACOG, PPACG, HVCEO, BRMPO, BMTS, METRO, BroMPO, MDMPO, MRPC, SWRPA, ARC, Bristol	21
Increase transit frequency, LOS, extent	BroMPO, MDMPO, AMBAG, PSRC, LCOG, SACOG, METRO, DRCOG, ITCTC	9	DRCOG, MTC, BroMPO, SCAG, DCHC, SANDAG, AMBAG, PSRC, LCOG, METRO, SWRPA, RV, WashCOG, HGAC, CCRPC, SACOG, PPACG, ITCTC	18

MPOs and Mitigation Strategies in MTPs (cont.)

Mitigation Strategy	MPOs including strategy in MTP	Count	MPOs that have implemented strategy	Count
Convert the public vehicle fleet and transit vehicles to alternative fuels	BRMPO,CCC, SANDAG, AMBAG, ARC	5	SWRPA, SCAG, BMTS, WashCOG, HGAC	5
HOV/Carpool/Vanpool/Commute Strategies				
HOV Lanes	MDMPO, SANDAG, WashCOG, ARC, SACOG, AMBAG	6	DRCOG, MTC, BroMPO, SCAG, MDMPO, DCHC, AMBAG, PSRC, WashCOG, ARC, METRO, SACOG	12
Employer-based Commute Strategies	CCC, AMBAG, BMTS, PSRC, Bristol, SACOG	6	PPACG, SCAG, WashCOG, BMTS	4
Car sharing	MTC, CCC, AMBAG, BMTS, ITCTC, SCOG, LCOG, CCRPC, SACOG, TCRPC	10	PPACG, SCAG, SANDAG, AMBAG, BMTS,ITCTC, RV, PSRC, WashCOG, LCOG, KACTS, CCRPC, SACOG, METRO	14
System Operations and Management Strategies				
Signal Control Management	ITCTC, TCRPC, LCOG	3	BroMPO, SCAG, BMTS, ITCTC, WashCOG, CHCRPC, LCOG, SACOG	8
Ramp Metering	AMBAG	1	BroMPO, SANDAG,AMBAG, METRO	4
Traveler information	SANDAG, Tahoe, SACOG, AMBAG, BMTS, ITCTC	6	HVCEO, BroMPO, SCAG, LCOG, SACOG, DCHC, AMBAG, METRO, MTC	9
Active Traffic Management	DRCOG, AMBAG, BMTS, LCOG, SACOG, SWRPA, MTC, PSRC, SCOG, RISP, METRO, WashCOG	12	SWRPA, SCTPO, SCAG, METRO, RV, SANDAG, BMTS, PSRC, WashCOG, ARC, SACOG	11
Add grade separations at major intersections or railway crossings		0	SCAG, SANDAG, PSRC, METRO	4
General roadway improvement	TCRPC, AMBAG	2	SANDAG, METRO, SACOG	3
Multimodal Freight Strategies				
Intermodal hubs (increased efficiency in cargo loading and unloading)	AMBAG, TCRPC, Bristol	3	AMBAG, METRO	2
Truck-only Tolls	TCRPC, Bristol	2		0
Rail Capacity Improvement (freight)	TCRPC, Bristol	2		0

Positive and Negative Impacts of GHG Mitigation Strategies

Strategies	Positive Impacts/Benefits	Negative Impacts/Challenges
Pricing		
Add toll lanes	- Raises some revenue - Alleviate congestion - Increase system capacity	- Requires capital for new lanes - Possibly politically unpopular - Possible equity issues - Environmental impact and energy cost of additional lanes - Long delay between initial project approval and completion of construction
Congestion pricing	- Raises some revenue - Alleviate congestion during peak hours - No major infrastructure investment	- Possibly politically unpopular - Possible equity issues
Incentivize more efficient vehicles or fuels	- May stimulate automotive/energy industry - No major permitting or infrastructure investment - Implementable quickly - Complements similar federal programs	- Requires funds for incentives - May actually increase VMT (as driving more efficient vehicles allows less money to be spent per mile travelled) - MPO may have limited jurisdiction
Land Use and Smart Growth Strategies/Non-Motorized Strategies		
Mixed Land Use	- Promotes public health - Alleviates congestion - Improved pedestrian and bicyclist safety - Promotes local economic development	- Requires modification of existing infrastructure - Benefits realized over extended period of time - MPO may have limited jurisdiction - Results are observed in the long term
Bicycle improvements	- Promotes public health - Improves safety - Reduces congestion - Reduces fuel consumption	- Requires social attitudinal shift - Requires parallel efforts for transit and roadway infrastructure
Pedestrian improvements	- Promotes public health - Improves safety - Reduces congestion - Reduces fuel consumption	- Requires mixed land use to maximize effectiveness
Safe Routes to School programs	- Promotes children's health - Reduces congestion in the vicinity of schools - Improves safety in neighborhood and near schools - Federally funded	- Possible security concerns need to be addressed
Adding intermodal hubs	- Makes transit more attractive - May generate economic activity and raise revenue	- Potentially expensive investment - MPO may have limited jurisdiction

Positive and Negative Impacts of GHG Mitigation Strategies (cont.)

Strategies	Positive Impacts/Benefits	Negative Impacts/Challenges
Public Transportation Strategies		
Urban Transit Expansion	- Reduces congestion - Improves accessibility and mobility for all citizens	- Investment requires strong backing from federal authorities - May not be publicly popular (issues of land acquisition, etc.)
Increase transit frequency, LOS, extent	- Reduces congestion - Improves accessibility and mobility for all citizens - More palatable than new transit infrastructure	- Logistical issues need to be addressed - May require substantial funding, depending on scope and nature of improvements being considered
Convert the public vehicle fleet and transit vehicles to alternative fuels	- May stimulate automotive/energy industry	- MPO may have limited jurisdiction - May require infrastructure investment - May evoke additional costs
HOV/Carpool/Vanpool/Commute Strategies		
HOV Lanes	- Reduces congestion	
Employer-based Commute Strategies	- Reduces congestion	- Trip substitution may occur (a corresponding increase in off-peak travel for a decrease in peak-hour travel) - MPO has no jurisdiction
Car sharing	- Reduces congestion	- Generally requires private enterprise participation - MPO has limited jurisdiction
System Operations and Management Strategies		
Signal Control Management	- Reduces congestion - Improves efficiency - Reduces driver stress levels	- May require advanced ITS infrastructure - May require substantial financial investment and replacement of existing infrastructure
Ramp Metering	- Reduces highway congestion/bottlenecks - Improves highway safety	- May increase travel times for some individuals
Traveler information	- Reduces congestion - May make transit more attractive - Reduces traveler frustration	- May require substantial ITS infrastructure - Medium of information dissemination is debatable (website vs. smartphone, etc.)
Active Traffic Management	- Reduces congestion	- Emission reduction is debatable (tradeoff between efficient travel and additional VMT) - Requires ITS infrastructure and human resources
Add grade separations at major intersections	- Reduces congestion - Improves safety for passenger and/or freight traffic - Allows for the uninterrupted flow of traffic	- Requires significant infrastructure investment - May requires additional ROW acquisition - May cause traffic disruption during construction phase
General roadway improvement	- Improves safety - Reduces wear and tear on vehicles - Simple to implement	- Least effective but most easily implementable GHG-reduction strategy

Positive and Negative Impacts of GHG Mitigation Strategies (cont.)

Strategies	Positive Impacts/Benefits	Negative Impacts/Challenges
System Operations and Management Strategies		
Signal Control Management	- Reduces congestion - Improves efficiency - Reduces driver stress levels	- May require advanced ITS infrastructure - May require substantial financial investment and replacement of existing infrastructure
Ramp Metering	- Reduces highway congestion/bottlenecks - Improves highway safety	- May increase travel times for some individuals
Traveler information	- Reduces congestion - May make transit more attractive - Reduces traveler frustration	- May require substantial ITS infrastructure - Medium of information dissemination is debatable (website vs. smartphone, etc.)
Active Traffic Management	- Reduces congestion	- Emission reduction is debatable (tradeoff between efficient travel and additional VMT) - Requires ITS infrastructure and human resources
Add grade separations at major intersections	- Reduces congestion - Improves safety for passenger and/or freight traffic - Allows for the uninterrupted flow of traffic	- Requires significant infrastructure investment - May requires additional ROW acquisition - May cause traffic disruption during construction phase
General roadway improvement	- Improves safety - Reduces wear and tear on vehicles - Reduces emissions (slight efficiency gain) - Simple to implement	- Least effective but most easily implementable GHG-reduction strategy
Multimodal Freight Strategies		
Intermodal hubs	- Reduces emissions - Improves efficiency of freight movements	- Small MPOs may not deal extensively with freight - MPO may not have jurisdiction over private operations
Truck-only Tolls	- May reduce congestion - Raises transportation revenue - May decrease wear on infrastructure	- Unpopular with freight companies - Possible negative economic impacts on regional economy
Rail capacity improvement	- Reduces highway congestion - Reduces emissions - Improves freight efficiency - May stimulate local economy	- MPO has limited jurisdiction over private operations or infrastructure - May not be viable in some areas (as most freight rail lines are privately owned)

APPENDIX F. INCORPORATING GHG INTO TRANSPORTATION PLANS

This appendix outlines research studies conducted on incorporating GHG into transportation planning process by various institutions.

Strategic Highway Research Program, Transportation Research Board: *Incorporating Greenhouse Gas Emissions into Collaborative Decision-Making Process*

This project synthesized information for practitioners on how GHG emissions can be incorporated into transportation planning and decision making. This included background information on the role of the transportation sector in GHG emissions, as well as the different trends and factors that will influence future GHG emissions. The project also identified different GHG emissions reduction strategies and information on cost effectiveness and other means of evaluating the feasibility of such strategies. The project developed a technical framework that provides information on the models, data sources, and methods that can be used to conduct GHG emissions analysis. The project developed case studies to illustrate different scales and institutional contexts for GHG analyses. The technical framework is described that can be used for considering GHG emissions in different transportation planning and decision-making contexts. The framework is organized around questions that guide analysts to the tools and data necessary to conduct a GHG analysis (see Table F1).

Table F1. GHG Analysis Framework.

Analysis Step	**Key Questions**
Determine information needs	• What stakeholders should be included in GHG strategy development and evaluation? • What is the scope of GHG emissions analysis?
Define goals, measures, and resources	• What goals, objectives, and policies relate to GHG reduction? • What GHG-related evaluation criteria and metrics will be used? • What are the baseline emissions for the region or study area? • What is the goal or target for GHG reduction? • How will GHG considerations affect funding availability and needs?
Define range of strategies for consideration	• What GHG reduction strategies should be considered? • Are strategies and alternatives consistent with a long-range plan and/or other relevant plans that meet GHG reduction objectives?
Evaluate GHG benefits and impacts of candidate strategies	• What calculation methods and data sources will be used to evaluate the GHG impacts of projects and strategies? • What are the emissions and other impacts of a particular project, strategy, or design feature?
Select strategies and document overall GHG benefits and impacts of alternatives	• What GHG-reducing strategies should be part of the plan, program, or project? • What are the emissions impacts for the overall plan, program, corridor, or project alternatives considered and the selected alternative?

Source: TRB, 2012. *Incorporating greenhouse gas emissions into the collaborative decision-making process*, report s2-c09-rr-1. http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-C09-RR-1.pdf

A case study outlined GHG analyses that have been undertaken for highway and transit projects. According to the case study, the GHG-reducing strategies that are most directly under the influence of transportation agencies include:

- Infrastructure provision, e.g., the design, construction, and maintenance of highway, transit, and other transportation facilities and networks.
- Management and operation of the transportation system, e.g., transportation system pricing policies, technologies, and operational practices.
- Provision of transportation services and demand management measures to encourage the use of less carbon-intensive modes, e.g., transit service improvements, rideshare and vanpool programs, and worksite trip reduction.
- Land use planning, e.g., regional coordination, funding, and technical assistance to support state and local efforts to develop more efficient land use patterns.
- Pricing strategies, e.g., tax and insurance policies, mileage-based pricing, or registration fees.
- Provision of alternative fuels infrastructure and alternative fuel vehicles for agency fleets.

The project also created a practitioner's guide on how GHG emissions can be incorporated into transportation planning and decision making. The guide describes four decision contexts—long-range planning, programming, corridor planning, and NEPA permitting—and lists questions that analysts should ask if stakeholder are interested in incorporating GHG emissions into each process.[18]

The findings suggest that the application of integrating GHG reduction strategies into transportation planning will involve a technical process, the decision guide and GHG planning, state legislation, regional action plans, and project-level analysis. The GHG technical process is a series of steps involving data collection and analysis of the implications of transportation choices on GHG, such as collecting information, defining goals and measures, identifying options, evaluating options, and selecting preferred option. A decision guide included in the project provides key decisions in the transportation process that are made through collaboration among partners and input from stakeholders.[19]

Center for Clean Air Policy: *Case Studies of Themes in State Transportation GHG Planning*

This study evaluated main themes of GHG planning in California, Washington, Oregon, and Florida. These states recognize that integrating GHG emissions and transportation planning can play a critical role in generating economic, equity, and environmental benefits for communities. The four states have created specific legislative frameworks striving for a collaborative platform to outline GHG planning goals. CCAP provides case studies of those four states, with an overview of the challenges, successes, and lessons for planning, implementation, and measurement as well as the role of technical assistance and capacity building resources to support the GHG reduction efforts.

Strategic interviews of key policy stakeholders from state and regional agencies as well as leading practitioners working on local project delivery were conducted. The case study shows that while the regulatory and legislative planning frameworks vary across the four states, they had similar themes in challenges and successes within GHG target setting, plan development, project implementation, and performance measurement. The common themes found in the case studies include:[20]

State/MPO Successes:

- Targets: Political leadership and collaboration.
- Plans: Agency and stakeholder partnerships formed.
- Projects: Local innovation and funding initiatives.
- Measurement: Investments in consistent model and data updates.

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[18] http://www.trb.org/Main/Blurbs/166940.aspx

[19] Integrating Greenhouse Gas into Transportation Planning
http://www.transportationforcommunities.com/ghg_application_kdps/26/0

[20] Center for Clean Air Policy: Case Studies of Themes in State Transportation GHG Planning
http://ccap.org/assets/Case-Studies-of-Themes-in-State-Transportation-GHG-Planning_CCAP-May-2011.pdf

State/MPO Challenges:

- Target: GHG reduction target allocation and benchmarking for regions and climate messaging.
- Plans: Dedicated, discretionary, and secure funding sources for planning and implementation.
- Projects: Regulatory barriers at the planning and implementation stages, continuity of support for projects.
- Measurement: Lack of consistent and transparent models and metrics for implementation.

Georgia Institute of Technology, Transportation Institute/University Transportation Center: *Transportation Planning for Sustainability Guidebook*

This guidebook presents critical issues involved in planning for sustainable transportation systems and reviews current practices in the United States. The guidebook describes potential data sources and how data have been used in sustainability-related initiatives.

The guidebook provides a useful resource for transportation professionals that have little experience with sustainability and provides best practices for implementation. The guidebook includes a case study to provide transportation agencies with a range of examples from which they can select the best practices for their sustainability priorities and needs. There has been a wave of state policies in response to regional efforts to reduce GHG emissions. According to the report, successful examples of environmental sustainability are listed in Table F2.[21]

Table F2. Summary of Environmental Sustainability Best Practices.

DOT	Practice	Description
Vermont	Energy and climate change action plan	Preventative measures to address impacts of air quality and climate change
California	Climate action program	Active climate change mitigation and adaptation measures, e.g., GHG reduction
Oregon	Climate change mitigation policies and practices	Efforts to address climate change through both internal and external practices that address vehicle miles traveled and system efficiencies
Illinois	Sustainability program	Initiatives to improve agency's internal sustainability (energy efficiency, emissions reduction, recycling)
Pennsylvania	Linking planning and NEPA	Training program to educate employees on linkages and overlaps between planning and NEPA to streamline both process

Adapted from: Transportation Planning for Sustainability Guidebook, Table 3-1
http://www.utc.gatech.edu/sites/default/files/projects/reports/amekudzi_sustainability_evaluation_and_planning_guideance_for_transportation_systems.pdf.

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[21] Transportation Planning for Sustainability Guidebook http://www.utc.gatech.edu/sites/default/files/projects/reports/amekudzi_sustainability_evaluation_and_planning_guideance_for_transportation_systems.pdf

The findings of this research also use performance measurement is a tool for transportation agencies to monitor and assess progress toward sustainability. Approximately 60 percent of the DOTs reported the use of performance measures. Example of implemented state DOTs performance measurement framework, see Table F3.

Table F3. Summary of Performance Measurement Frameworks and Reporting Best Practices.

DOT	Frameworks	Description
Minnesota	Performance-based planning & Programming	Framework using clear policy priorities, performance trend data, and performance forecasting to guide decision making
Washington	Gray Notebook	Quarterly report of goals and measures organized around state's legislative and strategic policy goals
Iowa	Results Iowa	Annual report and online monitoring system that outlines performance goals and measures, and assesses which targets have been met
Missouri	Tracker	Quarterly report of measures for 18 outcome areas covering environmental responsibility and economic development
California	State and Regional Measures	Reports on performance goals and measures at both the regional and state level

Adapted from: Transportation Planning for Sustainability Guidebook, Table 3-2.
http://www.utc.gatech.edu/sites/default/files/projects/reports/amekudzi_sustainability_evaluation_and_planning_guideance_for_transportation_systems.pdf.