Technical Report

Statewide On-Road Greenhouse Gas and Climate Change

TxDOT Environmental Affairs Division
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Table of Contents

List of Tables

List of Figures

Executive Summary

The Texas Department of Transportation (TxDOT) conducted on-road greenhouse gas (GHG) emissions analyses for Texas, assessed future Texas climate scenarios or projections and how that might impact the on-road transportation system, and summarized TxDOT strategies and programs that result in GHG reduction and transportation system resiliency and preservation.

TxDOT estimates more than 33 cents of every dollar programmed over the next ten years directly or indirectly result in GHG reduction and/or system resiliency and preservation while providing mobility and connectivity to all travelers across Texas (TxDOT, 2023j). In addition to the TxDOT goals mentioned in this Technical Report, **Section 3.3.1** discloses 10 TxDOT programs and strategies that directly or indirectly result in GHG reduction, and **Section 4.3** discloses 11 TxDOT plans, programs and strategies that directly or indirectly aid in system resiliency and preservation.

Four conditions impact on-road vehicle GHG emissions: 1) vehicle efficiency, 2) fuel carbon content, 3) distance traveled, and 4) travel efficiency. Of these four, TxDOT is only able to impact two: travel efficiency and distance traveled. The TxDOT strategic goal to “optimize system performance” and the TxDOT budgetary goal to “optimize services and systems” (TxDOT, 2024b), are how TxDOT addresses travel efficiency and distance traveled. GHG reduction through these two conditions for Texas and for other states, could collectively result in meaningful co-benefits (IPCC, 2023a), (USGCRP & Crimmins, NCA5, 2023a), (USDOE, USDOT, USEPA, USHUD, 2023). However, most transportation GHG reduction will occur through various vehicle and fuel technological advances (IPCC, 2023a), (USGCRP & Crimmins, NCA5, 2023a), (USDOE, USDOT, USEPA, USHUD, 2023). Sufficient forecast methods do not exist at the project- state-, or national-level to accurately predict when, and how fast vehicle and fuel technological advances will occur. Since this uncertainty impacts the accuracy of future on-road GHG emission estimates, TxDOT provided three scenarios for future on-road GHG emissions. For detail on GHG emissions and reduction, see **Section 3**.

Climate scenarios or projections indicate Texas will be warmer, drier, subject to increased intensity of extreme weather events, subject to additional sea level rise, and subject to higher storm surge (NOAA. Runkle, 2022a), (USGS, 2023c). These projections could result in temporary transportation system closures or detours due to extreme weather events, increased flooding and inundation potential, roadway rutting, buckling, cracking, and increased risk of power outages that could affect traffic signals and intelligent transportation systems (ITS). Warmer and drier conditions may increase wildfire potential that may result in temporary road closures or detours due to fire, smoke, limited visibility conditions, or minor structural repairs. For detail on climate and resiliency, see **Section 4**.

Project funding that results in GHG reduction and/or system resiliency and preservation is programmed into individual projects in regional and statewide transportation plans for the Texas multimodal transportation system. Understanding that the GHG reduction actions within TxDOT control cannot mitigate all transportation GHG emissions and understanding that transportation system operations, preservation and design are needed for transportation resiliency, TxDOT will seek ways to maximize the direct and indirect climate benefits per federal and state dollar spent on them, without sacrificing improvements associated with the primary use for the funds (TxDOT, 2023e), (TxDOT, 2023j), (TxDOT, 2024b). TxDOT actively collaborates in partnership with MPOs, local governments, transit authorities, federal agencies, and the public to plan, maintain, and enhance the Texas multi-modal transportation system for all Texas travelers. For more detail, see **Section 3.3.1**, **Section 4.3**, and web links in **Appendix F:** for **Project Development, Selection and Delivery (Project Life Cycle)** and **Metropolitan Planning Brochures.**

1.0 Introduction

Climate change is a current topic in public conversations. Climate change relates to transportation in two ways: transportation related greenhouse gas (GHG) emissions may contribute to climate change, and climate change has the potential to affect the transportation system (IPCC, 2023). As a result, members of the public are frequently interested in understanding how the Texas Department of Transportation (TxDOT) reduces emissions and addresses resiliency.

Inherent in NEPA is a "rule of reason" which ensures that agencies are afforded the discretion, based on their expertise and experience, to determine whether and to what extent to prepare an analysis based on the availability of information, the usefulness of that information to the decision-making process and the public, and the extent of the anticipated environmental consequences. This agency deference, combined with the expectation of the NEPA process to disclose and inform, has led TxDOT to address climate change considerations for certain NEPA project-level decisions in this programmatic, statewide analysis.

This report includes: 1) an overview of climate change, 2) statewide analyses for on-road GHG emissions and example project-level analyses, 3) TxDOT actions and funds that result in GHG reduction along with actions of others, 4) an assessment of climate change scenarios or projections for the state of Texas and an overview of global and U.S. scenarios or projections, 5) TxDOT actions and funding that aids in transportation system resiliency and preservation, 6) incomplete or unavailable information for specific climate change impacts, and 7) results and conclusions. This Technical Report provides information regarding climate change to the public and provides information for consideration during the environmental analysis of a project. This programmatic statewide analysis is used when project level GHG and climate change analysis of the project alternatives would provide limited information beyond what is contained in this Technical Report and would not help the decision-maker in evaluation of the project alternatives.

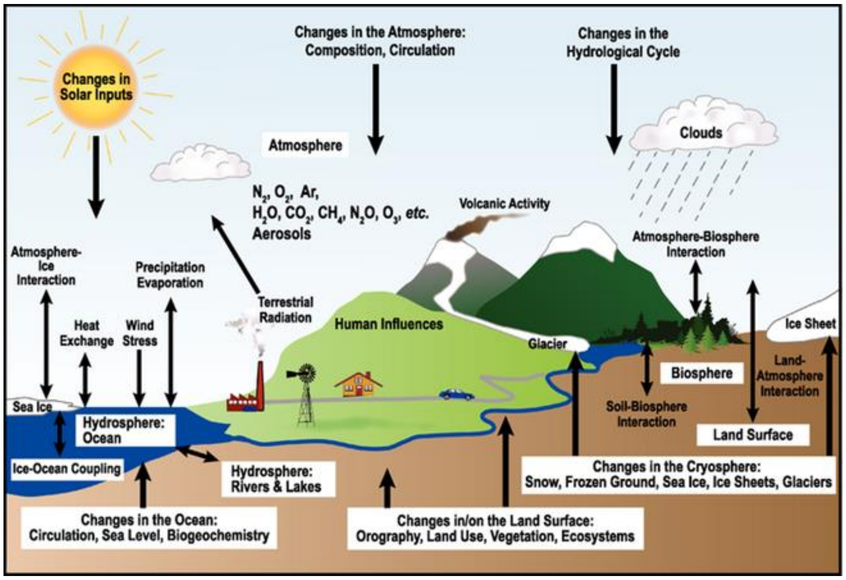
Appendix A provides additional detail regarding the methodologies, data, and assumptions used for the GHG analyses and climate change assessment. **Appendix B** contains the NOAA Texas Climate Summary. **Appendix C** contains the USGS National Climate Change Viewer projections for Texas. **Appendix D** provides a glossary. **Appendix E** provides a list of acronyms. **Appendix F** provides web links to several TxDOT brochures including: **TxDOT Pocket Facts**, **Bicycle and Pedestrian Program**, **Emergency Operations**, **Funding**, **Public Transportation**, **Transportation Technology, Project Development, Selection and Delivery (Project Life Cycle)**, **Metropolitan Planning**, and **TSMO Frequently Asked Questions**.

2.0 Overview of Climate Change and Greenhouse Gas Emissions

Climate change may result from natural processes or from human activities (IPCC, 2023). Changes in climate include changes in temperature, precipitation, ice, storm activity, sea level, and wind speeds (IPCC, 2023). **Figure 1** provides a diagram of the climate system.

Greenhouse gases refer to their ability to trap heat (energy) like a greenhouse in the lower part of the atmosphere. Atmospheric GHGs, including water vapor, carbon dioxide (CO_2), and other gases, trap some of the outgoing energy by retaining heat (EPA, 2023a).

Figure 1: Schematic View of the Components of the Climate System Their Processes and Interactions



Source: (Solomon, 2007)

EPA indicates many GHGs occur naturally or come from human actions (EPA, 2023a). Water vapor is the most abundant GHG and makes up approximately two thirds of the natural greenhouse effect. CO_2 is the second-most abundant GHG (NASA, 2024). CO_2 occurs naturally and through human actions (EPA, 2023a).

The effect each GHG has on global warming is a combination of the amount of their emissions and their global warming potential (GWP). GWP is a measure of how much energy the emissions of one ton of a gas will absorb over a given time-period, relative to the emissions of one ton of CO_2. The larger the GWP, the more a given gas warms the earth compared to CO_2 over that time-period. GHG emissions may be presented in terms of carbon dioxide equivalent (CO_2e), which are calculated as the product of the mass emitted of a given GHG and its specific GWP. CO_2e is calculated using Equation A-1 in 40 CFR Part 98.

The earth has gone through many natural changes in climate over time (IPCC, 2023). Since the industrial revolution began in the 1700s, the atmospheric concentration of CO_2 and other GHG emissions have continued to climb, primarily due to human activity (IPCC, 2023). Almost half of the human activity CO_2 emissions between 1750 and 2011 have occurred in the last 40 years primarily from fossil fuel emissions (e.g., coal, natural gas, gasoline, oil and/or diesel) (IPCC, 2023). This GHG emissions increase is projected to contribute to existing and future changes in climate (IPCC, 2023).

The U.S. Fifth National Climate Assessment (NCA5) (USGCRP & Crimmins, NCA5, 2023a) was issued on November 16, 2023. In the Overview for Chapter One, NCA5 discloses that (global) societal choices drive greenhouse gas emissions. It further states: “The choices people make on a day-to-day basis—how to power homes and businesses, get around, and produce and use food and other goods—collectively determine the amount of greenhouse gases emitted.” For more detail, see USGCRP & Crimmins, NCA5, 2023a.

The United Nations Intergovernmental Panel on Climate Change (IPCC) develops periodic global climate change assessments. The Sixth Assessment Report (AR6) was issued between 2021-2023. AR6 consists of four reports: AR6: 1) AR6 Synthesis Report: Climate Change 2023, 2) AR6 Climate Change 2022-Mitigation of Climate Change, 3) AR6 Climate Change 2022: Impacts, Adaptation and Vulnerability, and 4) AR6 Climate Change 2021: The Physical Science Basis. Each AR6 report described above has supporting information, such as: Headline Statements, Summary for Policymakers, Technical Summary, Frequently Asked Questions, Fact Sheets, and/or Press Conference materials. Some reports have full volumes along with shorter versions. For more detail, see IPCC, 2023.

3.0 Statewide On-Road System and GHG Analysis

TxDOT works in collaboration with metropolitan planning organizations (MPOs), local governments, transit agencies, and the public for a safe transportation system that supports travel choices, provides connectivity, and maximizes operational efficiency for all travelers. Travel choices that reduce single occupant vehicle trips, and operational efficiencies that reduce congestion have the added benefit of reducing GHG emissions**.** Additional capacity is considered when operational improvements are inadequate to address congestion or connectivity (TxDOT, 2023c), (TxDOT, 2023a) (TxDOT, 2024b).

TxDOT and local governments operate and maintain the Texas on-road transportation system. Based on the TxDOT 2022 Roadway Inventory Annual Report, the Texas on-road transportation system was comprised of 701,967 total lane miles (323,363 centerline miles) that included 200,291 on-system lane miles (80,997 centerline miles) and 501,677 off-system lane miles (242,367 centerline miles). An on-system roadway is part of the State Highway System and maintained by TxDOT. On-system roadways include interstate highways, US highways, state highways, and farm and ranch roads. An off-system roadway is not on the State Highway System and not maintained by TxDOT (i.e., city street or county road). Centerline miles are the total length of a road calculated by measuring the road's centerline. Total lane miles account for all lanes in a roadway. They are calculated by multiplying the centerline length by the number of lanes on a given corridor. **Appendix F** includes a web link for **TxDOT Pocket Facts** containing an overview of TxDOT and the Texas Transportation System including the roadway system. This on-road transportation system also includes transit and active transportation, for more detail see **Section 3.3** and web links in **Appendix F.**

Section 3.1 presents the statewide on-road and fuel-cycle GHG emissions analyses results and provides example project-level emissions. **Section 3.2** summarizes the emissions analyses. **Section 3.3.1** describes TxDOT strategies that focus on or have the added benefit of reducing transportation GHG emissions. **Appendix A** describes analysis methodologies used to estimate GHG emissions for the Texas on-road transportation system and associated upstream fuel-cycle emissions. Upstream fuel-cycle emissions are emissions generated by extracting, shipping, refining, and delivering fuels. Upstream fuel-cycle emissions are not under TxDOT control.

3.1 Emissions Analysis

EPA's Motor Vehicle Emissions Simulator (MOVES4 version) model generated the emissions estimates. EPA MOVES4 has not incorporated the following EPA and NHTSA final rules:

- On March 20, 2024, EPA finalized the Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-Duty and Medium-Duty Vehicles ("LD–MD Rule"). EPA projects the rule will avoid approximately 7.2 billion metric tons nationwide by the year 2055 (EPA, 2024b). EPA projected this rule could result in up to 56 percent of MY 2032 light duty new vehicle sales being battery electric (EPA, 2024b). These rules apply to vehicle model years 2027-2032.
- On March 29, 2024, EPA finalized the Greenhouse Gas Emissions Standards for Heavy-Duty (HD) Vehicles - Phase 3. EPA projected this rule will avoid approximately 1.025 billion metric tons of CO_2 by the year 2055 (EPA, 2024c). These rules apply to vehicle model years 2027-2032.
- On June 7, 2024, NHTSA finalized rules to update fuel economy standards for MY 2027 – 2032 for light duty vehicles and for MY 2030 - 2035 for commercial pickup trucks and work vans (NHTSA,

2024a). The USDOT press release (USDOT, 2024c) disclosed the final rules should prevent more than 710 million metric tons of carbon dioxide emissions by 2050.

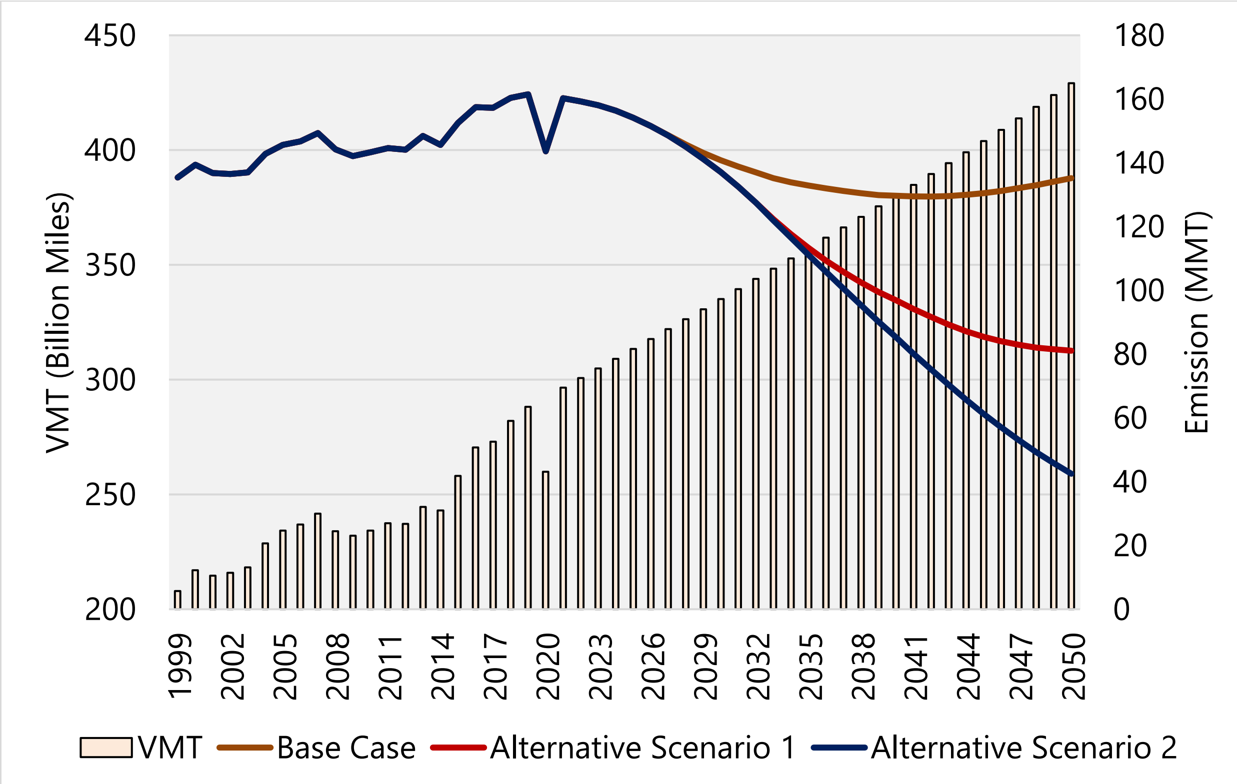
Page 5 of the U.S. National Blueprint for Transportation Decarbonization (U.S. Blueprint) (USDOE, USDOT, USEPA, USHUD, 2023) disclosed the vast majority of GHG transportation emission reductions will be through various vehicle and fuel solutions. Hydrogen is a potential emerging fuel mentioned in the U.S. Blueprint, but it is not yet known if hydrogen will be technically or economically viable. Of recent note, hydrogen fuel was $32.79 compared to an equivalent gallon of gasoline (DOE AFDC, 2024).

Since the U.S. Blueprint discloses vehicle and fuel technological advances will have the most impact on future transportation GHG emissions, TxDOT requested TTI generate three future emission estimate scenarios presented in **Figure 2** to help address how market forces, consumer choice and future regulatory changes may shape vehicle and fuel technological advances. The scenarios are:

- The Base Case used MOVES4 defaults that only include vehicle and fuel changes for the 2021 EPA rules for vehicles up to model year 2026. This is an unlikely worse-case scenario that excludes 2024 EPA vehicle rules and the 2024 USDOT-NHTSA fuel economy rules or any future technological advancements that may alter vehicles or fuels between model years 2027 – 2050.
- Scenario 1 used MOVES4 and applied the two EPA 2024 vehicle rules. These rules add requirements up to vehicle model year 2032. This scenario remains unlikely as it provides for no additional vehicle or fuel technological advances between vehicle model years 2032 to 2050.This scenario offers a bit more realistic worse-case scenario than just MOVES4.
- Scenario 2 used MOVES4 and applied the EPA 2024 vehicle rules. It also applied the average yearly change for model years 2027 to 2032 in the 2024 rules to vehicle model years 2033 to 2050. This scenario forecasts vehicle and fuel technological advances continuing through vehicle model year 2050 due to a combination of market conditions, consumer choice, and future regulations. Based upon emission reductions achieved since enactment of the 1970 Clean Air Act (EPA, 2024d), that resulted from technological advances since then, this scenario provides a reasonably plausible future case.

Figure 2 and **Table 1** provides trends for three future on-road GHG emission analysis scenarios and vehicle miles of travel (VMT) for the Texas on-road transportation system that includes both on-system (TxDOT) and off-system (local roads) VMT. **Table 1** includes on-road GHG emissions for the three emission scenarios and includes on-road and upstream GHG fuel cycle emissions for each scenario. In the base-year 2019 (prior to COVID pandemic), the estimated on-road Texas CO_2e emissions was 161 million metric tons (MMT). By 2050, the estimated CO_2e emissions range from 135 MMT to 42 MMT. If the EPA 2024 rules are a reasonable projection for future vehicle technological advances, emissions would be approximately 42 MMT. If technology changes more rapidly than the EPA 2024 rules, then 2050 emissions would likely be lower than 42 MMT. If technology changes more slowing than the EPA 2024 rules, then emissions are projected to be in the range of 42 MMT to 80 MMT. The Base Case provides a worse-case emission estimate; however, based on CAA history and emission trends (EPA, 2024d) and the 2024 EPA rules, technology is likely to advance beyond vehicle model year 2026 that is captured in the MOVES4 Base Case.

Figure 2: Texas Annual VMT and CO_2e On-road Emission Trends (in MMT)



Source data: TTI 2024 emissions analysis.

The VMT forecasts used in each emissions scenario are the same. The VMT forecasts account for historic and current population growth, and historic and current use of transit, active transportation, and trip avoidance (e.g., telework) options. Differences in historic and current parameters for VMT could impact emissions as follows beyond the levels projected:

- Population increases tend to increase VMT and GHG emissions, while population decreases tend to decrease VMT and GHG emissions; and
- Increased use in transit, active transportation, or trip avoidance options tend to reduce GHG emissions, while reduced use in these travel options tend to increase emissions.

GHG fuel and vehicle rules were first issued for MY 2012 vehicles. These GHG regulations are newer than other air emission fuel and vehicle rules that Congress directed be addressed under the 1970 Clean Air Act (EPA, 2023b). If GHG fuel and vehicle rules follow the reductions achieved for other pollutants since the 1970 CAA, additional GHG emission reductions will be achieved by additional technological advances in vehicles and fuels between now and 2050. Future technological advances that alter the transportation system, vehicles and/or fuels, combined with acts of nature (e.g., pandemic), societal changes, market forces, economics, land use decisions, and personal decisions could alter where and how people live, work or travel and further affect CO_2e emissions in ways that cannot be accurately accounted for at this time (NASEM, 2007), which is why TxDOT requested TTI conduct three emission scenarios to estimate a possible range for future GHG emissions. Additional uncertainty is disclosed in **Section 5**.

Table 1: Texas Annual VMT and Annual CO_2e On-road and Fuel-cycle Emission Trends

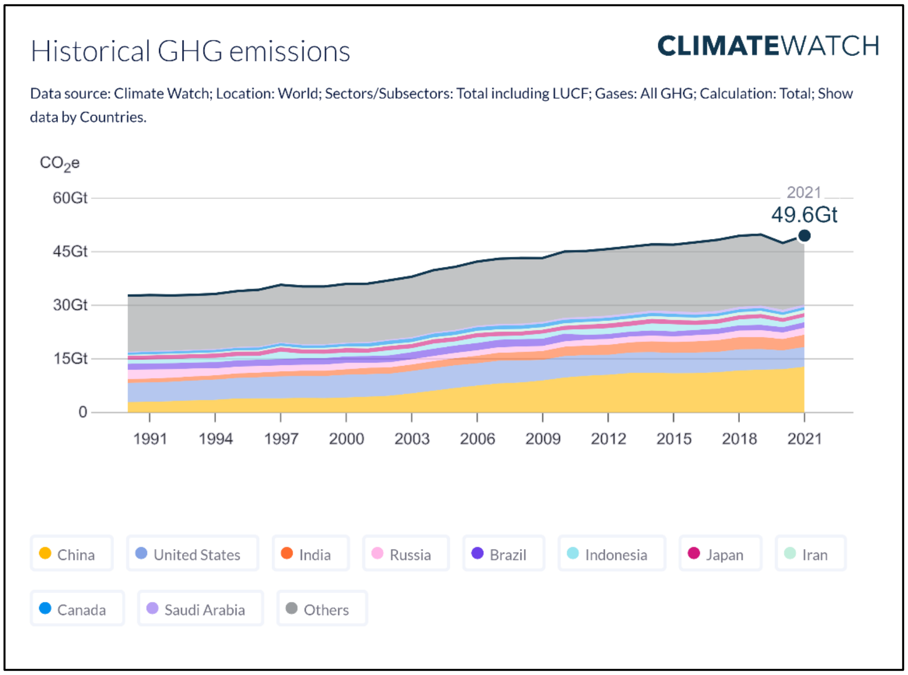
Year	Annual VMT (Billion miles)	Base Case On-road CO_2e (MMT)	Scenario 1 On-road CO_2e (MMT)	Scenario 2 On-road CO_2e (MMT)	Base-Case CO_2e On-road and Fuel Cycle (MMT)	Scenario 1 CO_2e On-road and Fuel Cycle (MMT)	Scenario 2 CO_2e On-road and Fuel Cycle (MMT)
1999	208	135	135	135	172	172	172
2000	217	139	139	139	177	177	177
2005	234	146	146	146	185	185	185
2010	234	143	143	143	182	182	182
2015	258	153	153	153	194	194	194
2019	288	161	161	161	205	205	205
2020	260	144	144	144	182	182	182
2021	297	160	160	160	204	204	204
2022	301	159	159	159	202	202	202
2023	305	158	158	158	201	201	201
2025	313	154	154	154	196	196	196
2030	335	141	137	137	179	174	174
2035	357	133	113	111	169	144	141
2040	380	130	97	85	165	123	108
2045	404	131	85	61	166	109	78
2050	429	135	81	42	172	103	54

Sources: TTI, 2024 for on-road emissions. TxDOT, 2024 for on-road and fuel cycle emissions.

The effects of global climate change depend upon actions and emissions from across the globe. **Figure 3: Global GHG Emission Trends by Country** disclose that for 2020, China was the largest generator of annual GHG emissions at 12.3 gigatons (Gt), the U.S. was second at 5.29 Gt, and India was third at 3.17 Gt. A gigaton is 1000 MMT.

Table 2 presents representative worldwide, national and Texas GHG emission trends from 1990 to 2021. According to EPA, the transportation sector is the largest source of GHG emissions in the U.S at 28% (EPA, 2024k). CO_2 is the largest component of these GHG emissions. On-road mobile sources generate most of transportation GHG emissions, at approximately 80% (EPA, 2024k). The transportation sector data reported by The U.S. Energy Information Administration (EIA) (EIA, 2021) includes all transportation emissions for on-road, off-road, marine, air and rail) (**Table 2**). Mobile-source related construction emissions for transportation, industry, and commercial and residential construction are a subset of the EIA Texas transportation sector emissions (**Table 2**). Additional construction related GHG emissions such as from the creation of building materials and pavements are a subset of the annual Texas statewide EIA emissions (**Table 2**) Upstream fuel cycle emissions are a subset of the annual Texas statewide EIA emissions (**Table 2**). Emission estimates vary somewhat depending upon the data sets, assumptions and analysis methods used. **Appendix A** presents three primary data sets and GHG analysis methodologies used to estimate various GHG emission levels. Depending on the data source, emission estimates are disclosed as either CO_2 or CO_2e (**Table 2**).

Figure 3: Global GHG Emission Trends by Country



Source: Climate Watch, obtained on 10/16/2023.

Table 2: Worldwide, National and Texas GHG Emission Trends

Trends for CO_2 and CO_2e (MMT) Emissions									
Area or Sector	1990	1995	2000	2005	2010	2015	2019	2020	2021
Worldwide CO_2e (Climate Watch)[1]	31,553	32,897	34,734	39,361	43,537	45,431	48,148	46,187	NP
Worldwide CO_2e (PIK)[1]	31,652	32,457	34,570	39,523	43,681	46,612	48,297	46,665	48,612
U.S Total All Sectors CO_2e[2]	6,487	6,771	7,275	7,477	6,982	6,676	6,618	6,026	6,340
TX Statewide CO_2[3]	570	590	673	645	616	655	683	625	664
TX Transportation Sector CO_2[3]	152	153	184	194	184	205	228	193	215
TX On Road CO_2e[4]	NP	135	139	146	143	153	161	144	160

Sources: **1**: (Climate Watch), **2**: (EPA, 2020), **3**: (EIA, 2021), **4**: (TTI, 2024). **Appendix A** has detail on data use and collection.

Emissions from individual roadway projects represent a very small subset of the emissions for the Texas roadway system that includes both TxDOT and local government roads. For example, according to TxDOT annual data (FHWA, 2023), the total lane miles in Texas between 2012 and 2021 increased by 23,543 miles of which 2,312 was interstate or freeway addition lane miles, with yearly averages of 2,354 for total lane miles and 231 for interstate and freeway lane miles (**Table 3: Texas Lane Miles**). With Texas systemwide total lane miles in 2021 at 698,839, the average year adds a nominal 0.34% total lane miles. The emission differences between the proposed and no-build project alternatives are even less (see the two example projects below).

Table 3: Texas Lane Miles

Year	Interstate and Freeways Lane Miles	Arterials, Collectors and Local Streets Lane Miles	Total Lane Miles	Annual VMT on Total Lanes (in billions)
2021	25,461	673,379	698,839	285
2012*	23,149	652,148	675,296	238
Difference 2021 - 2012	2,312	21,231	23,543	47
Yearly Average	231	2,123	2,354	5

Source: (FHWA, 2023). *Rounding differences result in ±1 Total Lane Miles.

For September 1, 2022, to August 31, 2023 (FY2023), 2448 projects on the TxDOT Four Year Project Dashboard (TxDOT, 2023l) consisted of:

- 10 projects greater than $150 million (9 were added capacity projects and 1 was adding an interchange).
- 28 projects between $50 million to $150 million (15 were added capacity projects, 5 were new or reconstructed interchanges, 4 were roadway rehabilitation or operational improvements, 1 was a bridge replacement and 1 was related to ferry operations).
- 88 projects between $15 million to $50 million (19 were added capacity projects).
- 2322 projects less than $15 million (14 were added capacity projects, 1380 were maintenance projects, and the rest were small construction projects predominantly rehabilitation, safety improvements, intersection or other operational improvements, aesthetics such as landscape and scenic enhancements, overlays, replacement or rehabilitation, traffic control devices, corridor traffic management improvements, addition of curbs, gutters and/or culverts, sidewalks or shared use paths, and/or local government projects).

A total of 57 projects for FY2023 were added capacity projects, or 2.3 percent of projects issued for construction. Taking the average lane miles added per year between 2012 and 2021 (see **Table 3**) of 2,354 and the 57 projects for FY2023, a hypothetical average added capacity project would add approximately 41.3 lane miles. TxDOT prepares more than 2,000 projects for construction or maintenance per average year. A range of 25 to 100 projects/year add capacity, so the average added capacity project adds a range of approximately 10-50 total lane miles per project. Project-level GHG analyses are summarized below for two example capacity projects that fall within the range for average added capacity total project lane miles.

Example 1: (Typical Traffic Corridor Added Capacity Project)

The project length was 6.9 miles. The preferred alternative would add approximately 41 total lane miles through the addition of frontage roads. Traffic volumes were 48,100 average vehicles per day in the 2019 base-year and projected to be 73,900 average vehicles per day in 2039. The existing configuration was an arterial with 6 main lanes proposed to be upgraded to an interstate consisting of 3 frontage road lanes on each side of 6 main lanes (3 lanes each direction), plus 5-foot sidewalks on each side and a 10-foot bicycle and mixed-use path on one side.

The emissions difference for the build compared to the no build alternative was 0.0047 MMT/year. The project level annual emissions included on-road and associated fuel cycle emissions plus 20-year annualized life-cycle construction and maintenance emissions. The project build to no-build difference is 0.0026% of 2023 Texas on-road systemwide and fuel cycle estimated emissions (184 MMT).

Example 2: (High Traffic Corridor Added Capacity Project)

The project length was 8.1 miles. The preferred alternative would reconstruct an urban interstate, add 36.7 lane miles of managed HOV lanes including for car/vanpool and bus rapid transit (2 lanes in each direction), and create 19.3 miles of shared use paths for bicycle, pedestrian, and other active transportation modes such as scooters. Traffic volumes were 207,215 average vehicles per day in the 2019 base-year and projected to be 303,700 vehicles per day by 2045.

The emissions difference for the build compared to the no build alternatives was 0.05 MMT/year CO_2e. The project level annual emissions included on-road and associated fuel cycle emissions plus 20-year annualized life-cycle construction and maintenance emissions. The project build- to no-build difference is 0.027% of 2023 Texas on-road systemwide and fuel cycle estimated emissions (184 MMT).

The annual difference between the build and no build alternatives for the two example projects are 0.0026 and 0.027%, respectively of 2023 Texas on-road systemwide and fuel cycle estimated CO_2e emissions (184 MMT). These minor differences between the build and no-build alternatives suggest that both typical and large complex project alternatives are a very small portion of systemwide emissions. Please note that the statewide CO_2e emissions do not include the life-cycle construction and maintenance emissions included in project-level emissions, so the project level GHG emissions for vehicles operating on the road is a smaller percent than disclosed above.

3.2 Summary

GHGs are different from other air pollutants evaluated in federal environmental reviews because their impacts are not local or regional due to their characteristic rapid dispersion into the global atmosphere (IPCC, 2023). From a quantitative perspective, global climate change is the cumulative result of numerous emissions sources, each of which represents a relatively small addition to global atmospheric GHG concentrations (IPCC, 2023). In contrast to broad-scale actions, such as those involving an entire industry sector or very large geographic area, there is currently no scientific methodology for attributing specific climate change impacts (e.g., global temperature change, global sea-level rise, change in extreme weather patterns) to emissions from a particular transportation project.

The scenario emissions analyses in **Figure 2** above provide a range in future emissions that approach an unrealistic worse-case emissions analysis in that it does not include all existing regulatory requirements to reduce vehicle and fuel emissions to a reasonable case that projects future technological advancements beyond MOVES4 that may occur between now and 2050.

The two project-level GHG emission examples show nominal differences between alternatives as well as nominal change to the Texas transportation system. Because of the nominal changes, the impacts would not be meaningful to a decision on a project or a choice among its alternatives. Reducing the majority of Texas on-road GHG emissions will depend on 1) how rapidly vehicle technology changes and 2) personal commute decisions; TxDOT does not control these factors. Conditions that reduce tailpipe emissions within TxDOT responsibility are programmed into individual projects in regional, and statewide transportation plans (**Section 3.3,** and **Appendix F:** web link for **Project Development, Selection and Delivery Brochure**).

3.3 Strategies that Reduce Greenhouse Gases

Strategies to reduce on-road GHG tailpipe emissions fall under three major categories:

- Travel demand management (TDM) provides reductions in VMT by encouraging the use of alternative modes and shared trips (e.g., telework, transit, rideshare, scooters, and bicycle and pedestrian facilities, and high occupancy vehicle (HOV) lanes);
- Traffic system management (TSM) reduces emissions by improving the operational characteristics of the transportation network to improve traffic flow and reduce congestion (e.g., traffic light timing, pre-staged wrecker service to clear accidents faster, or traveler information systems); and
- Technological advances, including but not limited to those required by federal engine and fuel controls implemented by EPA and vehicle and fuel efficiency rules issued by U.S. Department of Transportation (USDOT) National Highway Traffic Safety Administration (NHTSA).

International and national entities state vehicle and fuel technological advancements remain critical to achieving future roadway transportation GHG emission reductions:

- The U.S. Blueprint (USDOE, USDOT, USEPA, USHUD, 2023), page 5 states: “While the first two strategies—increasing convenience and improving efficiency—will contribute to reducing GHG emissions and produce significant co-benefits, transitioning to clean options is expected to drive the **majority** (emphasis added) of emissions reductions.” It goes on to explain that “'clean options … will require various vehicle and fuel solutions.”
- The U.S. Blueprint and the U.S. National Academies of Science, Engineering and Medicine (NASEM) indicate vehicle technological advances will reduce most GHG transportation emissions (USDOE, USDOT, USEPA, USHUD, 2023), (NASEM, 2023a).

According to the IPCC, transformative and disruptive changes are necessary to achieve net zero emission goals (IPCC, 2023a1). For the U.S., transformative and disruptive changes would require action beyond TxDOT control; including, but not limited to, a combination of international, federal, and state legislative action, private-business decisions, local government land use changes, global funding, global macroeconomic changes, personal commute decisions, and personal lifestyle changes. Transformative and disruptive change could alter communities, societies, financial institutions, and global politics, policies, and markets in positive or negative ways that cannot be accurately forecast due to complexities and unknowns with how such change may unfold.

Electric Vehicle Market Projections: Multiple sources indicate a transformative change may occur in vehicle manufacturing by 2030 with major shifts predicted from fossil-fuel or biofuel internal combustion engine powered passenger vehicles to passenger electric vehicles, with substantial increases beginning in 2025. Four sources of information are summarized below.

- EPA projected up to 56% of the MY 2032 light duty vehicles could be electric (EPA, 2024b).
- Bloomberg New Energy Finance (BNEF) issued the “Electric Vehicle Outlook 2023” (“EVO 2023”) (Bloomberg New Energy Finance, 2023). In the Executive Summary to this report, BNEF reviewed economics, technology, policy, and consumer behavior to predict EV adoption between now and 2040. The Executive Summary states: “EV sales are surging due to a combination of policy support, improvements in battery technology, more charging infrastructure, and new compelling models from automakers (Bloomberg New Energy Finance, 2023).
- Goldman Sachs stated: “We expect the automobile industry to undergo a major transformation between 2020 and 2030” (GoldmanSachs, 2023).

- The International Energy Agency (IEA) released "Global EV Outlook 2023" regarding global market projections for electric vehicles. The IEA disclosed that 10 million EVs were sold globally in 2022 (IEA, 2023a). This Outlook also indicated:
    - Over 26 million electric cars were on the road in 2022, up 60% compared to 2021 and more than 5 times the stock in 2018 (IEA, 2023a, page 14).
    - Mining and processing of critical materials will need to increase (IEA, 2023a, page 56).

Alternative Fueled Vehicles in Texas: For fiscal year 2023, the following alternative fueled vehicles were registered in Texas: 1 hydrogen fuel cell, 12 hybrid diesel electric, 1 methanol, 172 ethanol, 2,171 propane, 3,610 natural gas, 175,497 EVs, and 410,330 hybrid gasoline electric vehicles (TxDMV, 2023). Texas has 283,396 EVs as of June 11, 2024, (Dallas-Fort Worth Clean Cities, 2024).

3.3.1 TxDOT Strategies That Result in GHG Emission Reduction

TxDOT actively works in partnership with MPOs, local governments, transit authorities, federal agencies, and the public to plan, maintain, and enhance the Texas multi-modal transportation system. Four conditions impact on-road GHG emissions: vehicle efficiency, the carbon content of fuel, travel efficiency, and distance traveled. Different entities have the ability or responsibility to affect these conditions that reduce on-road GHG. For example, for vehicle efficiency, the federal government sets vehicle efficiency standards, drivers choose how efficiently to operate vehicles, and individuals make vehicle purchase decisions. The federal government regulates fuels, for example, EPA issues the Renewable Fuel Standards (RFS) that reduced the carbon content of gasoline. For distance traveled, TxDOT and local partners provide the transportation infrastructure to allow individuals to choose distances to travel and if those commutes will occur by vehicle, transit, active transportation, or be avoided altogether such as with non-transportation technology (e.g., telecommute).

TxDOT is committed working with our transportation partners and the public on travel efficiency and distance traveled, and both help reduce GHG emissions. Distance traveled includes both providing travel choice between roadways, transit and active transportation modes and providing connectivity within and between modes. The Texas on-road transportation system operates as efficiently as possible with available funds (see **Appendix F** web links for more detail).

TxDOT Goals

Although TxDOT transportation improvement efforts are not primarily focused on GHG reductions except for the two new IIJA programs, federal agencies have disclosed they result in nominal GHG reductions via transportation system efficiency and convenience (USDOE, USDOT, USEPA, USHUD, 2023, page 5). TxDOT goals connected to transportation GHG reduction conditions include "optimize system performance" strategic goal and "optimize services and systems" budgetary goal (TxDOT, 2024b). The goal to optimize system services includes supporting and promoting public transportation (see below discussion on Transit). The goal to optimize system performance includes ensuring the efficiency of the overall transportation system to facilitate movement of people and goods. System performance programs include the Congestion Management Process, Transportation Systems Management and Operations, Active Transportation, and Transit. The TxDOT Advanced Vehicle Technology (AVT) helps prepare Texas for changes that may occur by technological advances.

Dollars and Cents

In the 2024 Unified Transportation Plan (UTP) (TxDOT, 2023j), TxDOT identified a little over $100.5 billion in projected investments for transportation improvements over the next 10 years. Of the $100.5 billion projected funds, approximately $13.791 billion directly or indirectly results in GHG emission reduction. Approximately $19.950 billion directly or indirectly aids transportation system resilience and preservation. **Table 4** shows more than $33 billion in TxDOT 2024 ten-year fund projections that directly or indirectly result in GHG reduction or transportation system resiliency and preservation. While some programs have dual benefits, funds were allocated only to GHG reduction or resiliency to avoid fund double-counting. For example, $220,000,000 for landscaping and the TxDOT Green Ribbons (tree planting) program, was allocated to GHG emission reduction, although the funding for these two programs may also provide for resilient design (e.g., by providing natural shade structures).

The Infrastructure Investment and Jobs Act/Bipartisan Infrastructure Law (IIJA/BIL) Programs
IIJA/BIL became law on Nov. 15, 2021. IIJA/BIL (Public Law 117-58), Title I, Subtitle D contains climate change provisions for transportation that include three new climate change programs. Funding for these programs is distributed to the states based on formulas in federal law, and through competitive grant programs. Below is a discussion on the two formula programs that target GHG emission reductions. The "Statewide Resiliency Plan" in Section 4.3 discloses the resiliency formula program called "Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation" or "PROTECT."

- ***National Electric Vehicle Infrastructure (NEVI) Program***
  IIJA/BIL established NEVI which provides funding to states to deploy electric vehicle charging infrastructure along public roads to establish an interconnected network across states and the nation. Governor Abbott directed TxDOT to lead the way in developing a plan to ensure all Texans have access to EV infrastructure, including but not limited to, rural placement and connectivity. TxDOT submitted its Electric Vehicle Infrastructure Plan on July 28, 2022, and FHWA approved it on September 27,2022. For fiscal years (FY) 2022-2026, Texas will receive $407.8 million. TxDOT considers these one-time funds, congressional action would be needed to extent the funds beyond IIJA/BIL. As TxDOT implements the plan, TxDOT remains committed to collaborating and engaging with the public and interested parties on electric vehicle infrastructure. For more detail, see TxDOT, 2023b.

- ***Carbon Reduction Program (CRP)***
  The IIJA/BIL CRP provides funding to reduce transportation carbon emissions. The Texas allocation of CRP funding is $641.3 million from FY2022-2026. TxDOT programmed the CRP funds in the 2024 UTP and increased the funding to $1.250 billion for a 10-year projection (TxDOT, 2023j, page 207). In consultation with MPOs, TxDOT developed the Carbon Reduction Strategy (CRS) required under 23 USC §175 and submitted it to FHWA by November 15, 2023. The CRS purpose is to identify strategies that will reduce transportation carbon emissions. With input from MPOs and other stakeholders, TxDOT identified seven categories of strategies for the CRS: 1) travel demand management, 2) active transportation, 3) transit, 4) freight movement, 5) advanced technologies, 6) construction and maintenance, and 7) alternative fuels. Each strategy serves the CRP's purpose of reducing transportation emissions, as well as TxDOT's mission of and vision of delivering mobility, enabling economic opportunity, and enhancing quality of life for all Texans. The CRS disclosed: "Understanding that the projected transportation emissions reductions from these and other projects identified in the CRS will not completely offset estimated transportation emissions in any given year, TxDOT will seek ways to maximize emissions reductions per federal dollar spent on them" (TxDOT, 2023e). The CRS also disclosed that the results of a "high-level scan of MPO planning documents revealed that approximately 40 percent (emphasis added) of the projects within those plans would qualify as eligible activities under the CRP" (TxDOT, 2023f).

Table 4: 10 Year Fund Projections that Result in GHG Reduction or System Resiliency and Preservation

Transportation Project or Project Design Element	Funds Result in GHG Reduction	Funds Result in Resiliency and Preservation	How Funds Result in GHG Reduction or Transportation System Resiliency and Preservation
Signals, Lighting, Signs	$560,036,400		Improves traffic flow and safety. Improved traffic flow reduces idle emissions. Safer active transportation encourages trips without vehicles. Added benefit, reduces GHG emissions.
Rehab, Restore, Surface Treat (non-bridge)		$14,243,926,120	Helps preserve and/or enhance facilities. Added benefit for resiliency.
Operational Improvements	$3,800,272,492		Improves traffic flow, reduces congestion (no general purpose lanes). Examples: realigning ramps, add direct connectors or turn lanes, improve signals, and add new or enhance bicycle/pedestrian facilities. Added benefit, reduces GHG emissions.
Congestion Mitigation Air Quality	$2,322,790,000		These funds reduce criteria pollutants and/or congestion. Added benefit, reduces GHG emissions.
Bridge Structures Replace/Rehab		$4,587,980,491	Helps preserve and/or enhance facilities. Added benefit for resiliency.
Bike/Ped/Sidewalk/Curb Ramp/ ADA/Other	$1,537,473,801		Funds active transportation facilities including design for ADA compliance. Added benefit, reduces GHG emissions.
Landscape Programs	$220,000,000		Tree planting and landscape development programs. Added benefit, sequesters GHG. Although not counted in resiliency funds, helps reduce heat island effects by providing shade.
Culverts and Storm Drainage		$389,364,497	Manages storm water and drainage. Added benefit for resiliency.
Interchanges (Cat 12 only)	$1,802,336,305		Improves traffic flow and safety for people using vehicles or active transportation. Added benefit, reduces GHG emissions.
ITS	$160,000,000		Improves traffic flow. Safety for people using vehicles or active transportation. Added benefit, reduces GHG emissions. Added benefit, supports emergency response resiliency operations.
IIJA/BIL CRP	$1,250,492,601		Directly funds projects that reduce GHG emissions.
IIJA/BIL NEVI	$407,774,759		Directly funds electric vehicle charging to reduce range anxiety with electric vehicle ownership or use. EV's produce no tailpipe GHG. Funds are for 5 years.
IIJA/BIL PROTECT		$729,178,282	Directly funds resiliency projects. Funds are for 5 years.
Rural and Urban Transit	$1,730,000,000		Funds transit improvements. In FY 23, TxDOT allocated over $173.1 million in State and Federal funds directly to rural and urban transit districts. The 10-year estimate is 10 times the FY 23 funding, rounding down by $1M.
Total Programmed	$13,791,176,358	$19,950,449,390	
Funds Result in GHG Reduction or Resiliency and Preservation	$33,741,625,748		

Source: TxDOT 2024 UTP (TxDOT, 2023j) and IIJA funding as of November 1, 2023. This is a conservative estimate with funding detail in **Appendix A.3**, **Table A-3, and Appendix F:** web link for **Funding Brochure.**

Congestion Management Process

A Congestion Management Process (CMP) is a systematic approach required in transportation management areas (TMAs) under 23 CFR § 450.322 and 23 USC 134(k)(3), and 134(n). The CMP provides for travel demand reduction, job access projects, and operational management strategies. Additional requirements apply in certain nonattainment areas and those provisions are addressed in the project environmental document and in regional MPO transportation plans that direct TxDOT on which projects to develop. The following categories of strategies, or combinations of strategies, are examples of what a TMA should consider for their area: a) traffic operational improvements, b) intelligent transportation systems (ITS) including technologies as related to the regional ITS architecture, c) demand management measures including growth management, and congestion pricing, d) public transportation improvements, and e) when operational improvements are inadequate to address congestion or connectivity, additional capacity is considered (FHWA, 2018a), (FHWA, 2011). Since vehicles operating at low speeds or idling have higher emissions than vehicles traveling at higher speeds (DOE, 2015), reducing congestion reduces GHG emissions by decreasing the amount of time vehicles are on the road idling or operating at low speeds.

As Texas growth continues, a critical TxDOT goal is to optimize system performance which includes congestion management. TxDOT funds a variety of congestion management projects in the ten-year UTP. Items a) and b) above are discussed in more detail under Transportation Systems Management and Operations, and items c) and d) are discussed under Active Transportation and Transit. For item e) in FY2023, only 57 projects out of 2448 projects were added capacity.

Congestion Mitigation and Air Quality Improvement Program (CMAQ)

The CMAQ program funds transportation projects or programs that will contribute to attainment or maintenance of the National Ambient Air Quality Standards (NAAQS) for ozone, carbon monoxide (CO), and particulate matter (both PM10 and PM2.5) (TxDOT, 2024c, page 139), (FHWA, 2024a). This program has the indirect benefit of reducing tailpipe GHG emissions. Examples of projects include:

- Intersection and signal system improvements;
- Park-and-ride lots;
- High occupancy vehicle lanes;
- Vanpool and rideshare programs:
- Incident detection and response programs;
- Bicycle and pedestrian facilities;
- Conversion of public vehicles to alternative fuels/clean vehicles; and
- Transit system improvements.

Transportation Systems Management and Operations

TxDOT implemented the Transportation Systems Management and Operations (TSMO) program statewide to maximize mobility using available transportation funding. The TxDOT Traffic Safety Division oversees the development and implementation of TSMO for TxDOT along with TxDOT divisions and districts. The TSMO planning initiative serves to improve the project delivery process by integrating mobility-focused solutions throughout planning, design, construction, operations, and maintenance. TSMO mobility strategies and ITS technologies are relatively low in cost, can be implemented faster, and have higher benefit-cost ratios compared to projects adding roadway capacity. Texas' metropolitan cities are among the most congested locations in the nation (TxDOT, 2023c). Rural areas also have seen an increase in vehicles on the roadways—most notably, freight and commercial vehicles (TxDOT, 2023c).

With vehicle miles traveled (VMT) increasing as population expands in Texas combined with funds for infrastructure development, congestion is likely to worsen (TxDOT, 2023c).

By collaborating with partner agencies and implementing data-driven decisions, the transportation network will be safer, more efficient, and will improve reliability for travelers of all modes. For more detail, go to TxDOT's webpage entitled "Transportation Systems Management and Operations" (TxDOT, 2023c).

Active Transportation

TxDOT is developing a comprehensive Statewide Active Transportation Plan to establish a unified vision for the identification and implementation of strategic active transportation priorities and policies across Texas through 2050. TxDOT works with governmental entities and community stakeholders to plan for bicycle and pedestrian networks that integrate with local multimodal transportation systems**. TxDOT requires its design engineers to consider bicycle and accessible pedestrian accommodations on all construction and reconstruction projects on the state highway system. This means that TxDOT improves the state's bicycle and pedestrian network with many highway projects** (TxDOT, 2023j). Improvements to bicycle and pedestrian facilities depend on the needs of specific locations, but may include bike lanes, shared use paths, sidewalks, pedestrian crossing beacons, median islands, and curb ramps. For more information on TxDOT's consideration of bicycle and pedestrian infrastructure, see page 171 of the 2024 UTP (TxDOT, 2023j), the TxDOT webpage entitled "Statewide Active Transportation Plan," (TxDOT, 2023g), and **Appendix F:** web link for **Bicycle and Pedestrian Program Brochure**.

Transit

Texas public transportation services are provided primarily by three types of entities: rural transit districts, urban transit districts, and metropolitan transit authorities (MTAs) (TxDOT, 2023j). There are currently 36 rural transit districts, 32 urban transit districts, and 8 MTAs. In addition, a total of 24 stand-alone public and private entities offer service specifically for seniors and those with disabilities throughout the state. Over 205 million public transportation trips were made possible by these operators in Texas in FY 2023 (TxDOT, 2024). Texas transit programs are funded by a mix of federal, state, and local sources (Texas Comptroller's Office, 2023). The Federal Transit Authority (FTA) distributes funds to state and local transit providers, such as TxDOT and MTAs. MTAs are funded through a combination of their own local funds, including a dedicated sales tax, and are not eligible for state funding. MTAs may levy local sales taxes from 0.25 to 1 percent to help fund their operations (Texas Comptroller's Office, 2023). These local taxes exceeded $2 billion in FY2019 and comprised 78 percent of MTAs' total revenue (Texas Comptroller's Office, 2023).

TxDOT works with others to provide a safe, reliable network of transportation options for people who use alternatives to driving alone (TxDOT, 2023k)). TxDOT provides financial, technical and coordination assistance to Texas rural and urban public transit providers (TxDOT, 2023k). TxDOT does not directly plan or build public transportation systems, such as bus and light rail. TxDOT is responsible for distributing grant allocations to rural and urban transit districts, while MTAs receive their grants directly from the federal government. All rural, urban, and metropolitan agencies are responsible for operating and expanding their transit services (TxDOT, 2023j, page 170). TxDOT is working on a Statewide multimodal Transit Plan (SMTP) to help the department and its partners plan for the movement of people in a comprehensive, coordinated, multimodal transportation system (TxDOT, 2024a). For additional information on transit programs, please see (TxDOT, 2024a), and pages 166 -170 of the 2024 UTP in (TxDOT, 2023j), and **Appendix F:** web link for **Public Transportation Brochure.**

TxDOT and Advanced Vehicle Technology

The TxDOT Strategic Planning Division anticipates, plans, and implements strategies to facilitate and build transportation infrastructure including activities related to advanced vehicle technology (such as electric vehicles or technology for driver-less vehicles such as automated and connected vehicles). These programs are briefly summarized below, and more detail is available at the TxDOT Innovative Transportation webpage (TxDOT, 2023h) and in **Appendix F:** web link for **Transportation Technology Brochure**.

- TxDOT coordinates and participates in the Texas Technology Task Force (TTTF). A goal of the TTTF is to advance the development of a high-performance transportation system to continue to position Texas as a leader of economic activity and technological innovation.
- Governor Abbott directed TxDOT to establish a Connected and Automated Vehicle (CAV) Task Force. This statewide task force provides Texas with a single, unified source of information regarding the coordination and advancement of CAV and CAV technologies across the state.
- TxDOT created the Texas Innovation Alliance (TIA). The TIA is an action network of local, regional, and state agencies and research institutions who are committed to addressing community mobility challenges by creating a platform for innovation. The mission of the Alliance is to strategically develop, launch, and sustain a portfolio of advanced mobility projects across Texas. The TIA launched the Texas Proving Grounds, which was one of the original ten USDOT Automated Proving Ground sites. While the federal designation has ended, the Texas Proving Ground Partnership is still offering a precompetitive environment for automated vehicle (AV) testing. The TIA is currently being enhanced to be the FHWA sponsored Texas State Transportation Innovation Council (STIC). TxDOT tracks advanced vehicle test sites within Texas. For more detail see (TxDOT, 2023i).
- The Cooperative and Automated Transportation (CAT) program is an initiative established by TxDOT to integrate Connected Vehicles (CV), Automated Vehicles (AV) and related emerging transportation technologies into the state's transportation system. CAT offers numerous potential benefits and improvements for safety and to accommodate rapidly growing transportation demands by using technology to maximize transportation infrastructure performance.

Recycling, Clean Construction and Operation:
TxDOT has specifications for sustainable pavements that reduce energy consumption, increase recyclable use, and reduce air emissions including CO_2. Examples include:

- Warm Mix Asphalt (WMA)
- Recycled Asphalt Pavement (RAP)
- Recycled Asphalt Shingles (RAS)
- Coal and Other Combustion By-Products (e.g., fly ash)
- Recycled Tires
- Recycled Concrete
- Standard specifications for purchasing light emitting diode (LED) lighting; and
- Solar sign boards replacing diesel-powered sign boards.

Updating the TxDOT Fleet

TxDOT Fleet Operations is actively updating the TxDOT Fleet and seeking additional grant funds to enhance the process. In FY2023, the results included:

- 493 TxDOT bi-fuel cars and trucks (on-road vehicles) using liquefied petroleum gas (LPG) in addition to gasoline.
- 184 pieces of off-road equipment including forklifts using LPG and 52 units using electricity.

- 44 dedicated compressed natural gas (CNG) vehicles and 16 bi-fuel (gasoline and CNG) vehicles in the fleet.
- TxDOT vehicles used more than 655,514 gallons of alternative fuels, including biofuels, CNG and propane in FY 2023.
- 83 electric/hybrid-electric vehicles and 3,112 flex-fuel (E85) vehicles.
- 3,955 clean diesel vehicles.
- TxDOT received a grant from TCEQ for $437,000, to buy several alternative fuel vehicles including three Ford Lightning electric pickup trucks.
- Another TCEQ grant totaling approximately $450,000, if awarded, will fund an all-electric truck mounted attenuator (including the EV infrastructure) that will be located at the La Marque Area Office in Galveston County.

4.0 Assessment of Climate Change Scenarios or Projections

In this section:

- **Section 4.1** provides a summary of potential global and national climate change scenarios or projections.
- **Section 4.2** provides a summary of climate change scenarios or projections up to the year 2100 for Texas.
- **Appendix A** provides the methodology for the climate assessment.
- **Appendix B** contains the NOAA Texas Climate Summary.
- **Appendix C** contains the U.S. Geological Survey (USGS) National Climate Change Viewer data for Texas.
- **Section 4.3** discusses TxDOT strategies that address resiliency.

Section 5 discloses several major sources of data limitations and uncertainty that exist in climate change scenarios or projections.

The terms used in climate literature are evolving. The terms “climate projections,” “illustrative scenarios” or “illustrative pathways” are interchangeable, with more recent literature using “scenarios” or “pathways.” Projections/scenarios/pathways are created by climate models and are terms used by scientists in studies to explore and explain a range of possible futures (IPCC, 2023b, page 63). The terms provide a quantitative scientific set of assumptions or illustrations for future GHG emissions and climate change impacts and some projections/scenarios/pathways also add socioeconomic conditions, global to local climate policies, and future human activities. Projections/scenarios/pathways are however, neither predictions nor forecasts for the future (IPCC, 2023b, page 63).

The climate change scenarios or projections used for global, national, state, and local data were based on a group of global climate models called Coupled Model Intercomparison Project Phase 5 (CMIP5) using emission scenarios called Representative Concentration Pathways (RCPs) that reflect emission estimates for a specified radiative forcing (RF) (in watts per square meter, or Wm-2). An RF provides an indication of how warm the earth might be in the future based on a concept of heat balance, or what comes in versus what goes out.

Where the newer CMIP6 was available and used, it enhanced RCPs by using Shared Socio-economic Pathways (SSPs). SSPs add global scenarios for population, socioeconomic issues, land use, and policy choices. Slight differences exist in the global average temperature changes associated with RCPs and SSPs of comparative RF values. These changes are due to a slightly different mix of GHGs in the SSP emissions pathways, and from the use of more recent climate models than CMIP5 which used RCPs (IPCC, 2023b). "SSP-based scenarios are referred to as SSPx-y, where 'SSPx' refers to the SSP describing the socioeconomic trends underlying the scenarios, and 'y' refers to the level of radiative forcing resulting from the scenario in the year 2100" (IPCC, 2023b, page 63, footnote 105). SSP2-4.5 like RCP4.5, corresponds to intermediate emissions of CO_2e with emissions plateauing through 2050 and then large global GHG reductions by 2100. SSP5-8.5 like RCP8.5, corresponds to high emissions of CO_2e in 2100 with few additional worldwide GHG control measures by 2100. International and national entities are in the process of transitioning from CMIP5 which used RCPs to CMIP6 that used SSPs. When converting from CMIP4 to CMIP5, TxDOT noted federal agencies needed two or more years to update their climate tools to the newer version. TxDOT will monitor the U.S. Climate Resilience Toolkit (USGCRP, 2023b) for federal climate tool transitions from CMIP5 to CMIP6.

NEPA practitioners including TxDOT must ask the question of which climate scenarios or projections (RCPs and SSPs) to consider. TxDOT looked for information used by federal agencies and available to TxDOT and the public. TxDOT chose RCP8.5/SSP5-8.5 and RCP4.5/SSP2-4.5 since these scenarios or projections provide a range of high to low emissions for the year 2100. Each future scenario is compared to a historic climate data base-case such as 1960-2000, or 1901-2000. Base case years are disclosed in each federal agency climate tool used by TxDOT in this Technical Report.

TxDOT chose the RCP8.5/SSP5-8.5 high emissions scenario for use in this Technical Report to illustrate a potential worse case future; even though, IPCC AR6 states: "very high emission scenarios have become less likely but cannot be ruled out" (IPCC, 2023b, page 63, footnote 106). The IPCC AR6 report also states: "The high-end scenarios RCP8.5 or SSP5-8.5 have recently been argued to be implausible to unfold (e.g., Hausfather and Peters, 2020; see Chapter 3 of the AR6 WGIII)" (IPCC, 2021a, Chapter 4: Future Global Climate: Scenario-based Projections and Near-term Information, page 562). If global GHG reductions are more consistent with lower emission scenarios or projections than SSP2-4.5, then future climate impacts may be less impactful than scenarios in this Technical Report. If future climate reports do not use SSP5-8.5, TxDOT will re-evaluate scenario use. Climate experts use a range of scenarios because the complex nature of the climate system, climate models, and human factors makes it challenging to determine exactly how the climate will change in the future. TxDOT chose two scenarios to show a range of possible futures based on current climate models and data.

4.1 Overview of Global and National Climate Change Scenarios

This section provides an overview on global and national climate change scenarios. Depending on international efforts, global socioeconomic and societal issues, and technological advances known and yet to be determined, climate change is anticipated to have a potentially wide range of effects on temperature, sea level, precipitation patterns, and severe weather events. These factors in turn could affect human health and safety, infrastructure, and food and water supplies. Large elements of uncertainty within future scenarios or projections (NHTSA, 2016) make it extremely difficult to reliably predict the timing and scale of future changes in climate globally, nationally, and locally. Tables 5 and 6 provide a summary of implications from global and U.S. climate scenarios or projections. Up-to-date information from IPCC AR6, NCA5, and NOAA extreme weather and climate events are also briefly presented below.

Table 5: Projected Global and U.S. Climate Change Implications

Impacts to Natural Systems		Impacts to Humans	
Category	**Potential Impacts**	**Category**	**Potential Impacts**
Fresh water quality & supply	Increased irrigation needs; water shortages; variability of water supply; increased flood risk; salt water intrusion from sea level rise; increased acidity.	Food, fiber, and forestry industries	Increased tree mortality; crops and livestock productivity losses; changes to nutritional quality of grazelands and food crops; changing marine migration impacts to fishing industry; impacts to food prices and food security.
Species and habitats	Species range and migration pattern shifts; species' life-cycle event changes; diversity loss; threats to species unable to adapt to changing conditions; forest fire and pest infestation occurrence increases; habitat productivity changes; stimulated plant growth due to increased atmospheric CO_2.	Human settlements	Changes may affect services such as: 1) water/energy supply; 2) wastewater/stormwater; 3) transportation; 4) telecommunications; 5) building structures; and 6) social services. Agricultural income changes. Air quality changes. Some populations have higher risks, such as: low-income, elderly, children, and persons with health conditions.
Oceans and coastlines	Loss of coastal areas; reduction in coral reefs and other key marine habitats; increased vulnerability to severe weather and storm surge; increased salination in estuaries and aquifers; increased acidity due to chemical reactions with excess CO_2.	Human health	Increased morbidity and mortality due to excessive heat, storms, flooding and widfires; increases in respiratory conditions due to poor air quality and aeroallergens; increases in water and food-borne diseases; changes in seasonal patterns of vector-borne diseases; increases in malnutrition. Vulnerable populations have highest risks.
Air quality	Projected impacts on statospheric ozone recovery (elements of uncertainty).	Security	Threats in response to adversley affected livelihoods; compromised cultures; compromised settlements; increased and/or restricted migration; and reduction in provision of adequate essential services.

Sources:, (NHTSA, 2016), (TRB, NCHRP, 2014), (USACE, 2014), (USGS, 2023a), (United Nations, 2017), (USGCRP [Cavallaro, 2018) pp 21-40, and (NOAA, 2017), (NOAA. Sweet, 2022) (IPCC, 2023), (USGCRP & Crimmins, NCA5, 2023a)

The IPCC AR6 contains some of the more recent published information on global climate change. Some key findings from its 2023 Synthesis Report (IPCC, 2023b) include:

- "Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred" (IPCC, 2023b, page 5).
- Projected changes in extremes are larger in frequency and intensity as global warming increases (IPCC, 2023b, pages 46, 69, and 98).

Table 6: Existing and Projected Global Sea Level Rise

Climate Variable	Source	Indicator	Existing and Projected Changes
Global Sea Level Rise	IPCC[1]	Existing	From 1901 to 2010, historical global mean sea level rise increased 6.69 to 8.27 inches (0.17 to 0.21 meters (m)). Maximum global mean sea level during the last interglacial period (129,000 to 116,000 years ago) was, for several thousand years, at least 16 feet (5 m) higher than present and high confidence it did not exceed 32 feet (10 m) above present.
		Projected	Likely range of global sea level rise in 2018-2100 relative to 1986-2005 is 1.05 to 2.07 feet (0.32 to 0.63 m) for RCP4.5 and 1.48 to 2.69 feet (0.45 to 0.82 m) for RCP8.5.
	IPCC[2]	Projected	Relative to 1995–2014, the likely global mean sea level rise by 2100 is 0.92 to 1.8 feet (0.28 to 0.55 m) under the very low GHG emissions scenario (SSP1-1.9); and 2.1 to 3.3 feet (0.63 to 1.01 m) under the very high GHG emissions scenario (SSP5-8.5).
	NOAA[3]	Existing	Over the past 30 years global mean sea level rise has averaged approximately 0.12 inches/yr. (3 mm/yr.), based upon global tidal gauge data, or 3.54 inches over 30 yrs. (90 mm per 30 yrs.).
	NOAA[4]	Projected	The scenario projections of relative sea level (RSL) along the contiguous U.S. (CONUS) coastline are 2 to 7.2 feet (0.6 to 2.2 m) in 2100 Per NCA5, 1 – 6.6-foot sea level rise.
	IPCC and NCA[5]	Existing	The past century (1900-2000) had a global average sea level rise of 7 to 8 inches.
		Projected	IPCC projects 1 to 4 feet (0.3 to 1.3m) mean global average sea level as likely by the year 2100 relative to the year 2000. NCA5 projects 1 to 6.6 feet (0.3 to 2 m) mean global average sea level rise by 2100.

Sources and Notes: Unless otherwise specified, Future Climate Scenarios are based upon RCP4.5 and RCP8.5.
1) (Stocker, 2013). 2) (IPCC, 2023a, page 21). 3) (NOAA, 2017). 4) (NOAA, Sweet, 2022, page 61). 5) (IPCC, 2023a, Page 21, item B.5.3) and (USGCRP & Crimmins, NCA5, 2023a, Chapter 9: Coastal Effects under Key Message 1).

The NCA5 contains some of the more recent published information on national implications of global climate change (USGCRP & Crimmins, NCA5, 2023a). Some NCA5 “Report in Brief” key messages are provided below along with the Brief’s referenced page number (USGCRP. Crimmins, 2024).

- “Decarbonization will require innovative solutions across multiple sectors” (page 75).
- “Pathways to net zero” emissions “involve large-scale technological, infrastructure, land-use, and behavioral changes and shifts in governance structures” (page 61).
- “Scenarios that reach net-zero emissions include some of the following key options” (page 61)
    - “Improving energy efficiency in buildings, appliances, and light- and heavy-duty vehicles and other transportation modes.”
    - “Implementing urban planning and building design that reduces energy demands through more public transportation and active transportation and lower cooling demands for buildings.”
    - “Increasing the efficiency and sustainability of food production, distribution, and consumption.”
    - “Improving land management to decrease greenhouse gas emissions and increase carbon removal and storage, with options ranging from afforestation, reforestation, and restoring

coastal ecosystems to industrial processes that directly capture and store carbon from the air."

- "Adequately addressing climate risks involves transformative adaptation" (page 63). "In many cases, more transformative adaptation will be necessary to adequately address the risks of current and future climate change" (page 63). Examples of transformative adaptation:
  - "Redesigning cities and buildings to address heat" (page 63).
  - "Shifting water-intensive industry to match projected rainfall patterns" (page 63).
  - "Directing new housing development to less flood-prone areas" (page 63).
- "The choices people make on a day-to-day basis—how to power homes and businesses, get around, and produce and use food and other goods—collectively determine the amount of greenhouse gases emitted" (page 56).

NOAA's National Centers for Environmental Information (NCEI) collects data on extreme weather and climate events in the U.S. that have great economic and societal impacts known as "U.S. Billion-dollar Weather and Climate Disasters" (NCEI, 2023b). It collects public and private disaster loss data (including consumer prices index adjustment to 2023). From 1980 to July 2023, NOAA identified 360 events (8.2 events/year average) at a cost of $2,575.7 trillion ($58.58 billion/year on average), and loss of 15,958 lives (363 lives lost/year average) (NCEI, 2023b). Over the last 3 years, the averages are showing an increase: 60 events (20 events/year average), for $451.8 billion ($150.6 billion/year average) and loss of 1460 lives (487 lives lost/year average) (NCEI, 2023b).

4.2 Climate Change Scenarios or Projections for Texas

Based on the NOAA State Climate Summary data in **Appendix B**, and the USGS National Climate Change Viewer (NCCV) data in **Appendix C**, this section provides a qualitative summary of climate change scenarios or projections for the state of Texas. The NOAA Texas State Summary data was based on CMIP5 (NOAA. Runkle, 2022a). The USGS NCCV supplements the NOAA data with the newer climate modeling data from CMIP6.

Climate data sets disclose data for: 1) observed data (data with records and monitoring for climate variables), 2) for a historical time-period used for comparison to future scenarios or projections, and 3) time-periods for the future climate scenarios or projections. The difference in historic time-periods may result in slightly different results for the amount of change into the future. For example unless otherwise specified, NOAA used a historic range of 1901-1960, while NCCV used 1950-2014 (NOAA. Sweet, 2022), (USGS, 2023a). NOAA observated data was for the for the period of 1900–2020, and USGS was 1950-2014, unless otherwise specified (NOAA. Sweet, 2022), (USGS, 2023a). The NOAA climate future scenarios are for the period of 2006–2100, while USGS is 2015-2100 (NOAA. Sweet, 2022), (USGS, 2023a). NOAA used RCP4.5 and RCP8.5 to project low and high emission scenarios (NOAA. Sweet, 2022). USGS used SSP2-4.5, SSP3-7.0, and SSP5-8.5, (USGS, 2023a). SSP3-7.0 is a scenario in which countries prioritize issues of national and food security with a resulting average temperature increase of 3.6°C by 2100. The SSPs were used in IPCC AR6 and in NCA5 (USGS, 2023a).

The NOAA Texas Climate Summary and Texas USGS NCCV disclose the following climate scenarios or projections for Texas:

- Warmer and drier;
- Increasing intensity of extreme weather events (e.g., hurricanes, tornadoes, droughts, heat waves, cold waves, and extreme precipitation); and

- Increasing sea level rise and higher storm surge.

Implications for the Texas transportation system would be temporary closures or rerouting due to extreme events, flooding and inundation potential, roadway rutting, buckling, cracking that may increase maintenance costs or change pavement binders and chemistry, and increase in the risk of power outages that could affect traffic signals and ITS. Roadway closures, power outages, or rerouting requires TxDOT to work with local partners and the public to help ensure the safe movement of inviduals using all modes, including vehicular, transit or active transportation. Warmer and drier conditions may lead to longer wildfire seasons and increased wildfire potential that may result in temporary road closures due to fire, smoke or limited visibility conditions.

While overall precipitation is projected to decrease for Texas, severe precipitation events are likely to become more intense (NOAA. Runkle, 2022a). The location, frequency and severity of extreme weather remains uncertain (NOAA. Runkle, 2022a). Extreme weather events, such as major flooding, extreme heat, extreme cold, storm surge, and major storms have historically impacted people, communities, and the transportation system in Texas (USGCRP & Crimmins, NCA5, 2023a). The U.S. National research studies, including reports sponsored by the Transportation Research Board (TRB), have highlighted how climate change related extreme weather events are anticipated to further impact U.S. highways and other transportation infrastructure, for example, the 2014 TRB Strategic Issues Facing Transportation, Volume 2, Climate Change, Extreme Weather Events and the Highway System: Practitioner's Guide and Research Report, Table I-1. Additionally, the number of days in Texas subject to extreme heat is projected to increase (USGCRP & Crimmins, NCA5, 2023a, Chapter 26). These extreme events may increase maintenance costs by impacting pavement or bridge integrity such as by rutting, cracking, or slope stability issues, or temporarily limit or redirect multi-modal travel movement (USGCRP & Crimmins, NCA5, 2023a, Chapter 13: Transportation, pages 13-7 and 13-8).

4.3 TxDOT Strategies that Aid in Transportation System Resiliency and Preservation

For TxDOT, resilience is the ability to *support* and maintain a **multimodal** transportation system that can **safely move people, goods, and services** during adverse conditions, and can **anticipate**, **prepare** for, **adapt** to, **withstand**, **respond** to, and **recover** efficiently from both human and natural disasters and disruptions. TxDOT's resiliency efforts consider all travelers in Texas, regardless of race, ethnicity, or socioeconomic background. Developing strategies and programs to address resiliency given the uncertainty and variability in the range of climate scenarios or projections and timing of those changes requires flexibility. As data advances and knowledge grows on risks to system resilience and preservation, TxDOT programs have feedback loops to continuously improve data, programs, and decisions to enhance transportation system resiliency, sustainability, and preservation. Adaptation and resiliency strategies may be considered during planning, project development, final design, construction, emergency response, asset management and/or operational and maintenance activities. As mentioned in **Section 3.3.1** of this Technical Report, at least $19.950 billion (about 20% of projected funds for the next 10 years) either directly or indirectly result in transportation system resiliency, sustainability, and preservation (TxDOT, 2023j). This section discusses TxDOT strategies that directly or indirectly result in resiliency and preservation.

TxDOT Agency Goals

As steward of the Texas transportation system, TxDOT is responsible for ensuring the safety of the traveling public and the effective long-term operation of infrastructure assets. Agency goals associated with resiliency include optimize system performance and preserve our assets (TxDOT, 2024b); both goals are foundation stones for a resilient transportation system.

Statewide Transportation Resiliency Plan

Each year, the Texas transportation system is at risk to extreme weather events, Intelligent Transportation System (ITS) security threats, and other human-made hazards such as dam and levee failures. These hazards can damage transportation infrastructure and disrupt operations, with cascading impacts for public safety and health, freight and supply chains, and the Texas economy. In recognition of these potential impacts, TxDOT is developing the Statewide Resiliency Plan (STRP) to strengthen the resilience of the Texas multimodal transportation system. It is scheduled for completion in late 2024. The STRP will comprehensively evaluate the Texas transportation system's resiliency to a wide range of hazards, identify hazards and transportation disruptors, inventory assets, identify critical infrastructure, assess vulnerabilities and risk, develop, and prioritize strategies and performance measures, engage with internal and external stakeholders, and develop solutions and strategies to increase resilience. Initial key climate variables are coastal flooding, wildfire, rainfall flooding, drought, extreme heat, extreme cold, and ITS resilience. The STRP will include a list of strategies and projects that enhance the overall resilience of the transportation system in Texas. The list of projects will serve as the Resilience Improvement Plan (RIP) as referenced in the IIJA PROTECT Formula Program. TxDOT coordinates with FHWA to confirm project eligibility for PROTECT funds. For more information see TxDOT, 2023d.

TxDOT Transportation Asset Management Plan

The TxDOT 2022 Transportation Asset Management Plan (TAMP) presents a 10- year strategy for managing the state's pavements and bridges. TxDOT constructs, maintains, and inspects the largest network of pavements, bridges, and other assets in the country. TxDOT itself owns, maintains, and operates 201,225 lane miles of roads and 34,865 bridges, which carry 185.8 billion vehicle miles annually. The TAMP details TxDOT's asset management approach and describes the condition of the transportation system, future investment plans, potential risks to effective operation of the network, the relationship between federal and state condition goals, and TxDOT's success in addressing those goals.

Transportation asset management (TAM) relies on data-driven decision-making to choose the right improvements at the right time in an asset's lifecycle to sustain a desired level of performance in the most cost-effective way. Maximizing the life of a set of physical assets requires determining what treatments to perform on the assets over time. Life Cycle Planning (LCP) is used to define treatment strategies. LCP is performed at a network level and yields an overall treatment strategy for an asset class or other grouping of assets.

Practicing resiliency at TxDOT means to quickly recover from disruptions through careful preparation, rapid response, and constant adaptation. TxDOT and other local transportation agencies have a long history of risk analysis imbedded in their standard operating processes that consider risks and ensure the safety of the traveling public. The TAMP includes mitigation strategies and actions for each of the following identified risks: natural disaster, revenues and funding, heavy truck traffic, material and labor costs, staff knowledge and abilities, workforce capacity, increasing population, long-term performance decisions, cyberattack, and public health emergency. Potential climate change factors fall under multiple TAMP listed risks. For example, natural disaster planning includes design additions for high-risk construction and reconstruction projects to make pavements and bridges more resilient to extreme weather events. For more information see TxDOT, 2022a.

Transportation Systems Management & Operations (TSMO)

Section 3.3.1 contains more detail on TSMO since efforts result in both emission reduction and resiliency. TSMO resilience activities include preparation for severe weather, hurricanes, snow and ice, flash floods, tornadoes, wildfires, and ITS resilience (TxDOT, 2023c).

Intelligent Transportation System (ITS) Resilience

ITS is the backbone of a multimodal transportation and is used daily. ITS helps to optimize the transportation system by improving operations, efficiency, reliability, and safety. Transportation strategies supported by ITS:

- Traffic management (traffic signals, integrated corridor)
- Traffic incident management (camera, communication)
- Traveler information (sign boards, messaging systems, travel time information)
- Work zone management (queue detection, messaging systems)
- Road weather management (road weather information systems [RWIS], pavement sensors)
- Freight management (freight traffic navigation and detour information, rail crossings).

Maintenance

Extreme heat, drought, or precipitation events may result in premature pavement failure. The TxDOT Pavement Manual addresses pavement failure including both a routine monitoring system and a follow up investigation by the TxDOT Premature Distress Investigation Team. TxDOT improves and refines pavement designs to adapt to changing conditions. Pavement binders and/or base design and materials adjustments are made as needed.

Emergency Management and Response

Statewide Emergency Management Program: TxDOT is part of the statewide emergency management team working collaboratively with local, state, and federal emergency responders to address natural or people-made emergencies. As a steward of the transportation system, TxDOT is responsible for the safe movement of all people, including individuals without access to personal passenger vehicles, those experiencing disruptions in public transportation and active transportation facilities and those needing medical transport. TxDOT is part of the first responder team that initially enters areas impacted by a disaster to ensure that the transportation system is safe for movement. Some of TxDOT's first responder activities include: debris removal, structural integrity analysis, coordination with local electric providers to remove downed wires, assisting stranded individuals to safety, and providing fuel and water along impacted corridors.

Traffic Management: is deployed when roads are impassable due to human or natural events (e.g., flooding and wildfires). Traffic management reroutes traffic due to road closures and detours to maintain the safest movement possible through the transportation system before, during, and post event. Notification systems relay road closures and detours.

TxDOT Statewide Inclement Weather and Road Condition Notification System: available at DriveTexas™ or by phone at (800) 452-9292 and at: https://www.txdot.gov/driver/weather.html. Flash flooding is the leading cause of weather-related deaths in Texas. If you encounter a flooded road, "Turn Around, Don't Drown." More information on flooding is available at: https://www.txdot.gov/driver/weather/flash-floods.html. In addition, roadway signs and a variety of social media notifications provide the latest information on closures and detours.

Communication Strategies: before, during, and after the event are critical to conducting large response efforts. For example, the TxDOT DriveTexas.org website received more than 5,000,000 visits during and immediately after Hurricane Harvey. The site includes real-time updates made by TxDOT staff in the field and provides the most accurate information possible to emergency crews and the public regarding flooding, pavement damage, and road closures. Advanced planning includes having teams to ensure that TxDOT's emergency radio communications towers continue to function throughout emergencies.

Advance Preparation: Extreme weather may down traffic lights, cause flooding, damage roadway signs, or cause asphalt to buckle, but most extreme weather impacts lead to disruptions in travel rather than chronic damage to the pavement and other transportation structures. Advance preparation and practice along with pre-deploying crews and equipment remain critical for TxDOT to quickly respond to and then recover from extreme weather events.

Infrastructure Assessments: are conducted after an event to determine needed clean up and repairs.

Design

The final project design process occurs after completion of the environmental process in accordance with applicable design requirements. New infrastructure is designed to current industry standards.

TxDOT Stormwater Management Program: helps reduce the frequency and extent of downstream flooding, soil erosion, sedimentation, and water pollution. Consistent with FHWA guidance, designs for stormwater management seek to mitigate the potential effects of runoff rates and stormwater volumes using the latest available information.

Aesthetic and Landscape Design: helps reduce heat island effects by providing vegetative or structural shade elements for active transportation, transit stops and other community amenities.

Hydraulics Transportation and Infrastructure: related designs typically consider 2- to 100-year flood events, the overtopping event, and/or the 500-year flood event consistent with the TxDOT Hydraulic Design Manual. As of December 2023, design manuals used by TxDOT include the TxDOT 2019 Hydraulic Design Manual; FHWA 2016 Hydraulic Engineering Circular 17: Highways in the River Environment Floodplains, Extreme events, Risk, and Resilience; FHWA 2020 Hydraulic Engineering Circular 25: Highways in the Coastal Environment; and FHWA 2013 Hydraulic Engineering Circular 22: Urban Drainage Design Manual. Additional design information is available on the TxDOT Design Division Hydrology/Hydraulics website. Newer versions of these hydraulic engineering circulars and manuals may occur after issuance of this version of the Technical Report.

Use of Best Available Data: TxDOT uses the National Oceanic and Atmospheric Administration (NOAA) National Water Model that simulates observed and forecasted streamflow over the U.S. In Texas, the National Water Model can be applied to forecast flow modeling at 27,000 bridges and 15,700 stream reaches and provide rapid flood inundation mapping. Improved modeling and forecasting help roadway crews prioritize responses to roadway sheeting, especially during extreme precipitation events as well as improve emergency responders' ability to navigate safely into a flooded area to provide help where it is needed the most.

Precipitation frequency estimates published in NOAA Atlas 14 and the best available data from Federal Emergency Management Agency (FEMA) allows TxDOT to evaluate changing storm frequency and flood event designations with their associated probabilities of occurrence. TxDOT uses the NOAA and FEMA data to consider additional hazard and climate change considerations pre-NEPA, during-NEPA, and post-NEPA in the final design.

As newer data becomes available that information may also be considered during multiple phases of project development.

Statewide Transportation Report

The 2050 Statewide Transportation Report provides an evaluation of TxDOT transportation plan which develops a 24-year, long range plan containing transportation goals and targets. The primary statewide goals are to promote safety, preserve assets, optimize system performance, deliver the right projects, foster stewardship, and focus on the customer (TxDOT, 2024d).

The Texas Connected Freight Corridors Project

The Texas Connected Freight Corridors project is a collaborative effort with public and private stakeholders to deploy connected vehicle technologies to more than 1,000 commercial vehicles to improve traveler information, asset condition management, and system performance (TxDOT, 2024e) .

Connecting Texas 2050

TxDOT's new statewide long-range transportation plan is Connecting Texas 2050 (TxDOT, 2024f). It establishes the vision, objectives, performance measures, and strategic recommendations for Texas' multimodal transportation system through 2050. It integrates numerous planning efforts conducted by TxDOT and its partners and serves as the cornerstone transportation planning document for TxDOT. Connecting Texas 2050 identifies three key performance goals: Safety, Preservation, and Mobility, along with three strategic goals: Connectivity, Economic Vitality, and Stewardship. See page 50 for details on transportation system resiliency and sustainability.

Coastal Collaboration

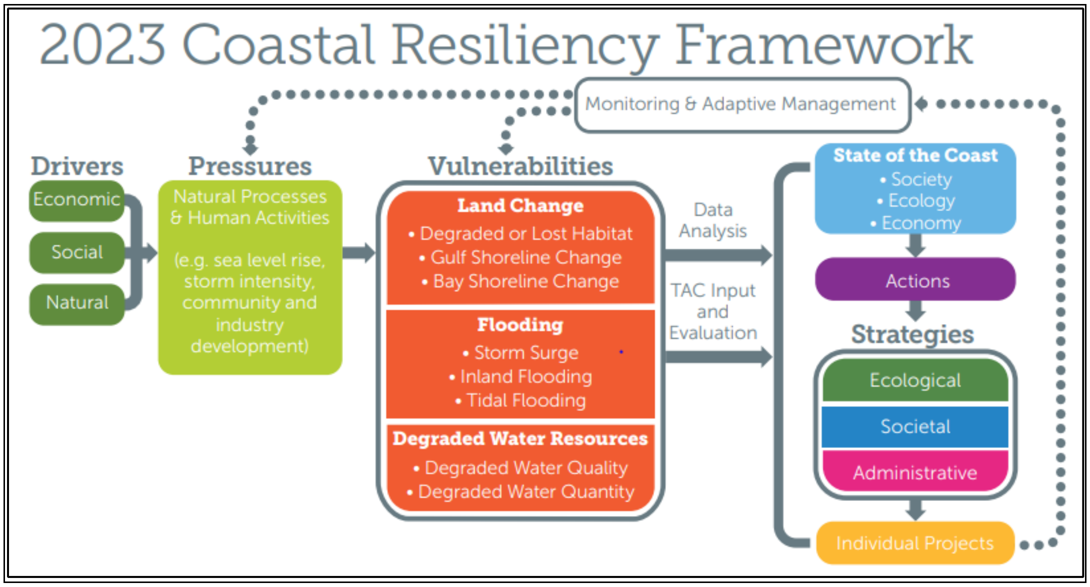
TxDOT collaborates with the Texas General Land Office on transportation projects within coastal areas subject to the GLO Texas Coastal Resiliency Master Plan (GLO, 2023) that promotes coastal resilience. **Figure 4** provides the Texas Coastal Resiliency Framework. Coastal resilience is defined as the ability of coastal resources and coastal infrastructure to withstand natural or human-induced disturbances and quickly rebound from coastal hazards. This definition encompasses the two dimensions of resilience: 1) taking actions to eliminate or reduce significant adverse impacts from natural and human-induced disturbances, and 2) responding effectively in instances when such adverse impacts cannot be avoided. To keep pace with the dynamic Texas coastline, the Plan will be updated regularly to allow the state to continually assess changing coastal conditions and needs, and to determine the most suitable way to implement the appropriate coastal protection solutions. The TxDOT Hydraulics Manual requires the consideration of the Master Plan coastal sea level rise and subsidence projections.

Extreme Weather Event Response Example

TxDOT's strategies include consideration of extreme weather events in planning, asset management, emergency response, project development and design, construction, and maintenance operations. During these events, TxDOT implements a combination of operational practices and emergency contingencies to maintain the safest possible movement through the transportation system.

TxDOT's response to Hurricane Harvey provides an example of operational strategies and practices for emergency response to an extreme weather event. Hurricane Harvey was the first Category 4 hurricane to hit Texas in 50 years and affected both coastal and inland areas of southeast Texas. It was equivalent to three major weather events in rapid succession. It accumulated a historic 50 inches of rain on the Houston area within several days. The National Hurricane Center called the flooding "catastrophic." It closed over 500 road segments (where one road could have multiple segments closed). The storm also downed traffic lights, damaged roadway signs and caused highway asphalt to buckle in some areas.

Figure 4: Coastal Resiliency Framework



Source: (GLO, 2023)

Communication strategies during and after the storm were critical for such a large response effort. The TxDOT DriveTexas.org website received more than 5,000,000 visits during and immediately after the storm. The site, which includes real-time updates made by TxDOT staff in the field, provided the most accurate information possible to emergency crews and the public regarding flooding, pavement damage, and road closures. Advanced planning included having teams to ensure that TxDOT's emergency radio communications towers continued to function.

After the storm, TxDOT conducted infrastructure assessments and began clean-up and repairs TxDOT initially inspected approximately 4,300 bridges in the storm zone and identified damage to 13 bridges and 1 culvert, or less than one-half of one percent of all bridges evaluated. There were no bridge collapses or major bridge damage, which is a testament to the resiliency of bridge design, construction, and routine maintenance. More than 600 TxDOT employees from around the state—some of whom dealt with their own personal losses—worked to assist local areas with debris removal in the hardest-hit coastal areas from Corpus Christi to Beaumont. By October 2017, TxDOT estimated costs due to this extreme weather event were over $150 million, including damage repair, equipment and facility costs, and the costs of mobilizing TxDOT's staff and crews.

In summary, advance preparation and practice helped TxDOT quickly respond and recover from the hurricane. Crews from across the state were pre-deployed to prepare for the storm. Staging for 2,500 crew members and more than 2,000 pieces of equipment occurred at TxDOT districts located just outside the storm zone.

In 2019, post Hurricane Harvey, TxDOT completed an extreme weather event risk framework for the greater Houston area with a grant awarded by FHWA (TxDOT, 2019). The results of the study indicated that almost 75 percent of the state-maintained lane-miles in the area (i.e., 7,069 pavement lane miles) in 2019, were at minimal risk from flooding (based on FEMA flood data). The analysis revealed that almost 12 percent of the state-maintained lane-miles in Harris County in 2019 were at risk of flooding in the case of 100-year events. The 2019 study suggests most impacts to roads would lead to disruptions in travel rather than chronic damage to the pavement structure so advance weather preparation remains critical for the traveling public.

5.0 Incomplete or Unavailable Information for Specific Climate Change Impacts Analysis (40 CFR Section 1502.21)

5.1 GHG Analysis Limitations

A level of uncertainty exists in the estimation of a state's impact on GHG emissions. This uncertainty results from limitations in travel demand forecasting, traffic operation analyses, and emissions modeling tools. Travel demand estimates are based on fuel use, traffic count data, local land use and plans, population and demographic forecasts and sources of traffic generation (e.g., employment centers).

Uncertainty surrounds the travel choices, demographic futures, and other parameters that serve as the foundation for travel demand forecasting. The estimation of travel speeds remains a key step in the process, as emissions vary significantly by vehicle operation. Average, design, or posted speed is available statewide and what is typically available for most projects, so the difference between congested and free-flow speed analysis is not available statewide and typically not available for most projects. Travel speeds are typically estimated using statistical relationships accounting for traffic volume, the roadway capacity, and free-flow speeds. These relationships may not fully represent the actual traffic conditions at specific locations in present or in future projections. Although EPA's MOVES emission factor model provides the best available tool for conducting transportation GHG analyses, there is some uncertainty with many of the model's input files often based upon national defaults. Application of these rates does not fully consider detailed location-specific vehicle operations including accelerations and decelerations, the variances by specific vehicle types by model year, and the variances by different road conditions and function. Changes in the future fuel supplies, fuel costs and fuel characteristics, and changing vehicle technology may dramatically change emissions in ways not accounted for by EPA MOVES model. More specifically, EPA and FHWA guidance for regulatory decision analysis do not account for rapid changes that may occur with vehicle technology over the next 20 or more years. The EPA MOVES model does not include all recently promulgated regulations and future regulatory changes for the time-period analyzed.

Technological advances may transform societies in ways that cannot accurately be predicted today just as cell phones changed communication and internal combustion engines changed horse, buggy, bike, and rail travel in the early 1900s. Other society factors can also influence communities and transportation, a recent example of this is the COVID pandemic that resulted in disruption to international and national supply chains, and changes to traffic patterns, commute choices, locations for living, and lifestyle choices.

5.2 Climate Change Analysis Limitations

Climate change analysis and forecasting models are complex and incorporate many different assumptions. Many models use past patterns to estimate future scenarios. However, projections for the future are not expected to follow the patterns of the past (IPCC, 2023). Limitations and uncertainties in the data limit the accuracy of climate scenarios or projections. General limitations for climate studies include natural variability and climate model uncertainty, human and scientific uncertainty, and climate tool uncertainties. Limitations and uncertainties are explained below.

5.2.1 Natural Variability and Climate Model Uncertainty

Natural variability refers to the changes in climate variables caused by the natural environment without any changes caused by anthropogenic (human) influences. Natural variability can introduce uncertainties by affecting the initial conditions used as baseline in the climate change models. For example, projections for both temperature and precipitation variables may be subject to greater uncertainty because they can significantly vary from year to year and may undergo significant changes within any given decade.

Scientific uncertainty refers to uncertainties in climate models associated with the parameters used and the state of science at the time of model use. For example, model structure and parameters can change over time, leading to uncertainties in future temperature and precipitation results or inconsistency with results from future modeling.

5.2.2 Human and Scientific Uncertainty

Human uncertainty refers to uncertainties in scenarios or projections for human caused GHG emissions. Human decision making is highly variable and can directly influence the quantity of GHG emissions emitted into the atmosphere. To address this uncertainty, this Technical Report used:

- RCP4.5/SSP2-4.5 (intermediate emissions scenario) is based on global carbon emissions peak and remain relatively flat through 2050 and then decline substantially by the year 2100 (IPCC, 2023).
- SSP3-7.0 is a scenario in which countries prioritize issues of national and food security with emissions between SSP2-4.5 and SSP5-8.5.
- RCP8.5/SSP5-8.5 (high emissions scenario) has little to no additional worldwide GHG control measures. This scenario assumes that humans continue to increase carbon emissions through 2100 (IPCC, 2023).

The scenarios reflect sets of emissions, societal choices, and economics up to 2100 that may or may not align with the actual future. Note that the scenarios are not actual projections, as there are no probabilities for their future realization attached (NOAA NCICS, 2023). They simply represent an internally consistent climate picture under certain assumptions about the future pathway of GHG emissions. RCPs and SSPs could change again based on different economic, technologic, demographic, and policy choices in the future. Future GHG emissions from human sources may vary greatly and on different trajectories than these scenarios. However, the emissions scenarios provide a range of potential climate change scenarios or projections.

5.2.3 Climate Model Uncertainty

The primary climate data used in this report is from CMIP5 and CMIP6 for NCA4, NCA5, and IPCC AR6. Some general uncertainties and limitations of global climate models (CMIPs) include the following (R. J. Stouffer et. al., 2017):

- The models use different equations to represent the Earth’s physical processes.
- Poor quantification of radiative forcing in climate models.
- Climate model simulations, when compared to observations, reveal a wide variety of errors on various time and space scales.
- On time scales of a decade or shorter, the influence of natural variability on the model climate tends to be larger than the response to changes in radiative forcing (Hawkins and Sutton 2009), especially at space scales smaller than hemispheric. The RCPs and emissions portion of SSPs are generalized emissions scenarios and not year-by-year forecasts of emissions, and statistical downscaling method assumes that the future climate will behave similarly to the historical climate in terms of atmospheric and oceanic circulation patterns, which may not be true at every location.
- Calculating a single average value for climate variables for the state or even county level inevitably also introduces error, in that the average cannot accurately represent every location

in the state or a county. The error for any location depends on differences in the environment such as elevation and proximity to lakes, a coast, or mountains.

Another source of uncertainty in the models is the lack of site-specific information and local forecasts based on downscaled global models. Applying local forecasts may result in biases due to natural variability.

5.3 Changing Policy

Congress passed the current transportation law (IIJA) in 2021 (Congress, 2021). Congress passed the Inflation Reduction Act in 2022, that includes funds to help reduce GHG (Congress, 2022). Between now and 2050, additional federal and international laws, rules, policy, market conditions, and personal choice will likely impact GHG emission levels and future climate impacts. However, at this time, it is not possible to accurately predict or forecast the trajectory of GHG emissions and climate change based on changes yet to occur.

6.0 Results and Conclusions

GHGs are different from other air pollutants evaluated in federal environmental reviews because their impacts are not local or regional, but rather global due to their characteristic rapid dispersion into the global atmosphere (IPCC, 2023). From a quantitative perspective, global climate change is the cumulative result of numerous emissions sources, each of which represents a small incremental addition to global GHG concentrations (IPCC, 2023). In contrast to broad-scale actions, such as those involving an entire industry, there is currently no scientific methodology for attributing specific climate change impacts (e.g., global temperature change, global sea-level rise, change in extreme weather patterns) to emissions from a particular transportation project or set of projects.

Section 3.1 discloses the results of three scenarios for Texas on-road GHG emissions because it is not possible to accurately predict the future due to the inherent uncertainty in projections related to demographics, social change, technology, policy decisions, socioeconomic conditions, future land-use, and inability to accurately forecast exactly where people will work and live (NASEM, 2007), **Section 3.1** discloses the nominal emissions differences between alternatives for two example project-level analyses. Future on-road GHG emissions may be affected by changes that may alter where people live and work and how they use the transportation system, including but not limited to: 1) the results of vehicle technological advancements and/or federal policy for vehicle and fuel controls, 2) market forces and economics, 3) individual choice decisions, 4) acts of nature (e.g., pandemic) or societal changes, and 5) other technological advancements.

By 2100, the NOAA State Climate Summary and Texas USGS NCCV data project Texas will be warmer, drier, subject to increased intensity of extreme weather events, experience additional sea level rise, and experience higher storm surge. Implications for the Texas transportation system would be temporary closures due to extreme weather events, increased flooding and inundation potential, roadway rutting, buckling, cracking, and increased risk of power outages that could affect traffic signals and ITS. Warmer and drier conditions may lead to longer wildfire seasons and increased wildfire potential that may result in temporary road closures due to fire, smoke, or limited visibility conditions.

TxDOT is scheduled to complete the Statewide Resiliency Plan by late 2024. This Plan will build on existing TxDOT strategies that address future climate scenarios in accordance with TxDOT and FHWA planning, design, asset management, maintenance, emergency response, and operational policies and guidance. The flexibility in these TxDOT activities and programs for the Texas traveling public and the Texas transportation system help TxDOT consider and plan for, adapt to, and be more resilient to risks to the transportation system. TxDOT will continue to partner with various state and federal agencies on data needs (e.g., TWDB on inland flooding and hydraulic data) and resilience measures to improve design and operation of the Texas transportation system. TxDOT will continue to collaborate with transportation partners and the public on our efforts to address system resiliency.

According to the IPCC, transformative and disruptive changes are necessary to achieve net zero emission goals (IPCC, 2023a1). Such change would require action beyond TxDOT control; including, but not limited to, a combination of international, federal, and state legislative action, private-business decisions, local government land use changes, global funding, global macroeconomic changes, personal commute decisions, and personal lifestyle changes. Transformative and disruptive change could alter communities, societies, financial institutions, and global politics, policies, and markets in positive or negative ways that cannot be accurately forecast due to complexities and unknowns with how such change may unfold.

Over the next 10 years of projected funds in the 2024 TxDOT UTP, it is estimated that more than 33 cents of every dollar either directly or indirectly result in GHG emission reduction and/or transportation system resilience and preservation (TxDOT, 2023j), (**Sections 3.3.1 and 4.3**). By developing and implementing strategies that directly or indirectly reduce GHG emissions and increase system resiliency and preservation, TxDOT provides mobility and connectivity to all travelers across Texas while doing its part to implement IIJA/BIL climate provisions. Even though approximately one-third of TxDOT projected funds reduce GHG emissions or provide for system resiliency and preservation, TxDOT does not control vehicle and fuel technological advances that change through a combination of multiple factors, such as market forces, economics, consumer choice, and/or laws and regulations. Sufficient forecast methods do not exist at the project- state-, or national-level to accurately predict, when, and how fast various vehicle and fuel technological advances will occur. Studies disclose conditions that TxDOT is able to implement only provide for nominal GHG reductions, yet collectively with other states would have meaningful co-benefits (IPCC, 2023a), (USGCRP & Crimmins, NCA5, 2023a), (USDOE, USDOT, USEPA, USHUD, 2023). TxDOT actions that directly or indirectly result in tailpipe GHG reductions and improve system resiliency and preservation are programmed into individual projects in regional and statewide transportation plans (**Section 3.3** and **Section 4.3**). For the reasons mentioned in this section, this programmatic analysis of the Texas roadway transportation system is for use with certain proposed projects during environmental project development, where the project level analysis would not be meaningful to a decision on a project or a choice among its alternatives.

Appendix A: Methodology for Greenhouse Gas and Climate Change Analysis

This section identifies methodologies used for the statewide CO_2e emissions estimate (**Section 3**) and the assessment of projected climate variables for the state of Texas (**Section 4**).

EPA MOVES4 (emissions model) was used for the emissions analysis.

Currently, TxDOT is not using the social cost of GHGs to monetize the climate change effects of statewide GHG emissions because it does not aid in the decision-making process for individual highway projects and because NEPA cautions against agencies using monetary cost-benefit analyses where there are important qualitative issues at stake (see 40 CFR 1502.22). Some important qualitative issues include various uncertainties that would make such monetization highly speculative, such as: 1) the inability to accurately predict vehicle and fuel technological advancements that may occur over the next 20 – 40 years especially if those are transformative changes, and 2) the inability to forecast market conditions, future policy changes, future land use, and personal choice decisions that may affect future transportation emissions. In addition, TxDOT does not use a monetary cost-benefit analysis to assess other aspects of a project.

For the **Table 2: Worldwide, National and Texas GHG Emission Trends**, the following paragraph provides detailed information on how the table was developed, when the data was collected, and additional data source information. Sources: **1**: (Climate Watch) https://www.climatewatchdata.org/ : downloaded data on 07232023, select “GHG Emissions” to open “Global Historical Emissions.” Selected the following options: “Climate Watch” for Data Source, “World” for “Countries/Regions, “Total including LUCF” for Sectors, “All GHG” for Gases, “Total” for Calculations, “Countries” for Show Data by, and “Stacked area chart” for Chart Type. Below the chart is a table with the data per year and used the download button to receive the table in a CSV file format. This process was repeated choosing to generate the CO_2e (PIK) row, using:” PIK” for Data Source, “World” for “Countries/Regions, “Total excluding LULUCF” for Sectors, “KYOTOGHG” for Gases, “Total” for Calculations, “Countries” for Show Data by, and “Stacked area chart” for Chart Type. **2**: (EPA, 2020), Table ES-2: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (MMT CO_2 Eq.) is on pages ES-7 to ES-9 under either "2020 Complete Report" or "2020 Executive Summary" was used for 2015-2018 data. The Backup data for Table ES-2 is under "2020 Main Report Tables" and contains the 1990, 1995, 2000, and 2010 data. Data for years 2019-2021 is from Page ES-5 of Table ES-2 in EPA (2023) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021. U.S. Environmental Protection Agency, EPA 430-R-23-002, https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2021, published 2023. **3**: (EIA, 2021), scroll through webpage until each state is individually listed under "State carbon dioxide emissions from fossil fuels tables" and selected "Texas Excel spreadsheet” option. **4**: (TTI, 2024).

A.1 Greenhouse Gas Analysis Methods

Three primary options exist to estimate transportation emissions, and each one produces slightly different emission results because they use different sets of data and data assumptions.

- The first is a fuel consumption-based method with a national average fuel economy used by EPA and EIA.
- The second option uses a VMT-based method obtained from a metropolitan travel demand model.
- The third option uses VMT based on population projections. VMT-based projections typically start with historic traffic data from state and local traffic counting equipment and apply either national fleet mix defaults or state- or local- specific fleet mix data.

For Texas on-road emissions, TxDOT requested the Texas A&M Texas Transportation Institute (TTI) to update the emissions from the TCEQ *MOVES3 On-Road Trend Emissions Inventories for 1990 and 1999 through 2060* (2023 Trends Report) (TCEQ, 2023) with MOVES4. The VMT estimates for this Technical Report were from the 2023 Trends Report. For the 2023 Trends Report, TTI developed and produced Highway Performance Monitoring System (HPMS)-based annual emissions estimates for each of the 254 Texas counties and reflect population projections and historic traffic count data. The level of detail in the final emissions estimates were aggregate emissions by county and vehicle class. Texas has metropolitan-based travel demand models, but no detailed statewide travel demand model exists to conduct the emissions analysis.

The operational (on-road) CO_2e emissions were calculated based on annual operational emission projections for a base year of 1999 through a design year of 2050. The year 2050 is consistent with the design year (final year) of the *Connecting Texas 2050*, known as the Texas Statewide Long-Range Transportation Plan. **Table A-1** describes the methods employed for CO_2e emission calculations for Texas.

Table A-1: GHG Emission Methodology Matrix

Traffic Data/Inputs		
Source of Traffic Data	Texas A&M Texas Transportation Institute VMT from the 2023 TCEQ Trends Report.	
Vehicle Miles Traveled (VMT)	Calculated using FHWA Highway Performance Management System (HPMS) methods.	
Emissions Activity Type	**Description/Assumptions**	**Tool Employed***
Operational Emissions	"Tailpipe" CO_2 emissions from vehicles using Texas roadways.	TCEQ Trends Report updated using MOVES4, for a Base Case and 2 Scenarios.
Fuel Cycle	Emissions generated by extracting, shipping, refining, and delivering fuels.	FHWA Multiplier of Operational Emissions from GREET model (1.27 or 27%)
Conversion of CO_2 to CO_2e	CO_2e is calculated using the EPA methodology found in MOVES4 documentation: CO_2-equivalent = CO_2 + (25 * CH_4) + (298 * N_2O).	

The Environmental Protection Agency's (EPA) latest emissions model MOVES4 (EPA, 2023c) was used in this Technical Report. See page 8 of the EPA, 2023c reference for a list of all rules incorporated into MOVES4, including the 2023 HD Standards and the 2021 Revised 2023 and Later Model Year LD Standards that occurred after release of MOVES3.

The two EPA 2024 rules were enacted after the release of MOVES4 and are included in Emission Scenarios 1 and 2; these 2024 rules are excluded in the Base Case. The two Alternative Scenarios were designed, and adjustment factors (AFs) were developed to adjust the MOVES4 default Base Case. Since the two new rules only updated standards for MY2027 through MY2032 vehicles, the calculations for MY2027 through MY2032 AFs were identical for both scenarios. These AFs were developed based on a ratio between the MY's emissions standard to MY2026's (i.e., MY2027 AF = MY2027 standard/MY2026 reference standard). AFs were source type specific as each source type has its standard for the MY.

For Alternative Scenario 1 forecasts the vehicle technology would stay constant from MY2032 through MY2050; thus, the AFs for MY2032+ remained constant. For Alternative Scenario 2 forecasts additional technological advances through MY2050, further reducing emissions. To simulate this, it was forecast that each source type's AF would continue to reduce at the same pace (i.e., the average rate of change between MY2027 through MY2032 AFs) towards MY2050 (i.e., MY2033 passenger car AF was 9% lower than MY2032's, MY2034's was 9% lower than MY2033's, etc.).

The AFs were multiplied by their corresponding base case emission rates to form alternative emission rates. The emission rates for all three scenarios were then multiplied with the statewide VMT by source type and MY to calculate the statewide GHG emissions.

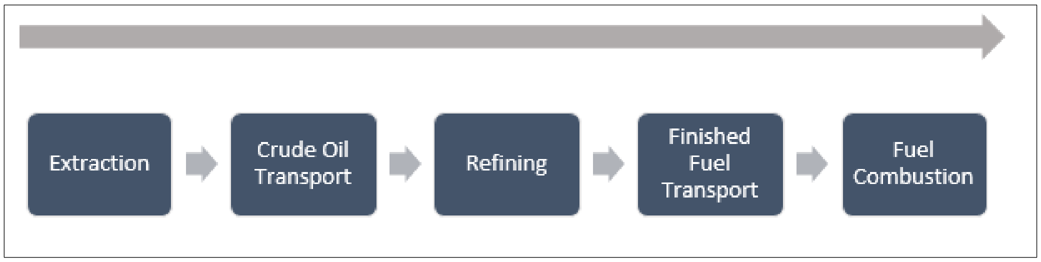
The following parameters and assumptions were used to prepare the state emissions analysis.

- CO_2-equivalent = CO_2 + (25 * CH_4) + (298 * N_2O).
- Emission rates were developed using EPA's latest MOVES4 emission model, released in September 2023.
- The Base Case scale run was performed for Dallas County and the month of July for all years between 1999 and 2050 (52 MOVES4 runs). Due to time constraints, the TTI study team used the emission rates from Dallas County as a proxy for the entire state of Texas. Dallas County was chosen as it is one of the largest in terms of vehicle population and VMT in the state, and it contains all MOVES4 source use types (SUT), fuel types (FT), and road type combinations in MOVES4. Additionally, from previous studies, it was evident to TTI that Dallas was a good surrogate for the statewide average, because CO_2, CH_4 and N_2O emission rates do not exhibit substantial variations across different Texas areas. For each analysis year, the output CO_2, CH_4, and N_2O emissions by source type and model year (MY) were divided by their corresponding default activity output for vehicle miles traveled (VMT) to obtain source type and model year-specific emission rates (in grams per mile). These default emission rates were used in the base case.
- Default national average electric vehicle (EV) fraction and no local values were implemented.
- The statewide Vehicle Miles of Travel (VMT) here are identical to the 2023 Trends Report, sponsored by the Texas Commissions on Environmental Quality (TCEQ) and developed in fiscal year (FY) 2022.
- Base Case refers to a scenario where the emission rates were derived directly from MOVES4 values, with no alterations.
- Alternative Scenario 1 considers the impacts of rules introduced after MOVES4 had launched, namely those that affect vehicle model years (MYs) 2027 through 2032 (EPA 2024 rules). For this scenario, TTI assumed the standards to remain constant after MY 2032.
- Alternative Scenario 2 forecasts additional technological advances would occur after MY 2032. An adjustment factor was introduced for each source type to reduce emission rates even further out to MY 2050, based on yearly average changes for the EPA 2024 rules.
- The CO_2, CH_4, and N_2O emission rates by source type, analysis year, and model year were multiplied by the corresponding VMTs to calculate the statewide CO_2-equivalent emissions.
- The CO_2-equivalent emissions and VMT shown here account for the entire state of Texas, which includes all road types, source types, and fuel types.

Population-based VMT trends, as used in this analysis, do not allow for comparison between build and no-build scenarios, so the analysis cannot fully predict emissions due to free flow or congested portions of the network. In addition, only design or average speed data is available for most proposed projects, which prohibits the ability to accurately analyze free flow and congestion emissions of project-level build and no-build scenarios.

FHWA encourages the disclosure of fuel-cycle emissions when conducting GHG analyses. Fuel-cycle GHG emissions include "well-to-pump" emissions, which are the emissions generated by extracting, shipping, refining, and delivering fuels (Figure A-1). These emissions represent approximately 27 percent of GHG emissions from fuel consumption on a per-vehicle-mile basis. Most roadway congestion relief projects aim to reduce fuel-cycle GHGs along with exhaust emissions. Fuel-cycle GHG emissions will also decrease if motorists make personal decisions to use less fuel. As recommended by FHWA, operational emissions were multiplied by 1.27 to account for fuel-cycle GHG emissions. This multiplier came from the GREET model, using EPA prorated estimates of fuel-cycle emissions based on national default fractions of VMT by vehicle type and national average fuel sales to generate one fleet-average adjustment factor for use in GHG analysis.

Figure A-1: Well-to-Wheel Process



A.2 Climate Change Assessment Methodology

A qualitative assessment was completed to evaluate the potential vulnerability of the Texas on-road transportation system to projected potential climate change impacts, with scenarios or projections ranging up to the year 2100. The analysis incorporates historic and projected climate change impacts for Texas from the 2022 NOAA State Climate Summaries (**Appendix B**) and the 2023 USGS National Climate Change Viewer in **Appendix C**). International, national, and state data was reviewed from several sources, including but not limited to the 2023 NCA5, 2017 NCA4 volume I, 2018 NCA4 volume II, 2014 NCA3, USGS National Climate Change Viewer, 2022 NOAA State Climate Summary for Texas, IPCC AR5, IPCC AR6, NOAA Global and Regional Sea Level Rise Scenarios: CMIP5, CMIP6, and NHTSA EIS documents for CAFE standards. **Section 5** discusses several major sources of uncertainty inherently included in the data sources and climate change scenarios or projections, such as the effects of natural variability, future human emissions, sensitivity to GHG emissions, and natural climate drivers. Background information, historic climate information and future scenario details are available at (NOAA NCICS, 2023). USGS NCCV background and data set information is available at (USGS, 2023b).

The climate change scenarios or projections used in this report were based on a combination of RCPs and SSPs; primarily RCP4.5/SSP2-4.5 and RCP8.5/SSP5-8.5, unless otherwise specified.

The climate assessment for Texas includes a qualitative discussion on how climate variables may impact the transportation system design, maintenance or operation and identifies how a combination of existing and evolving state and local transportation activities and programs address resiliency and adaptation (**Section 4.3**).

A.3 Funding Detail

Table A-3: Transportation Fund Details for Table 4: 10 Year Fund Projections that Result in GHG Reduction or System Resiliency and Preservation

Funding Category	Category Total/ Grand Total	Category Subset	Subset %	Funds Result in GHG Reduction	Funds Result in Resiliency, Preservation
Cat 1: Preventive Maintenance and Rehabilitation	$18,667,880,000	Signals, Lighting, Signs	3%	$560,036,400	
Cat 1: Preventive Maintenance and Rehabilitation		Road Surface and Rehab	61%		$11,387,406,800
Cat 2: Metro and Urban Area Corridor Projects	$11,487,980,409	Operational Improvements	9%	$1,033,918,237	
Cat 4: Statewide Connectivity Corridor Projects	$17,780,433,610	Operational Improvements	12%	$2,133,652,033	
Cat 5: Congestion Mitigation and Air Quality Improvement	$2,322,790,000		100%	$2,322,790,000	
Cat 6: Structures and Replacement and Rehabilitation (Bridge)	$4,681,612,746	Replace, Rehab, Widen, Maintain	98%		$4,587,980,491
Cat 7: Metropolitan Mobility and Rehabilitation	$5,751,838,385	Operational Improvements	11%	$632,702,222	
Cat 7: Metropolitan Mobility and Rehabilitation		Rehab	5%		$287,591,919
Cat 9: Transportation Alternatives	$1,736,508,188	Bike/ped/other	56%	$972,444,585	
Cat 10: Supplemental Transportation Projects	$2,433,528,107	Sidewalks/ Curb ramps	15%	$365,029,216	
Cat 10: Supplemental Transportation Projects		American with Disabilities Act	set amount	$200,000,000	
Cat 10: Supplemental Transportation Projects		Green Ribbon	set amount	$200,000,000	
Cat 10: Supplemental Transportation Projects		Landscape Awards Program	set amount	$20,000,000	
Cat 10: Supplemental Transportation Projects		Carbon Reduction Program	set amount	$1,250,492,601	
Cat 10: Supplemental Transportation Projects		ITS	set amount	$160,000,000	
Cat 10: Supplemental Transportation Projects		Culverts and Storm drains	16%		$389,364,497
Cat 11: District Discretionary	$6,943,047,030	Rehab, Restore, Surface Treat	37%		$2,568,927,401
Cat 12: Strategic Priority	$20,025,958,943	Interchanges	9%	$1,802,336,305	
IIJA/BIL NEVI			set amount	$407,774,759	
IIJA/BIL PROTECT			set amount		$729,178,282
Rural and Urban Transit: FY23 was $173.1 million (state funds and fed 5307, 5310, 5311, 5339)		10-year = FY23 X 10		$1,730,000,000	
Cat 3: Non-traditionally Funded Transportation Projects	$4,986,593,894	unable to determine	unable to determine	unable to determine	unable to determine
Cat 8: Safety Projects	$3,747,421,009	unable to determine	unable to determine	unable to determine	unable to determine
Grand Total - Amount Programmed	**$100,565,592,321**			**$13,791,176,359**	**$19,950,449,391**
Grand Total - GHG Reduction or Resiliency and Preservation	**$33,741,625,749**				

Source: TxDOT 2024 UTP (TxDOT, 2023j) and IIJA NEVI and PROTECT funding as of November 1, 2023. NEVI and PROTECT fund amounts are from FHWA IIJA/BIL Funding Tables (FHWA, 2022a), (FHWA, 2022b).

Table A-3 Notes:

The **Table A-3** discloses UTP Transportation Fund Category details used to create **Table 4: 10 Year Fund Projections that Result in GHG Reduction or System Resiliency and Preservation.**

The $33+ billion of $100.5 billion over a 10-year period (TxDOT, 2023j) is a conservative estimate on funds that result in GHG emissions reduction and/or system resiliency and preservation. To ensure this was a conservative estimate, Category 12 funds for interchange improvement were included, while $4.3 billion for interchange improvements under Categories 2, 4 and 7 was excluded. Emergency response funds are excluded as these are determined after event occurrence and may use various fund categories. It is not currently possible to breakdown project funds for corridor projects with multiple design elements; therefore, design elements for these projects that result in GHG reduction or more resilient design are excluded, such as funds for a corridor’s bike and ped facilities, high occupancy vehicle or bus rapid transit lanes, or more resilient design elements such as enhanced stormwater system or increased bridge height to minimize flood potential.

Most funds provide indirect benefits, meaning the funds have a legislative purpose and use for a reason other than GHG reduction or transportation system resilience. For example, transit and active transportation help reduce emissions (including GHG) by providing alternatives to personal passenger vehicle travel. CMAQ is another indirect example. CMAQ’s goal is to reduce certain criteria pollutant transportation emissions (such as ozone, carbon monoxide and particulate matter) and reduce congestion. CMAQ has the added benefit of reducing GHG emissions. Regarding indirect resilience funds, the funds are listed under categories such as maintenance, rehabilitation, or replacement, but have additional benefits such as using good engineering practices or life cycle assessments to consider what might be needed for projected changes to temperature, weather patterns or other factors. See **Section 4.3** for more detail.

The UTP is a large document; some funds are specifically listed as a fund category or subcategory, while others are distributed within multiple categories. CMAQ and CRP funds are each listed separately in the UTP. The National Highway Performance Program (NHPP) and PROTECT are distributed among multiple categories as disclosed on page 191 of the 2024 UTP. TxDOT considers NEVI and PROTECT one-time funding programs under IIJA/BIL.

Table 4 and **Table A-3** may vary by ±$2, due to rounding differences.

Appendix B: NOAA National Centers for Environmental Information State Climate Summaries 2022 150 – TX

https://www.txdot.gov/content/dam/docs/environmental/725-01-rpt-appendixb.pdf

Appendix C: U.S. Geological Survey (USGS) National Climate Change Viewer Summary for Texas

https://www.txdot.gov/content/dam/docs/environmental/725-01-rpt-appendixc.pdf

Appendix D: Glossary

Adaptive Capacity	Ability to modify asset to maintain function.
Anthropogenic	Resulting from or produced by human beings. (IPCC).
Atmosphere	The gaseous envelope surrounding the Earth. The dry atmosphere consists almost entirely of nitrogen (78.1% volume mixing ratio) and oxygen (20.9% volume mixing ratio), together with several trace gases, such as argon (0.93% volume mixing ratio), helium, and radiatively active greenhouse gases such as carbon dioxide (0.035% volume mixing ratio), and ozone. The atmosphere also contains water vapor, whose amount is highly variable but typically 1% volume mixing ratio. The atmosphere also contains clouds and aerosols. (IPCC).
CAFE standards	The Corporate Average Fuel Economy standards set by the National Highway Traffic Safety Administration (NHTSA). Congress enacted CAFE standards in 1975 with the purpose of reducing energy consumption by increasing the fuel economy of cars and light trucks. NHTSA has set standards to increase CAFE levels rapidly over the next several years. (NHTSA).
Carbon dioxide (CO_2)	A naturally occurring gas, also a by-product of burning fossil fuels and biomass, as well as land use changes and other industrial processes. It is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance. It is the reference gas for comparison to other greenhouse gases. (IPCC).
Carbon dioxide (CO_2) equivalent (CO_2e)	Greenhouse gas emissions are frequently measured in carbon dioxide (CO_2) equivalent. To convert emissions of a gas into CO_2 equivalent, multiply its emissions by the gas's global warming potential (GWP). The GWP considers the fact that many gases are more effective at warming the Earth than CO_2 per unit mass. (EPA).
Cascade of uncertainty	The process whereby uncertainty accumulates throughout the process of climate change prediction and impact assessment. (IPCC).
Climate	Usually defined as the "average weather," or as the statistical description in terms of the mean and variability of relevant quantities (e.g., temperature, precipitation, and wind) over a time-period ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organization. (IPCC).
Climate change	A statistically significant variation in the mean state of the climate or its variability, persisting for an extended period (typically decades or longer). Natural processes and anthropogenic changes cause climate change. (IPCC).

Climate variable	A condition, event, or trend related to climate variability and change that can exacerbate hazards. For example, increasing frequency and intensity of drought conditions can be a climate variable for forests and crops. Rising sea level is another climate variable. (NOAA).
Criteria pollutants	The Clean Air Act requires EPA to set National Ambient Air Quality Standards (NAAQS) for six common air pollutants (also known as “criteria air pollutants”). These pollutants are present in the U.S. and can harm your health and the environment. These include ground-level ozone, particulate matter, carbon monoxide, lead, sulfur dioxide, and nitrogen dioxide. (EPA).
Criticality	Measure of asset importance to the system.
(Transportation) Disruptors	Transportation disruptors are significant delays, interruptions, or stoppages in the flow of trade caused by natural disasters, heightened threat levels, acts of terrorism, or transportation security incidents (as defined in section 70101(6) 1 of title 46).
Emissions	The term used to describe the gases and particles emitted by various natural and human-related sources. (EPA).
Exposure	The presence of assets in areas subject to changes in climate.
Extreme weather	A weather event that is rare at a particular place and time of year, including, for example, heat waves, cold waves, heavy rains, periods of drought and flooding, and severe storms. (USGCRP).
Fuel-cycle emissions analysis	Also referred to as lifecycle analysis or well-to-wheel analysis. Used to assess the overall greenhouse gas impacts of a fuel, including each stage of its production and use. (EPA).
Global change	The term “global change” means changes in the global environment (including alterations in climate, land productivity, oceans and other water resources, atmospheric chemistry, and ecological systems) that may alter Earth’s capacity to sustain life ((USGCRP, Our Changing Planet: The U.S. Global Change Research Program for Fiscal Year 2020, 2020), page 1).
Global warming	The observed increase in average temperature near the Earth’s surface and in the lowest layer of the atmosphere. In common usage, “global warming” often refers to the warming that has occurred due to increased emissions of greenhouse gases from human activities. Global warming is a type of climate change; it can also lead to other changes in climate conditions, such as changes in precipitation patterns. (USGCRP).

Global warming potential (GWP)	The Global Warming Potential (GWP) allows comparisons of the global warming impacts of different gases. It is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given time-period, relative to the emissions of 1 ton of carbon dioxide (CO_2). The larger the GWP, the more that a given gas warms the Earth compared to CO_2 over that time-period. (EPA).
Greenhouse gases	The gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds. Water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. (IPCC).
Greenhouse gas effect	The Earth gets energy from the sun in the form of sunlight. The Earth's surface absorbs some of this energy and heats up. The Earth cools down by giving off a different form of energy, called infrared radiation. But before all this radiation can escape to outer space, greenhouse gases in the atmosphere absorb some of it, which makes the atmosphere warmer. As the atmosphere gets warmer, it makes the Earth's surface warmer, too. (EPA)
Incomplete or unavailable information	The incomplete or unavailable information provision in the Council on Environmental Quality (CEQ) regulations implementing NEPA (40 CFR § 1502.22) is recognition of the potential difficulty associated with obtaining essential and credible data necessary to complete the analysis of certain types of impacts in certain situations, especially those actions that require the preparation of an Environmental Impact Statement. (FHWA).
Infrastructure Investment and Jobs Act (IIJA/BIL)	IIJA became law on 11/15/2021 (Public Law 11758). IIJA is also the Bipartisan Infrastructure Law (BIL). The law provided funding for infrastructure projects, including for: roads, bridges, and major projects; passenger and freight rail; highway and pedestrian safety; public transit; broadband; ports and waterways; airports; water infrastructure; power and grid reliability and resiliency; resiliency, including funding for coastal resiliency, ecosystem restoration, and weatherization; clean school buses and ferries; electric vehicle charging; addressing legacy pollution by cleaning up Brownfield and Superfund sites and reclaiming abandoned mines; and Western Water Infrastructure.
NEPA process	The National Environmental Policy Act (NEPA) process, also referred to as the environmental process, begins when a federal agency develops a proposal to take a major federal action as defined in 40 CFR § 1508.18. The environmental review under NEPA can involve three distinct levels of analysis: Categorical Exclusion (CE) determination, Environmental Assessment/Finding of No Significant Impact (EA/FONSI), and Environmental Impact Statement/Record of Decision (EIS/ROD). (EPA).

On-road transportation system	Includes both on-state roadways (e.g., interstates, state highways, farm-to-market roads) and off-state roadways (e.g., local city streets or county roads) throughout the state of Texas.
Paris Climate Accord	The Paris Climate Accord or the “Paris Agreement” is an international plan that sets long-term goals to guide all nations to substantially reduce global greenhouse gas emissions to hold global temperature increase to well below 2°C above pre-industrial levels and pursue efforts to limit it to 1.5°C above pre-industrial levels.
Representative Concentration Pathway (RCP)	Representative Concentration Pathway (RCP) are GHG concentration trajectories adopted by the IPCC based upon a range of radiative forcing values in the year 2100 (2.6, 4.5, 6, and 8.5 W/m2, respectively). The higher values mean higher GHG and therefore higher global temperatures and more pronounced effects of climate change.
Resilience	The capacity of a community, business, or natural environment to prevent, withstand, respond to, and recover from a disruption. For example, installation of backflow preventers in the stormwater systems of a coastal city increased their resilience to flooding from extreme high tides. (NOAA).
Scenario	A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technological change, prices) and relationships. Note that scenarios are neither predictions nor forecasts but simply provide a standard set of the implications of developments and actions.
Sensitivity	The degree to which assets could be physically damaged and/or result in service interruption if exposed to a specific hazard.
Shared Socioeconomic Pathways (SSP)	Like RCPs, SSPs are climate change scenarios tied to various climate policies resulting in low to high emissions. SSPs also project socioeconomic global changes up to 2100 for the differing climate policies. SSPs provide data accompanying the scenarios on national population, urbanization, and gross domestic product per capita.
Tipping Point	A tipping point is a level (or threshold) that, when exceeded, may lead to large or abrupt changes to climate. (USGCRP (Melillo, Jerry, T.C. Richmond, and G.W. Yohe, Eds.), 2014).
Unified Transportation Plan (UTP)	The UTP is TxDOT’s 10-year plan that guides the development of transportation work across the state and authorizes the distribution of construction dollars expected to be available over the next 10 years.
United Nations	The United Nations is an international organization founded in 1945. The UN’s Intergovernmental Panel on Climate Change (IPCC) assesses science related to climate change.

U.S. Climate Resilience Toolkit	A website that contains 500 digital tools for climate issues including climate data, tools for resilience, and case studies. Various federal agency climate tools are available on this website.
Vulnerability	The degree to which an asset or systems is susceptible to adverse impacts.

Appendix E: Abbreviations and Acronyms

AR6	IPCC Sixth Assessment Report
AVT	Advanced Vehicle Technology
BIL	Bipartisan Infrastructure Law – another name for IIJA
CAFÉ	Corporate Average Fuel Economy Standards
CAMPO	Capital Area Metropolitan Planning Organization
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
CH	Methane
CMAQ	Congestion Mitigation Air Quality
CO_2	Carbon dioxide
CO_2e	Carbon dioxide – equivalent
CMP	Congestion Management Process
CPRG	Climate Pollution Reduction Grants
CRP	Carbon Reduction Program
DCT	Drive Clean Texas
DFW	Dallas-Fort Worth
DOE	U.S. Department of Energy
DOT	Department of Transportation
EIA	U.S. Energy Information Administration
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
EV	Electric Vehicle
FAST	Fixing America’s Surface Transportation Act
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FTA	Federal Transit Authority
GCM	General circulation model
GHG	Greenhouse gas
GLO	Texas General Land Office
GWP	Global warming potential
HGAC	Houston-Galveston Area Council
HGB	Houston-Galveston-Brazoria
HPMS	Highway Performance Monitoring System
HURDAT	Atlantic Hurricane Database
IEA	International Energy Agency

IIJA	Infrastructure Investment and Jobs Act (includes transportation infrastructure)
IPCC	Intergovernmental Panel on Climate Change
I/M	Inspection and Maintenance
ITS	Intelligent Transportation System
JCAP	Joint Center for Artificial Photosynthesis
LED	Light Emitting Diode
LOCA	Localized Constructed Analogs
LRTP	Long Range Transportation Plan
MAP-21	Moving Ahead for Progress in the 21st Century Act
MMT	Million Metric Tons
MOVES	Motor Vehicle Emissions Simulator
MPO	Metropolitan Planning Organization
MTA	Metropolitan Transit Authority
NASEM	U.S. National Academy of Sciences, Engineering, and Medicine
NCA3	Third National Climate Assessment
NCA4	Fourth National Climate Assessment
NCA5	Fifth National Climate Assessment
NCCV	National Climate Change Viewer
NCTCOG	North Central Texas Council of Governments
NEVI	National Electric Vehicle Infrastructure
NEPA	National Environmental Policy Act
NHPP	National Highway Performance Program
NHS	National Highway System
NHTSA	National Highway Traffic Safety Administration
NOAA	National Oceanic and Atmospheric Administration
NOx	Nitrogen Oxides
NTRD	New Technology Research and Development
N2O	Nitrous oxide
PM	Performance Measure
ppm	Parts per million
PROTECT	Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation
RAP	Recycled asphalt pavement
RAS	Recycled asphalt shingles
RCP	Representative Concentration Pathways
RFG	Reformulated gasoline
RFS	Renewable Fuel Standard
RVP	Reid Vapor Pressure

STRP	Statewide Transportation Resiliency Plan
SSP	Shared Socio-economic Pathways
SUT	Source use type
TAMP	Transportation Asset Management Plan
TCEQ	Texas Commission on Environmental Quality
TDM	Travel demand management
TEMPO	Texas Association of Metropolitan Planning Organizations
TERP	Texas Emission Reduction Program
TRB	Transportation Research Board
TSM	Traffic System Management
TSMO	Traffic System Management and Operations
TTC	Texas Transportation Commission
TTI	Texas A&M Texas Transportation Institute
TxDOT	Texas Department of Transportation
TxLED	Texas Low Emissions Diesel
U.N.	United Nations
USACE	U.S. Army Corps of Engineers
USDOT	U.S. Department of Transportation
USGCRP	U.S. Global Change Research Program
USGS	U.S. Geological Survey
UTP	Unified Transportation Program
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound
WMA	Warm Mix Asphalt

Appendix F: TxDOT Information Brochure Web Links

The following web links direct the reader to TxDOT information and educational brochures containing additional detail for the Texas Transportation System.

TxDOT Pocket Facts- TxDOT Pocket Facts FY 2022 // CY 2021 – 2022 is available at:

https://www.txdot.gov/content/dam/docs/news/txdot-pocket-facts.pdf

TxDOT 2023-2024 Educational Series: Bicycle and Pedestrian Program Brochure is available at: https://ftp.txdot.gov/pub/txdot/sla/education-series/bicycle-pedestrian.pdf

TxDOT 2023-2024 Educational Series: Emergency Operations Brochure is available at: https://ftp.txdot.gov/pub/txdot/sla/education-series/emergency-ops.pdf

TxDOT 2023-2024 Educational Series: Funding is available at: https://ftp.txdot.gov/pub/txdot/sla/education-series/funding.pdf

TxDOT 2023-2024 Educational Series: Public Transportation Brochure is available at: https://ftp.txdot.gov/pub/txdot/sla/education-series/public-transportation.pdf

TxDOT 2023-2024 Educational Series: Transportation Technology Brochure is available at: https://ftp.txdot.gov/pub/txdot/sla/education-series/transportation-technology.pdf

TxDOT 2023-2024 Educational Series: Metropolitan Planning Brochure is available at: https://ftp.txdot.gov/pub/txdot/sla/education-series/metro-planning-org.pdf

TxDOT TSMO Frequently Asked Questions is available at: https://ftp.txdot.gov/pub/txdot-info/trf/tsmo/tsmo-faqs.pdf

Appendix G: Technical Report Revision History

Revision History	
Effective Date Month, Year	**Reason for and Description of Change**
January 2025	Version 5 released. Removed discussion of socioeconomic data in accordance with Executive Order titled "Ending Illegal Discrimination and Restoring Merit-Based Opportunity" (January 21, 2025). Removed references to revoked CEQ guidance in accordance with Executive Order titled "Unleashing American Energy" (January 20, 2025). Other minor edits.
November 2024	Released Version 4. Updates from more recent references including but not limited to NCA5 and IPCC AR6, added new GHG analyses, added updated climate change assessment, added two examples of GHG analyses for added capacity projects, provided additional information on TxDOT programs, and updates in response to public comments received.
June 2021	Version 3 released.
October 2018	Version 2 released.
October 2017	Version 1 draft, not released.

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