Statewide Climate Change Assessment and On-Road Carbon Dioxide Emissions Analysis Technical Report

The environmental review, consultation, and other actions required by applicable Federal environmental laws for this project are being, or have been, carried-out by TxDOT pursuant to 23 U.S.C. 327 and a Memorandum of Understanding dated December 16, 2014, and executed by FHWA and TxDOT.

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1.0 Introduction

Climate change[1] is a current topic in public conversations. Climate change relates to transportation in two ways: first, transportation emissions may contribute to climate change[2], and second, the changing climate has the potential to affect the transportation system[3]. Members of the public are frequently interested in understanding how the Texas Department of Transportation (TxDOT) is responding to the changing climate and how transportation projects may contribute to climate change. Because climate is a global issue[4], it is difficult to examine potential impacts on an individual project level. This report provides available data regarding climate change in the state of Texas and examines how TxDOT is planning for, analyzing, and responding to the changing climate and its future projections.

2.0 Regulatory Background and Guidance

The National Environmental Policy Act (NEPA) and implementing regulations require agencies to evaluate reasonably foreseeable effects of major federal actions on the human and natural environment. The purpose of NEPA is to provide decision-makers with information with which to evaluate and choose among alternatives when taking an action.

In December 2014, the United States Council on Environmental Quality (CEQ) redrafted the 2010 Draft NEPA Guidance on Consideration of the Effects of Climate Change and Greenhouse Gas Emissions (CEQ Guidance) and disclosed that "climate change is a particularly complex challenge given its global nature and inherent interrelationships among its sources, causation, mechanisms of action, and impacts."[5] CEQ issued its final CEQ Guidance on August 1, 2016, and then rescinded it on April 5, 2017.

As Chief Justice Roberts and the Environmental Protection Agency (EPA) acknowledged in *Massachusetts v. Environmental Protection Agency* (549 U.S. 497 [2007]), "the connection is far too speculative to establish causation" when attempting to trace the effects of a specific action through the complex web of the earth's atmosphere. With regard to linking greenhouse gas (GHG) emissions to global warming, EPA states that:

> "…predicting future climate change necessarily involves a complex web of economic and physical factors including: our ability to predict future global anthropogenic emissions of [greenhouse gases] and aerosols; the fate of these emissions once they enter the atmosphere (e.g., what percentage are absorbed by vegetation or are taken up by the oceans); the impact of those emissions that remain in the atmosphere on the radiative properties of the atmosphere; changes in critically important climate feedbacks (e.g., changes in cloud cover and ocean circulation); changes in temperature characteristics (e.g., average temperatures, shifts in daytime and evening temperatures); changes in other climatic parameters (e.g., shifts in precipitation, storms); and ultimately the impact of such changes on human health and welfare (e.g., increases or decreases in agricultural productivity, human health impacts)."[6]

TxDOT concurs with EPA, CEQ and Justice Roberts that these issues are highly complex. These complexities and uncertainties make climate change different from other environmental issues considered under NEPA. Analysis of climate effects for an individual project has limited value, because the GHG contribution of a single transportation project to global climate change cannot be quantified. Speculation

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[1] (USCGRP, 2014)
[2] (EPA, 2017)
[3] (FHWA, 2015)
[4] (United Nations 2017)
[5] (CEQ 2014, 2)
[6] (Massachusetts v. Environmental Protection Agency 2007).

is not required under NEPA and does little to promote the intent of NEPA or provide relevant information to decision-makers. In addition, a project-level analysis of climate change would also need to consider, to the extent possible, future global politics and policy, global finances and economics, and global security and defense.

Climate science is evolving, and climate models incorporate many different assumptions. Most models rely on past patterns to calibrate results; however, one of the challenges associated with climate change is that the future is not expected to follow the patterns of the past, which makes it difficult to assess the accuracy of the models. Additionally, the models are intended to analyze the global climate, and results must be scaled down to assess climate predictions at a more local level. The combination of assumptions, uncertainty of model results, and scaling mean that it is not possible to reliably assess climate change effects directly attributable to GHG emissions associated with an individual transportation project.

For these reasons, TxDOT has conducted a statewide analysis[7] of climate stressors and the GHG contributions[8] of the on-road transportation system in Texas. Our goal is to provide reasonably available information to the public and to agency decision-makers for consideration during the project development activities that occur following completion of the environmental process (i.e., during design, maintenance and asset management). In instances of incomplete or unavailable information, NEPA requires disclosure of the lack of relevant data (e.g., unavailable or incomplete data) and evaluation of impacts based on theoretical approaches or research methods generally accepted by the scientific community (40 Code of Federal Regulations [CFR] Section 1502.22) (see **Section 8** for further information).

3.0 Overview of Texas and its On-road Transportation System

If demographic trends continue as they have for the past decade, the population of Texas will double by 2050, with most of the growth occurring in the state's already congested metropolitan areas.[9] The Texas Transportation Commission (TTC) annually approves the agency's Unified Transportation Program (UTP)—the 10-year, $70-billion project-funding plan aimed at enhancing safety, reducing congestion, improving connectivity and maintaining the state's highway system. The UTP dedicates funding for 1,210 centerline miles of added capacity and improvements, including $2.5 billion in projects to relieve congestion as part of the Texas Clear Lanes initiative. The UTP is part of the comprehensive planning and programming effort that encompasses the first 10 years of the statewide long-range transportation plan. It authorizes projects for construction, development and planning activities and includes projects involving highways, aviation, public transportation, and state and coastal waterways. The UTP contains approved funding categories.

Texas is the top exporter and one of the top importers of goods in the nation. Much of Texas' $1.4-trillion annual economic output is transported on or through our state's highways, railroads, maritime ports and inter-coastal waterways, border crossings, airports and even pipelines. The Texas on-road transportation system includes:

- A total of 677,577 on-state[10] and off-state[11] system lane miles.

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[7] (CEQ 2016) This Guidance allowed an agency to take a programmatic approach and encouraged disclosure of a reasoned explanation for the chosen approach. .

[8] GHG emissions consist of on-road tailpipe emissions and upstream fuel cycle emissions. For this analysis, these are measured by converting GHG emissions to CO2-equivalent (CO2E) emissions.

[9] (TxDOT 2016)

[10] An example of an on-state system roadway is an interstate, state highway, or farm-to-market road.

[11] An example of an off-state system roadway is a local city street or county road.

- A total of 707.2 million average daily vehicle miles traveled (VMT) for the combination of on-state and off-state system roadways.[12]
- Over 53,000 bridges, more than 80 percent of which are rated as being in good or better in condition. If these bridges were a single structure, it would stretch from San Francisco to Boston.

Multi-modal systems that interact with the on-road system include:

- 304 airports in Texas, comprising the largest airport system in the nation;
- The Gulf Intracoastal Waterway, which includes over 400 miles along the Texas Coast in addition to the miles of connected rivers and channels; and
- Almost 3,000 transit vehicles in operation that received capital funds through TxDOT.

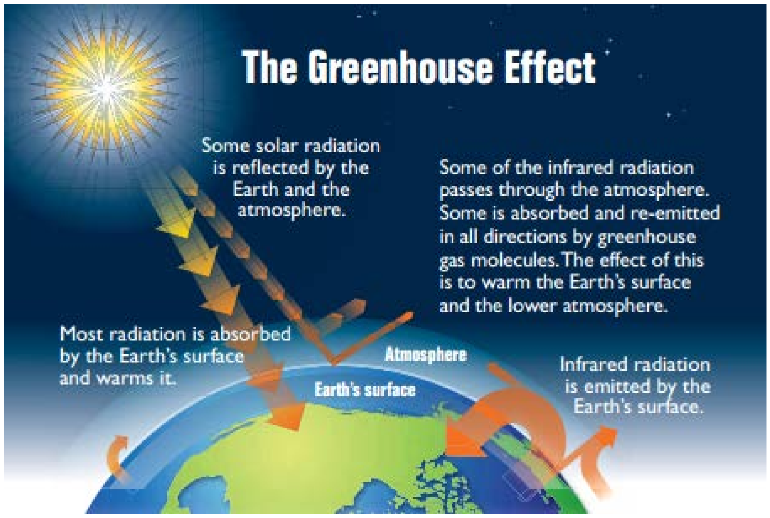
4.0 Overview of Climate Change and Greenhouse Gas Emissions

According to EPA, climate change refers to any substantial change in measures of climate (such as temperature, sea level or precipitation) lasting for an extended period (decades or longer). Climate change may result from natural factors and processes or from human activities.[13] Changes in climate have been documented by researchers, including changes in temperature, precipitation, storm activity, sea level, and wind speeds. When climatic activity results in an effect on the human and/or natural environments, they are often referred to as climate "stressors." Since transportation infrastructure is designed to withstand locally expected climate stressors of the magnitude and frequency that have historically been experienced, the risks from climate change to the transportation system can come from an amplification of existing stressors[14].

The warming of the Earth is called the "greenhouse gas effect" as shown in **Figure 1**[15], where energy from the sun drives the Earth's weather and climate by heating the Earth's surface; in turn, the Earth radiates energy back into space. Without this natural greenhouse effect, temperatures would be much lower than they are now, and life as it is known today would not be possible. "Greenhouse gases" were named for 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 somewhat like the glass panels of a greenhouse. **Figure 2** provides a schematic diagram of components of the complex climate system.

[12] (TxDOT 2015, Section 4.2 Historical Trend-Tables)
[13] (EPA, 2014)
[14] (FHWA 2015)
[15] (EPA, 2014)

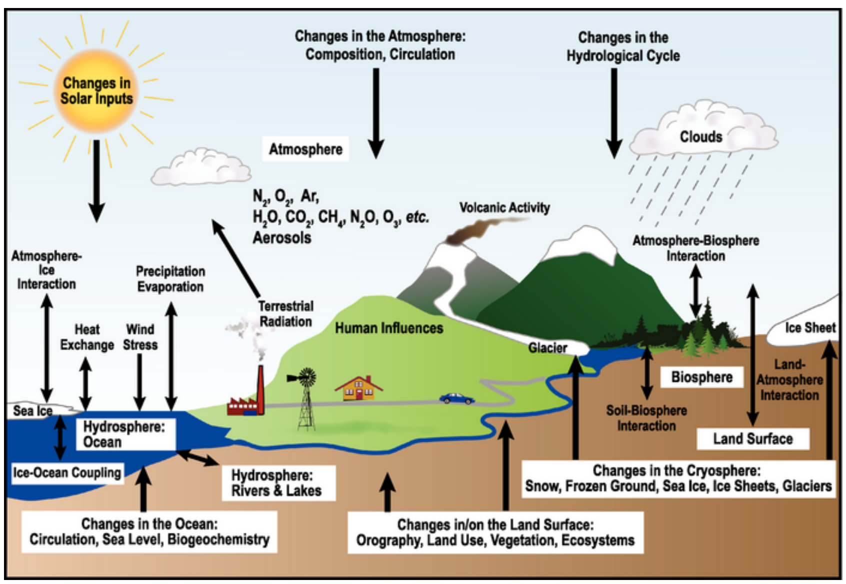
Figure 1: Greenhouse Gas Effect



Source: (EPA 2014)

Figure 2: Schematic View of the Components of the Climate System,

Their Processes and Interactions



Source: (Solomon 2007)

Many GHGs occur naturally and remain in the atmosphere for periods ranging from decades to centuries. 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 and stays in the atmosphere for approximately 30 to 95 years. CO_2 occurs naturally as well as being generated through human action.

The Earth has gone through many natural changes in climate over time. Since the industrial revolution began in the 1700s, atmospheric concentration of GHG emissions have continued to climb, primarily due to humans burning fossil fuel (e.g., coal, natural gas, gasoline, oil and/or diesel) to generate electricity, heat and cool buildings, and power vehicles. According to the Intergovernmental Panel on Climate Change (IPCC), this increase in GHG emissions is projected to contribute to future changes in climate.

To date, national ambient air quality standards, criteria or thresholds have not been established by Congress or EPA for GHG emissions. However, scientific literature addressing the sources of GHG emissions and their potential impacts on climate change exists, including reports from the, the National Academy of Sciences, EPA, and other federal agencies. Federal standards do exist to reduce GHG tailpipe emissions. The Corporate Average Fuel Economy (CAFE) standards are jointly issued by EPA and the National Highway Traffic Safety Administration (NHTSA). When new standards are proposed, Environmental Impact Statements (EISs) are prepared to analyze the anticipated environmental impact of the standards. These EISs provide substantial information regarding GHGs and climate change and include modeling of alternative future GHG emissions and climate stressor scenarios.

5.0 Introduction to Methodology for Climate Change Assessment and Greenhouse Gas Analysis

This section briefly describes TxDOT's approach to the climate change assessment and greenhouse gas analysis, and Appendix A provides additional detail regarding the methodologies, data used, and assumptions.

Unlike air pollutants evaluated in federal NEPA reviews, sources for GHG emissions are typically evaluated globally or per broad-scale sector (e.g., transportation, industrial, etc.) and are not assessed at the local or project-specific level, since the impacts are global and not localized or regional. In addition, from a quantitative perspective and in terms of both absolute numbers and emission source types, global climate change is the cumulative result of numerous and varied natural and human emission sources. Each source makes a relatively small addition to global atmospheric GHG concentrations. In contrast to broad-scale actions such as those involving an entire industry sector or a very large geographic area, it is unlikely that any individual transportation project would generate enough GHG emissions to significantly influence global climate change. It is for this reason that TxDOT discloses emission estimates for the entire Texas on-road transportation system rather than on a project level.

TxDOT has conducted an assessment of climate change stressors[16] projected for Texas and a statewide analysis of the GHG contributions[17] of the on-road transportation system. Our goal is to provide reasonably available information to the public and to provide information for consideration during the project development activities that occur following completion of the environmental process (i.e., during design, maintenance and asset management).

6.0 Assessment of Climate Change Stressor Projections on the State of Texas

In this section, a background summary of potential global and national climate change projections is provided based on a variety of sources. A qualitative assessment was completed to evaluate the potential vulnerability of the Texas on-road transportation system to potential climate change impacts, typically projected between the years 2070 and 2100, unless otherwise specified. Shorter-term projections (including for the period of the TxDOT long-range transportation plan through 2040) were not consistently available among the data reviewed. The analysis incorporates available information on historic and projected climate change impacts for the state of Texas (**Section 6.2**). Data was reviewed from several

[16] 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 stressor for forests and crops. Rising sea level is another climate stressor. (NOAA).

[17] GHG emissions consist of on-road tailpipe emissions and upstream fuel cycle emissions. For this analysis, these are measured by converting GHG emissions to CO_2-equivalent (CO_2E) emissions.

sources, including: the 2014 National Climate Assessment (NCA); the U.S. Geological Survey (USGS) National Climate Change Viewer; the Assessments from the International Panel on Climate Change IPCC); U.S. National Oceanic and Atmospheric Administration (NOAA) Global and Regional Sea Level Rise Scenarios; U.S. Army Corp of Engineers (USACE) Procedures to Evaluate Sea Level Change; the four NHTSA EISs for CAFE standards; and the Texas A&M Wildfire Risk Assessment Portal (TxWRAP). It should be noted that there are several major sources of uncertainty inherently included in the data source projections regarding climate change, such as the effects of natural variability, future human emissions, sensitivity to GHG emissions, and natural climate drivers. These limitations and uncertainties are discussed in **Section 8**.

The climate change projections used in this analysis were based on Representative Concentration Pathways (RCPs). RCPs are GHG concentration trajectories used for climate modeling and research and are based on assumptions relating to the level of GHG emissions now and into the future. The high and low CO_2E concentration RCP options were chosen for the TxDOT analysis. RCP8.5 (high emissions estimated to be approximately 1370 parts per million [ppm] CO_2E in 2100) is a business as usual case with little to no additional worldwide GHG control measures. RCP4.5 (low emissions estimated to be approximately 650 ppm CO_2E in 2100) refers to a high level of GHG controls recommended to keep temperature rise below 2^{o} C in 2100.

6.1 Overview of Global and National Climate Change Projections

Depending on international efforts, the global economy and technological advances 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, which in turn could affect human health and safety, infrastructure, and food and water supplies. Large elements of uncertainty within future projections[18] make it extremely difficult to reliably predict the timing and scale of future changes in climate for the state of Texas and its inhabitants (people and other organisms). There are, however, a variety of studies, including but not limited to publications from NHTSA, IPCC, the U.S. Global Change Research Program (USGCRP), NOAA and NCA, that have published broad climate change predictions for the U.S. and worldwide (**Table 1**).

[18] (NHTSA, 2016)

Table 1: Potential Global and U.S. Implications of a Changing Climate

Impacts to Natural Systems		Impacts to Humans	
Category	Potential Impacts	Category	Potential Impacts
Fresh water quality and supply	Increased irrigation needs; water shortages; variability of water supply; increased flood risk; salt water intrusion from sea level rise; increased acidity from the formation of carbonic acid with CO_2 combines with water.	Food, fiber, and forestry industries	Increased tree mortality; productivity losses in crops and livestock; changes to nutritional quality of pastures, grazelands, and food crops; impacts to fishing industry from changing marine migrations; impacts to food prices and food security.
Species and habitats	Shifts in range and migration patters of species; changes in timing of species' life-cycle events; threats to sensitive species unable to adapt to changing conditions; increased occurrence of forest fires and pest infestations; changes in habitat productivity; stimulated plant growth due to increased CO_2 in the atmosphere, depending on plant species.	Human settlements	Changes may affect services such as: • Water/energy supply • Wastewater/stormwater • Transportation • Telecommunications • Social services Changes in agricultural income; air quality changes. Vulnerable populations have higher risks, including low-income, elderly, children, and those with existing 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; increases in respiratory conditions due to poor air qualtiy 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 (large elements of uncertainty).	Security	Threats in response to adversley affected livelihoods; compromised cultures; increased and/or restricted migration; reduction in provision of adequate essential services.

6.2 Projected Impacts of Climate Stressors on the State of Texas

This section provides a qualitative discussion of projected climate change impacts for the state of Texas based upon projections of climate stressors. Climate change projections vary widely by region, and predicted impacts may be more severe in other areas than in Texas. For example, according to the NCA, the Northeastern and Midwestern portions of the U.S. may experience the greatest change in heavy precipitation. **Table 2** shows the potential climate stressor baseline data and future projections.

<u>Precipitation</u>

In Texas, the increase in the number of wettest days for all counties is between -0.08 and 0.65 days under the Lower Emissions Scenario (RCP 4.5) and between -0.06 and 0.70 days under the Higher Emissions Scenario (RCP 8.5). The USGS indicates a change between -0.22 to 0.65 inch in monthly runoff in Texas. With less than one day change in the number of wettest days and less than one inch change in monthly runoff for any Texas county, overall precipitation except for intensity is not anticipated to significantly change from historic conditions. However, the potential exists for Texas to experience stronger storm intensities that may include greater downpour and flooding per event, even though the ability to predict the frequency, intensity and location of severe storm events due to climate change is limited. See **Table 2** for additional information.

Extreme Heat/Higher Temperature

The NCA projects an increase in the number of hottest days across Texas to range from less than one to up to 34 days per year. The USGS predicts annual mean maximum temperature[19] across the state may increase temperature up to 3.08 to 6.25ºF. Per the NCA, other portions of the U.S. are projected to experience up to 15ºF or more change (highest temperature changes are projected for Alaska). Extreme heat conditions and higher temperatures may accelerate pavement degradation rates, which may increase roadway maintenance and construction material costs compared to current figures. As discussed in the following section, TxDOT continues to evaluate pavement design and materials to address excessive heat conditions in order to reduce pavement deterioration and maintenance costs. Final design decisions consider available data on current and future projections and take place after the completion of the environmental process.

Drought

The NCA indicates Texas currently experiences 18 to 55 consecutive dry days at a time, and this may increase by less than one day to almost seven additional days across the state. USGS projects mean annual soil storage may change slightly throughout the state, ranging from a reduction of 0.008 to 0.045 inches. The combination of projected increases in consecutive dry days, reduced moisture in soil, and rising temperatures may increase drought conditions throughout much of the state.

[19] The mean maximum temperature is the average daily maximum temperature averaged over the time-span of 1 year.

Table 2: Summary of Projected Climate Change Stressors for the State of Texas

Climate Variable	Source	Indicator	Existing and Projected Changes
Temperature	NCA[1]	Projected	For RCP4.5, 0.74 to 6.08 days change and for RCP8.5 18.72 to 33.74 days in number of hottest days per year
		Existing	93.1 to 104.4 °F Temperature range of historical "7 hottest days" per year
	USGS[2]	Existing	70.6 to 8.59 °F annual mean maximum temperature
		Projected	3.08 to 4.5 °F (RCP4.5) to 4.64 to 6.25 °F (RCP8.5) change in annual mean maximum temperature
Drought	NCA[1]	Existing	18.18 to 55.19 days for the number/range of consecutive dry days
		Projected	0.74 to 6.91 days predicted increase in the number of consecutive dry days
	USGS[2]	Existing	0.056 to 4.602 inches existing mean soil storage
		Projected	0.045 to 0.008 inches (RCP4.5), 0.071 to 0.008 inches (RCP8.5) predicted change in annual mean soil storage
	USGS[2]	Existing	0.419 to 3.069 inches in monthly evaporative deficit
		Projected	0.196 to 0.419 inches (RCP4.5), -0.6228 to 0.629 inches (RCP8.5) predicted change in annual mean evaporative deficit per month
Wet	NCA[1]	Projected	Less than 1 day decrease or increase (ranging from -0.077 to 0.7029 day) in the number of wet days per year between RCP4.5 and RCP8.5
Monthly Runoff	USGS[2]	Existing	0.036 to 1.24 inches (0.91 to 31.47 mm)
		Projected	-0.094 to 0.65 inches (RCP4.5), -0.221 to 0.035 inches (RCP8.5)
Wildfire Potential	TxWRAP[3]	Existing	TxWRAP provides current wildfire potential across Texas.
Sea Level Rise	IPCC[4]	Existing	From 1901 to 2010, historical global mean sea level rise was between 6.69 to 8.27 inches (0.17 to 0.21 meters) change. 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 meters) higher than present and high confidence it did not exceed 32 feet (10 meters) above present.
		Projected	In the range 2081-2100, the likely range of global sea level rise relative to reference period of 1986 to 2005 is 1.05 to 2.07 feet (0.32 to 0.63 meters) for RCP4.5 and 1.48 to 2.69 feet (0.45 to 0.82 meters) for RCP8.5.
	NOAA[5]	Existing	Over the past 30 years global mean sea level rise has averaged approximately 0.12 inches/year (3 mm/year), based upon global tidal gauge data, or 3.54 inches over 30 years (90 mm per 30 years).
		Projected	By year 2100, 0.98 to 8.20 feet (0.3 to 2.5 meters) global sea level rise with intermediate scenario of 3.28 foot (1.0 meter). The intermediate option is slightly higher than the IPCC "likely range" scenario.
	USACE[6]	Projected	By year 2100, 0.6 to 4.9 feet (0.2 to 1.5 meters) global sea level rise.
	NCA[1]	Existing	The past century had a global average sea level rise of 8 inches.
		Projected	1–4 feet mean global average sea level is projected by the year 2100 with a plausible high of 3 to 4 feet. The study suggests decision-makers may wish to use a broader range of scenarios for risk based analysis within the range of 8 inches to as much as 6.6 feet.

Sources and Notes:

Future Climate Scenarios are based upon RCP4.5 and RCP8.5. RCP4.5 = ~650 ppm CO2E in 2100 representing a high degree of CO2 emission controls and RCP8.5 = ~1370 ppm CO2E in 2100 representing business as usual with little to no CO2 control measures implemented worldwide.

1 (USCGRP 2014) It projects climate data for the years 2041–2070.

2 (USGS 2016) The climate projections used was 2050-2074 compared to 1950–2005.

3 (Texas A&M Forest Service 2017) The Wildfire Risk Assessment Portal provides current fire intensity scale ranges from 1 (very low) to 5 (very high). The Portal does not project future year scenarios.

4 (Stocker 2013)

5 (NOAA 2017) The local sea level rise projections from the NOAA report are available for all six global sea level rise scenarios as well as low, median, and high sub-scenarios.

6 (USACE 2014)

Extreme Weather Events

Extreme weather events such as major flooding, storm surge, and major storms historically impacted the state's transportation system. National research, including reports sponsored by the Transportation Research Board (TRB), has highlighted how climate change related extreme weather events may further impact U.S. highways and other transportation infrastructure.[20]

While it is difficult to predict the severity and frequency of future extreme weather events, climate change is thought to be connected to a potential for more severe storms. Historical data has been collected for extreme weather events with differing frequencies and degrees of accuracy. Examples of recent intense precipitation events include storms that plagued the Midwest during the 1993 flooding of the Mississippi and Missouri River system, the Chicago area in 1996, and the Houston region during Tropical Storm Allison in 2001,[21] in addition to the extreme precipitation from Hurricane Harvey in 2017[22]. NOAA has collected data regarding hurricanes since the late 1800s, which is summarized below as an example of the types of data available to establish baselines and assess climatological trends.

Most of the information about hurricanes in the Atlantic Ocean is available through NOAA's Atlantic hurricane database (or HURDAT), which extends back to 1851. These data have limitations, especially before daily satellite imagery became available at the National Hurricane Center in 1966. Only the historic storms that made landfall or were observed and recorded by maritime activities were documented prior to 1944; those that remained in the Atlantic were not generally captured. Starting in 1944, aircraft reconnaissance covering approximately half of the Atlantic basin began monitoring tropical cyclones and disturbances with the potential to develop into tropical storms and hurricanes.

The most complete data relies on satellite imagery from 1966 forward, and data collection methods continue to improve. As accuracy of the data continues to evolve, challenges arise in comparing recent and historical data and drawing conclusions regarding climatological trends. For example, in the last decade, an increase in short-lived tropical storms and hurricanes was documented; however, this apparent increase is likely due to improved monitoring capabilities[23].

Table 3 summarizes hurricane activity in the Atlantic basin (1966-2016) and along the U.S. coastline (1900-2016). Additional statistical information is available from the NOAA Hurricane Research Division.

[20] (TRB, NCHRP 2014, Table I.1)
[21] (NRC, 2008)
[22] Multiple news outlets.
[23] (Landsea 2010)

Table 3: Historic Hurricane Activity

Atlantic Basin (1966-2016) and U.S. Landfall and/or Coastline/Maritime/Aircraft Observation (1851-1965)

Category	Average (1968 – 2016)	Maximum (1851 – 2016)	Highest Maximum Years (1851 – 2016)	Minimum (1851 – 2016)	Lowest Minimum Years (1851 – 2016)
Named Storms (Tropical Storms, Hurricanes and Subtropical Storms)	11.7	28 20 19	2005 1933 1887, 1995, 2011, 2012, 2010	1 3 4	1914 1930 1857, 1868, 1883, 1884, 1890, 1917, 1925, 1983
Hurricanes	6.3	15 12 12 11	2005 2010 1969 1933, 1887,1995,1950	2 1 0	2013, 1895, 1982, 1919, 1917, 1890, 1930 1905, 1925 1907,1914
Major Hurricanes	2.4	7 7 6 6 6 6 6 6	2005 1961 1933 1950 2004 1996 1926 1964	0	32 years with 0, last 2013
USA Land-falling Hurricanes	1.7	7 6 6 6 4 5 5	1886 2005 2004 1985 1933 1893 1909	0	33 years with 0, last 2015
Accumulated Cyclone Energy (energy for entire tropical cyclone season)	95.4	259 250 243 231 230	1933 2005 1950 1893 1923	3 7 13 17 18	1914 1925 1907 1983 1855

Data Source: (NOAA 2017)
Named Storms = Tropical Storms, Hurricanes and Subtropical Storms
Hurricanes = Saffir-Simpson Hurricane Scale 1 to 5
Major Hurricanes = Saffir-Simpson Hurricane Scale 3, 4, or 5

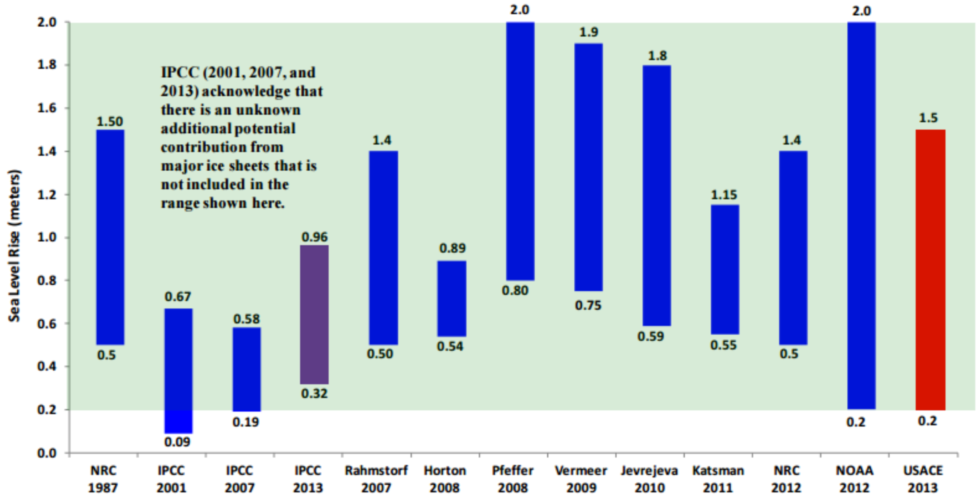
Sea Level Rise

Sea level rise has occurred historically across the globe and it is projected to increase in the future. Currently there are some differences among researchers reviewed regarding historical global sea level rise and projected global sea level rise, particularly projected sea level rise.

For historical sea level rise, the IPCC, 5th Assessment disclosed historical global sea level rose 6.69 to 8.27 inches between 1901 through 2010. Comparatively, NCA indicates in the past century global sea level rose eight inches. NOAA indicates sea level rose 3.54 inches in the past 30 years.

Global sea level rise for 2081–2100 (lower- and upper-end projections) vary among different sources reviewed (**Figure 3**). Most commonly, these differences are due to the level of uncertainty captured by the reported sea level rise ranges; the differences in the probability of occurrence; the various scientific approaches employed to generate the sea level rise estimates; and the overall objectives of each publication.

Figure 3. Comparison of Minimum and Maximum Estimates of Global Sea Level Rise by 2100



Source: (USACE 2014)

According to the IPCC 4th Assessment, the “likely” range of global sea level rise will be between 0.6 to 4.9 feet by the year 2100. The most recent IPCC publication (5th Assessment) narrowed this range to 1.05 to 2.69 feet for the “likely” range of values between RCP4.5 and RCP8.5 between the years of 2081 to 2100. The IPCC estimates are based on general circulation model (GCM) ensemble outputs for the 21st century. The “likely” range of values have up to 67-percent probability that global mean sea level rise will fall within the range. NOAA projects between 1 to 8-foot sea level rise, with an “intermediate” rate of 3.28 feet. The intermediate rate was closest to the IPCC “likely” range. For comparison to historical trends, an 8-foot sea level rise by 2100 (the maximum estimate by NOAA) is more than 10 times greater than that experienced between 1900 through 2010, or a difference of 12 inches per decade (projected) versus 0.75 inches per decade (historical). NCA projects a 1 to 4-foot global sea level rise by 2100. USACE provided a range of 0.6 to 4.9 feet in sea level rise by year 2100.

The main contributing factor to the difference between global sea level rise and local sea level rise is vertical land movement. Vertical land movement can consist of uplift or subsidence (lowering) of the land relative to sea level. Vertical land movement varies on the regional and local scale due to a number of factors, including: tectonics on geologic scale rates, sediment deposition, the presence of land-based ice (infrequent in Texas coastal areas), and/or anthropogenic (human-induced) impacts in the area.

Along the Texas coastline, historic local sea level rise rates vary from 1.9 and 6.6 mm/yr based on the NOAA tide gauge data. This variation in local sea level rise between tide gauges in Texas is a direct result of differing vertical land movement rates along the Texas coastline. These rates vary primarily due to anthropogenic impacts and to a lesser extent due to differences in local sediment deposition from rivers in Central and Eastern Texas[24].

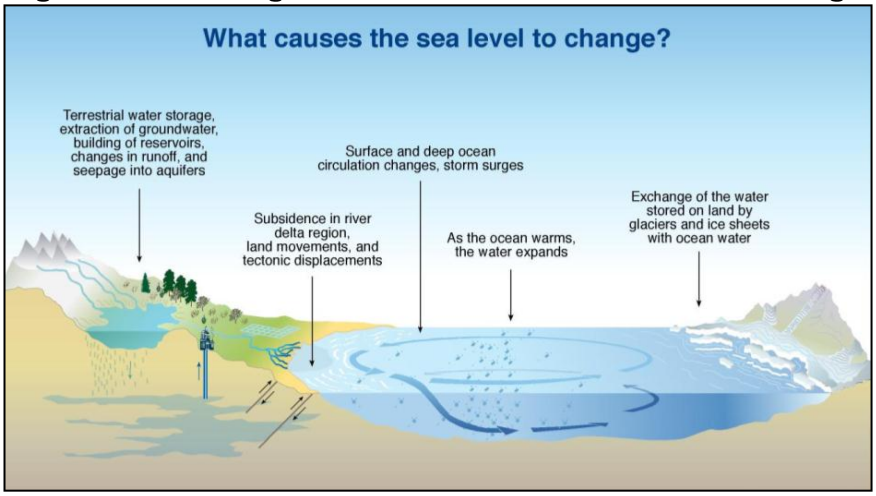
A study by Paine[25] compared geologic scale (from 12,000 years ago to present) rates of vertical land movement in Central Texas, from sediment cores, to historic rates (years 1900-1990), from tide gauge records. Paine found that the geologic scale rates show a long-term land subsidence rate of 0.05 mm/yr whereas the historic rates were 20-100 times faster – the historic rates published by Paine in 1991 were 2.4-3.0 mm/yr. The conclusions of Paine’s study state that the higher historic subsidence rates are largely due to anthropogenic factors. These factors include groundwater and hydrocarbon withdrawal that result in compaction of the sediments and rock that contained those resources. Paine’s findings have been

[24] (Letetrel, 2015)
[25] (Paine, 1991)

further confirmed by additional studies from the United States Geological Survey[26]. In coastal Texas groundwater extraction is the primary driver of subsidence with hydrocarbon withdrawal also having a significant but more localized contribution, particularly in the Houston-Galveston area[27].

Figure 4 illustrates the combination of sources impacting sea level rise or subsidence, and Figure 5 illustrates the potential changes to the Texas Gulf Coast due to the combination of sea-level rise and subsidence. Other unique circumstances may also contribute to subsidence. After the hurricane of 1900, the entire city of Galveston was raised,[28] with some areas raised by up to 16 feet. Additional subsidence occurs in the Galveston area as the fill used to raise the city compacts over time.

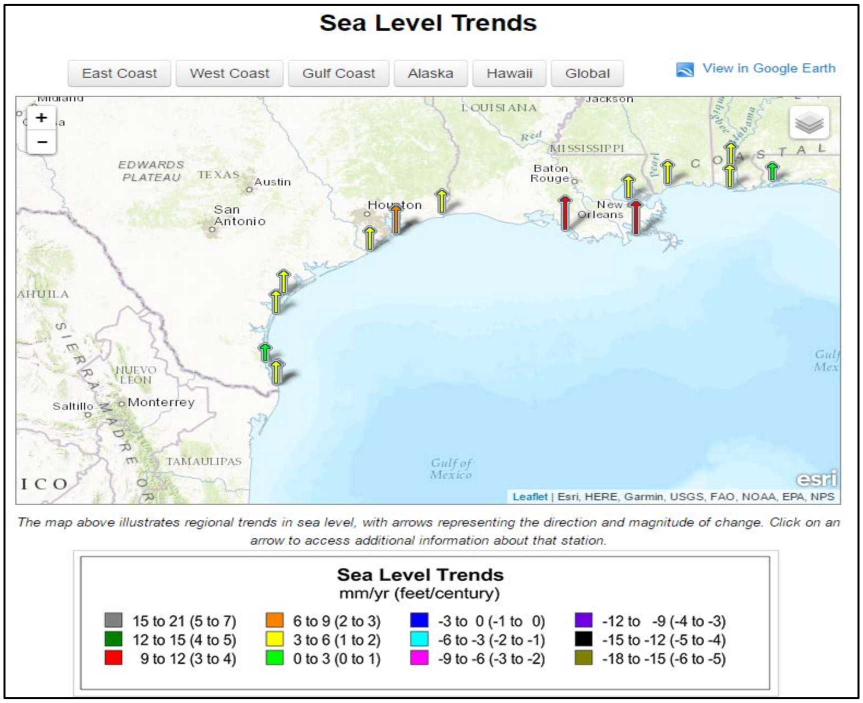
Figure 4: Contributing Factors to Global and Local Sea Level Change



Source: (Watson 2001)

[26] (Coplin, 1999), (Letetrel, 2015)
[27] (Paine, 1991), (Qu, 2015)
[28] Texas State Historical Association, Texas Almanac, Galveston's Response to the Hurricane of 1900.

Figure 5: Gulf of Mexico Regional Sea Level Rise Trends



Source: (NOAA 2017)

6.3 Adaptation and Resiliency Strategies

Resilience is the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions. Based on the climate stressors discussed above, adaptation and resiliency strategies may be considered during the post-NEPA design, construction, and/or maintenance activities for the Texas on-road transportation system to maximize limited transportation funds while considering potential extreme weather or climate change risk projections.

Additionally, the Fixing America's Surface Transportation Act (FAST Act) requires the planning process to consider projects and strategies to: improve the resilience and reliability of the transportation system, stormwater mitigation, and enhance travel and tourism.[29] The FAST Act requires new strategies to reduce the vulnerability of existing transportation infrastructure to natural disasters.[30] The FAST Act provides an estimated average of $23.3 billion per year for the National Highway Performance Program (NHPP) to support the condition and performance of the National Highway System (NHS), enable the construction of new facilities on the NHS, and ensure that investments of federal-aid funds in highway construction are directed to support progress toward achieving performance targets established in a State's asset management plan for the NHS.[31] The Federal Highway Administration (FHWA) and state departments of transportation (DOTs), including TxDOT, are working to implement the new requirements of the FAST Act. As part of this effort, TxDOT has identified climate stressors for each of the 254 counties in Texas. TxDOT plans to consider these data programmatically (i.e., during planning, hydraulic design, asset management, emergency response, and maintenance operations, including but not limited to pavement integrity).

[29] FHWA, Fixing America's Surface Transportation Act or "FAST Act," Metropolitan Planning.
[30] FHWA, Fixing America's Surface Transportation Act or "FAST Act," Metropolitan Planning.
[31] (FHWA, 2017)

Projected climate stressors are considered as part of normal TxDOT practices including but not limited to those described in the TxDOT Pavement Design Manual and the TxDOT Hydraulic Design Manual. The Pavement Design Manual indicates both the facility and its known conditions are assessed for construction, and then the facility and conditions (including changes to temperature and precipitation) are monitored for pavement maintenance needs and adjustments over time. In addition, the Pavement Design Manual describes the TxDOT forensics team that examines the cause of premature pavement failures in an effort to prevent repetition. Should temperature increases, increased dry spells, flooding, rising sea levels or storm surge result in future pavement cracking or rutting, this process would address maintenance needs and use the information to improve future pavement designs. TxDOT continually improves and refines pavement designs to adapt to changing conditions. Project funding, location, alternatives selection decisions and resiliency design consider the risk of roadways potentially subject to current or future coastal storm surge or sea-level rise.

Precipitation, Flooding and Sea-Level Rise

Storm water management helps reduce the frequency and extent of downstream flooding, soil erosion, sedimentation, and water pollution. Consistent with FHWA guidance, stormwater detention and retention facility design capacity uses the latest information available and typically considers 2- to 100- year flood events. In addition, some infrastructure design considers a 500-year flood event (e.g., bridge scour which relates to the erosion of soil surrounding bridge foundations).

Should storm frequencies and intensities alter flood event designations and their associated probabilities of occurrence, TxDOT would continue to consider that information in final design after such data is updated by Federal Emergency Management Agency (FEMA) or other agencies with jurisdiction. Due to practical and/or financial considerations, projects cannot be designed and built to withstand every possible storm event (i.e., 500- or 1,000-year storm events or unusual flooding events such as Hurricane Harvey). Therefore, during such events, TxDOT implements a combination of operational practices and emergency contingencies to maintain safe and efficient movement through the transportation system.

The final design process for projects in the UTP follows conclusion of the environmental process in accordance with applicable design requirements, such as the FHWA 2016 *Hydraulic Engineering Circular 17: Highways in the River Environment–Floodplains, Extreme Events, Risk, and Resilience;* FHWA 2014 *Hydraulic Engineering Circular 25: Highways in the Coastal Environment: Assessing Extreme Events*; and FHWA 2013 *Urban Drainage Design Manual,* including but not limited to Chapter 8 for stormwater detention and retention facilities. Other design information is available on the TxDOT Design Division Hydrology/Hydraulics website.

Extreme Heat and Drought

Extreme heat and drought may result in premature pavement failure. Pavement failure is addressed in the TxDOT Pavement Design Manual using the TxDOT forensics team that examines the cause of premature pavement failures. As needed, adjustments would be made to pavement binders and/or base design and materials. Although TxWRAP does not provide future projections, drought conditions may increase the likelihood of wildfires that reduce visibility and threaten roads and infrastructure. However, the Bastrop fire, one of the larger recent fires in Texas, occurred with only minor damage to guardrails and no damage to pavement. Roads were temporarily closed due to fire hazard and/or visibility.

The potential for increased temperature and number of dry days may increase wildfire potential. Operational decisions (e.g., temporary closures) associated with any potential wildfire are the same for individual project-level build or no-build alternatives. Any damage to transportation infrastructure would be addressed through the emergency maintenance program (e.g., guard rail damage repairs).

Extreme Weather Events

TxDOT includes consideration of extreme weather events in its planning process, asset management, emergency response activities, and maintenance operations. For example, in planning, the purpose of the UTP is to provide for the safe movement of people and goods based upon available funding. System connectivity helps move traffic if a given roadway is temporarily shut down due to extreme weather or severe storms, and evacuation routes help move traffic during weather emergencies (such as when a hurricane approaches Texas coastal areas). During these events, TxDOT implements a combination of operational practices and emergency contingencies to maintain safe and efficient movement through the transportation system, as previously mentioned for other types of unusual weather.

Implementation of the federal Moving Ahead for Progress in the 21st Century Act (MAP-21), the FAST Act, and associated regulations will result in expanded consideration of resiliency. For example, a project to replace infrastructure that has been repeatedly affected by flooding or storm surge may not meet funding priority requirements in planning, or may require design modifications or relocation to improve resiliency of future infrastructure.

Recent and Local Initiatives

On June 21, 2017, TxDOT hosted the FHWA Texas Resilience and Planning Workshop. FHWA published a summary report on September 20, 2017. There were 48 attendees for the workshop, including representatives from nine Texas Metropolitan Planning Organizations (MPOs). Peter Smith, Director of Planning and Programming at TxDOT, described TxDOT's perspective on extreme weather and resilience, as reflected in the summary report.

> "Texas experiences a wide variety of extreme weather events, including storm surge, river flooding, snow and ice storms, and drought. TxDOT began working on climate resilience in 2011 with its Statewide Freight Resiliency Plan. The plan identified areas in the State that are at high risk for disruption to freight systems due to extreme weather. It found that risk is elevated in areas with large and growing populations. The Resiliency Plan is divided into three stages: prepare, detect and respond, and recover. Mr. Smith noted that the State emphasizes planning for disaster response and recovery, but has focused less on preparing for extreme events by evaluating vulnerabilities and opportunities for resilience.
>
> Moving forward, TxDOT is starting to think of resilience at the systems level by looking not only at the design of individual roads and bridges, but also at critical links in the system and potential ways to build redundancy. Resilience strategies TxDOT is considering can be grouped into three categories: protect, accommodate, and retreat.[32]

A North Central Texas Council of Governments (NCTCOG) representative presented "Considerations for Integration of Infrastructure Resilience and Asset Management with Long-Range Planning in North Central Texas" and mentioned that in 2015, NCTCOG conducted a vulnerability assessment as one of the FHWA pilot projects. NCTCOG has begun addressing vulnerabilities through its $2.5 billion Transportation Asset Management Program. The program includes the comprehensive review of facilities to identify where rebuilding is necessary and where lower cost techniques will suffice. This program helps to maximize incident detection, enhance potential alternate routes, and identify at-risk locations to apply technology for notifications on extreme events occurrence, such as flooding at low-water crossings.[33]

A Capital Area MPO (CAMPO) representative mentioned CAMPO received funding from FHWA in 2011, to conduct a vulnerability assessment using the FHWA Framework. CAMPO evaluated five climate

[32] (FHWA, 2017, p. 3)
[33] (FHWA, 2017, pp. 5-6)

impacts: flooding, drought, extreme heat, wildfire, and extreme cold and ice on critical assets, including key roadway and transit facilities. The results of the vulnerability assessment were incorporated into the vision and goals section of its 2040 Long Range Transportation Plan (LRTP). CAMPO discussed several studies and initiatives to contribute to building resilience that may be incorporated into the next LRTP."[34]

Each MPO typically provides more detailed information on any local initiatives on its website. The Texas Association of Metropolitan Planning Organizations (TEMPO) maintains a website that includes contact information for all MPOs in Texas.

7.0 Statewide On-Road GHG Analysis

The analysis methodologies described in **Section 4** and **Appendix A** have been applied for the Texas on-road transportation system in order to estimate GHG emissions. This section summarizes the analysis results for the state of Texas on-road transportation system and assesses current mitigation measures.

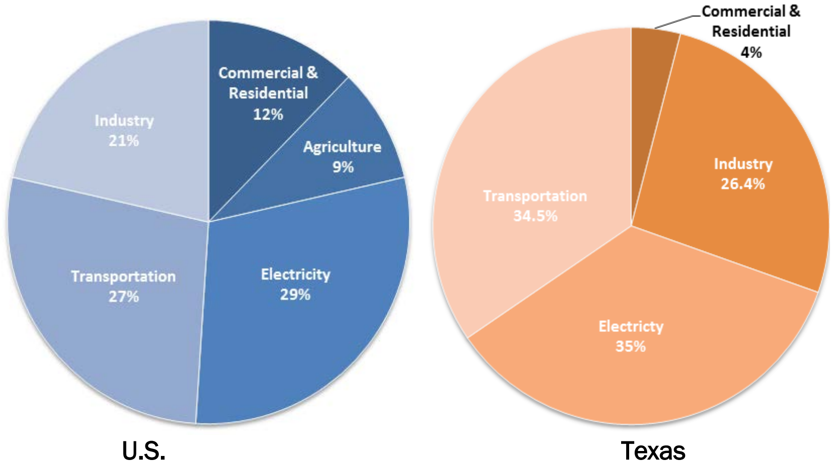
7.1 Quantification of Emissions

On-road GHG emissions are ultimately dependent on the choices of individual commuters and vehicle and fuel technologies regulated at the national level, as well as characteristics of the transportation system (such as availability of transit). The emissions analysis serves as a proxy[35] for analyzing the GHG emissions associated with the Texas on-road transportation system and their potential contribution to global climate change.

The transportation and electrical energy sectors were the two largest sources of total GHG emissions in the U.S. and the state of Texas in 2014 (**Figure 6**). Total GHG emissions in the U.S. were 6,870 million metric tons (MMT) of CO_2E, and transportation's contribution was 1,810.3 MMT[36]. Generally, the majority of GHG emissions relating to transportation include CO_2 emissions resulting from combustion of petroleum based products (e.g., gasoline) in personal and commercial vehicles, trains, ships and airplanes. CO_2 is the largest component of these GHG emissions. According to the U.S. Energy Information Administration (EIA), the total annual CO_2 emissions in Texas during 2014 were 641.7 MMT, including 221.6 MMT from the multi-modal transportation sector. In 2014, approximately 76 percent of transportation emissions were due to on-road emissions, which would result in 169.3 MMT for 2014 Texas on-road emissions.[37] The EIA data gives a slightly lower estimate than the Texas Commission on Environmental Quality (TCEQ) Emission Trends Report (**Figure 7** and **Table 4**).

[34] Workshop, page 5
[35] (CEQ 2016) Pages 4 and 10 discuss using GHG emissions as a proxy for climate change.
[36] (EPA 2016)
[37] (EPA, 2017, pp. Annex 3-2)

Figure 6: Total U.S. and Texas GHG Emissions by Economic Sector in 2015



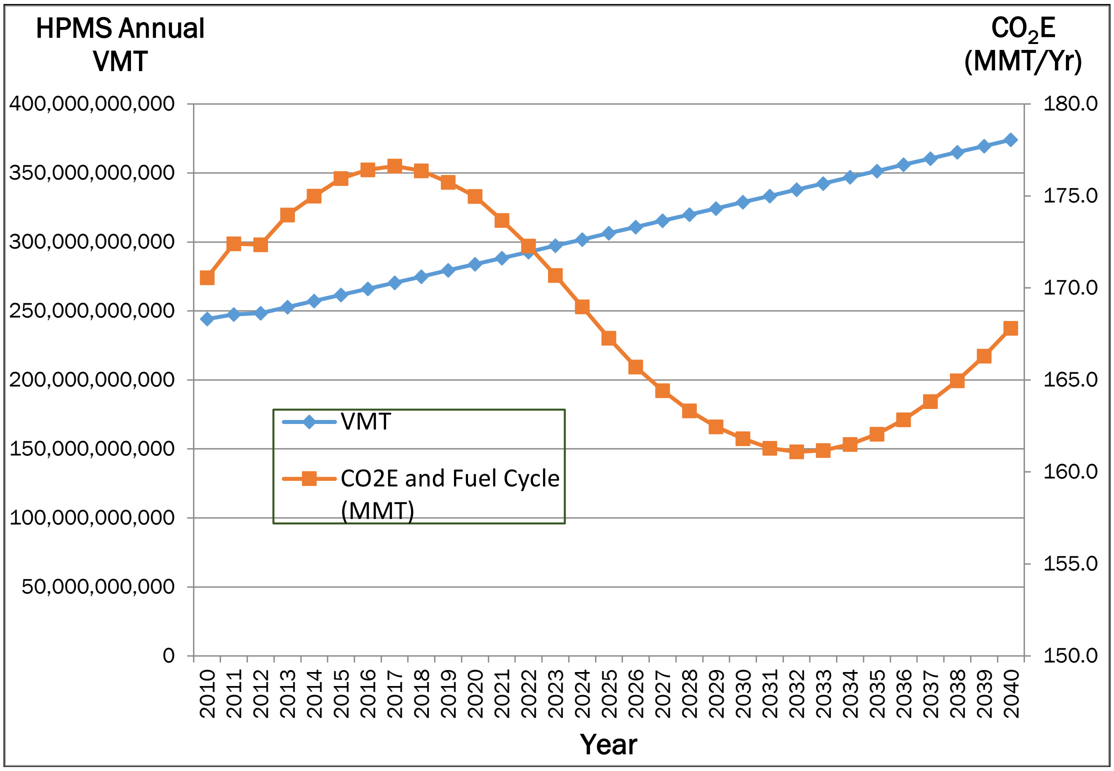
Sources: U.S. graphic: (EPA 2017); Texas data from (EIA 2016)

Three primary options exist to estimate transportation emissions, and each one produces slightly different emission results when comparing different sets of data. 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 locally specific fleet mix data. TxDOT is using VMT estimates based on population projections, historic traffic count data, and Texas county-specific fleet data. Texas has metropolitan-based travel demand models, but no detailed statewide travel demand model exists to conduct the emissions analysis.

The historic and predicted relationship between Texas on-road VMT and tailpipe and fuel-cycle emissions is shown in **Figure 7** and **Table 4.** EPA's Motor Vehicle Emissions Simulator (MOVES2014 version) emissions model was used to estimate emissions. MOVES2014 does not account for the heavy-duty diesel CAFE standards for model years 2018–2029, which should further reduce the emission projections provided in **Figure 7** and **Table 4**. The population-based VMT trend (**Figure 7** and **Table 4**) is slightly higher (261.6 billion VMT for 2015) than the VMT reported under the FHWA Highway Statistics series (258.1 billion VMT for 2015) (**Table 5**), resulting in emission estimates that are slightly higher than emissions would be if based on reported VMT.

In the base year 2010, Texas on-road and fuel-cycle CO_2E emissions are estimated to be 171 MMT per year; by 2040, emissions are estimated to be 168 MMT. Emissions are estimated to peak in 2017 at 176.6 MMT and reach a minimum in 2032 at 161.1 MMT. The maximum emissions are reached as more of the 2012 and future model-year vehicles enter the Texas fleet. This is a situation in which technology reduces emissions more than VMT increases it. The minimum is reached after all 2012–2025 model-year vehicles have saturated the fleet, at which point emissions begin to increase as VMT increases. Changes to future regulations, market penetration for new vehicle and/or fuel technological advances, economics and personal decisions regarding travel options could substantially lower future emissions.

Figure 7: Texas VMT and Annual CO_2E On-road and Fuel-Cycle Emissions Trends (in MMT)



Data Source: (TCEQ 2015)
To obtain fuel-cycle emissions, the statewide annual emissions were multiplied by 1.27 (EPA fuel-cycle factor is 27% of on-road emissions). Million metric ton conversion is (annual tons/1.10231131092 metric tons/U.S. tons)/1000000.

Table 4: Texas Annual VMT and Annual CO_2E

On-road and Fuel-cycle Emission Trends

Year	VMT	CO_2 On-road (MMT)	CO_2E On-road and Fuel Cycle (MMT)	Population
2010	244,182,719,140	132	171	25,145,561
2015	261,663,541,083	137	176	27,000,199
2020	283,863,291,807	136	175	28,921,650
2025	306,318,028,813	130	167	30,905,192
2030	328,874,805,063	126	162	32,927,245
2035	351,418,191,557	126	162	34,962,746
2040	374,030,177,339	130	168	37,022,513

Data Source: (TCEQ 2015)
To obtain fuel-cycle emissions, the statewide annual emissions were multiplied by 1.27 (EPA fuel-cycle factor is 27%). Million metric ton conversion is (annual tons/1.10231131092 metric tons/U.S. tons)/1000000.
CO_2 to CO_2E conversion is CO_2/0.986 CO_2E.

Table 5: Texas Lane Miles and Annual VMT 2011-2015

Year	Interstate and Freeways Lane Miles	Arterials, Collectors, and Local Streets Lane Miles	Total Lane Miles	Annual VMT
2015 (1)	23,735	653,842	677,577	(2) 258,122,000,000
2014 (3)	23,734	653,841	677,575	(4) 243,076,000,000
2013 (5)	23,277	652,303	675,580	244,525,000,000
2012 (6)	23,149	652,148	675,296	(7) 237,836,000,000
2011 (8)	22,921	651,375	674,296	(9) 237,440,000,000
2015–2011 Lane Additions	813	2,468	3,281	20,682,000,000
Average Yearly Lane Additions	163	494	656	4,136,400,000

Sources: (1) (FHWA 2017)
(2) (FHWA 2016)
(3) (FHWA 2015)
(4) (FHWA 2015)
(5) This data was the result of a new TxDOT data system. Based on this information, Statewide vehicle-miles traveled (VMT) decreased 1.48% when compared to the 2013 data, contrary to an expected increase based on other economic indicators which suggest traffic growth in Texas.
(6) (FHWA 2014)
(7) (FHWA 2014)
(8) (FHWA 2013)
(9) (FHWA 2013)

As discussed under **Section 7.3** for Mitigation, the CAFE standards for model year 2012–2029 are estimated to reduce nationwide GHG emissions by 62,200 to 127,300 MMT. NHTSA EISs for each standard have substantial discussion of GHGs and climate change and include modeling of alternative future GHG emissions and climate stressor scenarios. These large GHG reductions across the nation are estimated to only change potential global impacts of temperature and sea-level rise to hundredths and thousands of an inch (0.008–0.06 inches) or of degrees Fahrenheit (0.0005–0.027^{o}F) (**Table 6**).

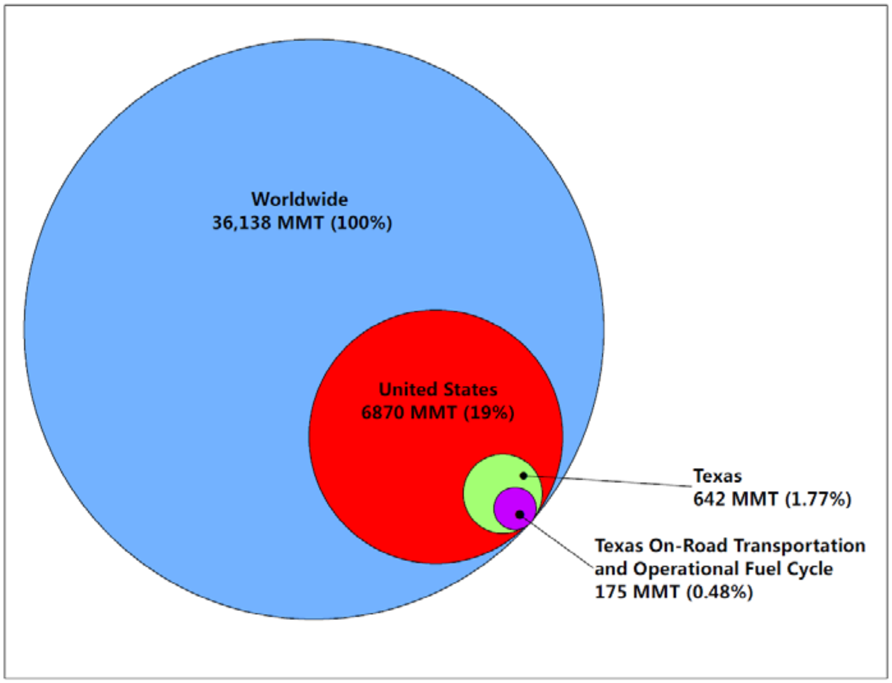
In 2014, approximately 36,138 MMT of CO_2 emissions were emitted worldwide, of which 175 MMT CO_2E (0.49 percent of total global emissions) were due to Texas on-road and fuel-cycle emissions[38]. **Figure 8** provides a comparison of 2014 Texas (on-road transportation and fuel cycle CO_2E and Texas CO_2 emissions) and U.S. CO_2E emissions to worldwide CO_2 emissions. For the given year, the purple circle represents all vehicles traveling on existing roadways in Texas as well as vehicles traveling on newly constructed roadways. New construction roadways are a small percentage of total roadways in Texas. For example, the average annual lane addition in the current UTP is 121 miles/year, versus our existing system which is 677,577 miles.

Individually proposed TxDOT on-road projects and their alternatives are a very small subset of worldwide or nationwide emissions (**Figure 8**). The purple circle in **Figure 8** reflects operational and fuel-cycle emissions from all existing roads, plus the average 2,000+ projects per year that TxDOT environmentally approves, so any individual project would be a small portion of the purple circle. The differences between the build and no-build alternatives of a given project would be even less discernible. Even with the large GHG emission reductions associated with the U.S. 2012–2029 CAFE standards, these reductions are estimated to have a nominal influence on global temperature and global sea level rise. Quantifying an individual project's impact on global climate change is not possible, which is why the rescinded CEQ guidance recommended using GHG estimates as a proxy for climate change impacts and allowed taking

[38] Worldwide emissions from (World Bank 2017). Different sources provide data for CO_2 and CO_2E. CO_2 is less than CO_2E. For example CO_2E worldwide according to IPCC for 2013 was 49,000 MMT.

a programmatic approach (e.g., developing a statewide analysis) as an alternative. The uncertainty in any project-level analysis would be further compounded by the assumptions required for the input data, the margin of error of the models, and the limitations on the ability to predict *anything* 50 to 80 years into the future for any individual project.

Figure 8: Comparison of 2014 Texas, U.S., and Worldwide CO_2 Emissions



Source: TxDOT, 2017

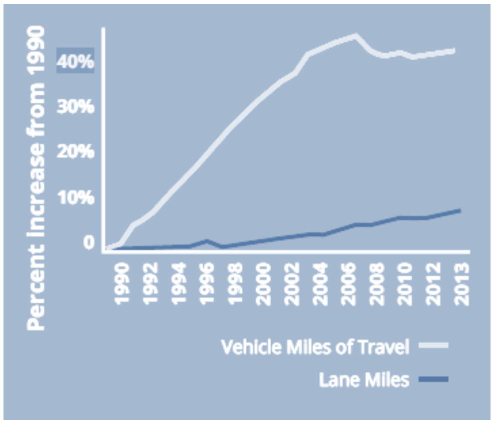
7.2 Congestion-related Impacts

Increasing congestion is a nationwide[39] (**Figure 9**) and worldwide[40] challenge. Congested travel delays caused U.S. drivers to waste more than 3 billion gallons of fuel in 2014 (versus 0.5 billion gallons of fuel in 1982) and cost the U.S. $160 billion in 2014. Traffic congestion leads to more problems than just traffic jams. Traffic congestion creates a ripple effect that impacts nearly every aspect of our lives, whether we drive or not, in more ways than we realize:[41]

- Increased stress and pollution that affect our health and environment;
- Increased fuel consumption and vehicle wear and tear that affect our finances;
- Increased costs of goods and services due to increased fuel usage and delivery times;
- Increased collisions, injury, law suits, and insurance rates;
- Decreased time to spend with family and friends, at work, etc.; and
- Decreased emergency response times that can mean the difference between life and death.

[39] (Schrank 2015)
[40] (INRIX Research 2016)
[41] (TxDOT 2016)

Figure 9: Percent Increase in U.S. VMT and Lane Miles



Source: (USDOT)

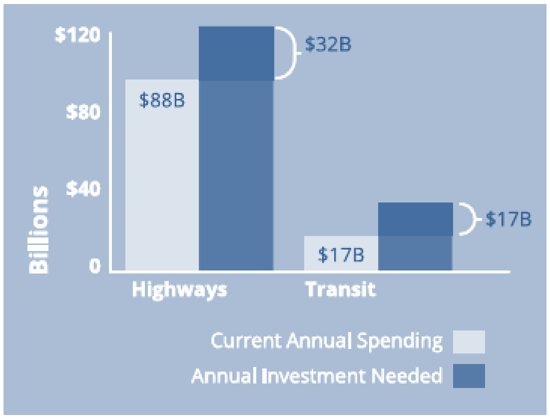
Less congestion equals reduced emissions. Reducing congestion while meeting the demands of population growth and economic expansion requires a multi-pronged approach that includes a mix of strategies, including new funding streams, new roadway construction, increased transit, better operations, flexible work schedules and personal travel decisions.

Since the mid-1990s, inflation and steep increases in construction materials have reduced the purchasing power of federal transportation funds by nearly 40 percent. Consequently, the balances of most dedicated transportation funds have declined as expenditures have exceeded revenues.[42] Vehicle fuel efficiency has improved since the oil embargo of the 1970s, which allows more miles of travel using less fuel. From 2005 to 2014, the average fuel economy per passenger vehicle has increased by 12 percent[43], further reducing fuel taxes. These changes result in increased congestion, because the U.S. transportation system cannot keep up with growing demand and maintenance needs (Figure 10). With congestion increasing worldwide,[44] policymakers across the globe are grappling with transportation systems and their funding challenges.

With current funding levels in the TxDOT UTP, the “rate of growth” in congestion is managed through the combination of system operational improvements; travel-demand reduction strategies; and capacity additions (1,210 lane-mile additions versus 677,577 existing lane miles). Since funding has not kept up with demand, the additional lane miles are added to help reduce congested, stop-and-go traffic. While there is no silver bullet to erase congestion, the Texas Clear Lanes program is intended to help improve conditions on the most congested roadways in the five largest metropolitan areas of Texas.

[42] (USDOT)
[43] (USDOT, p. 116)
[44] (INRIX Research 2016)

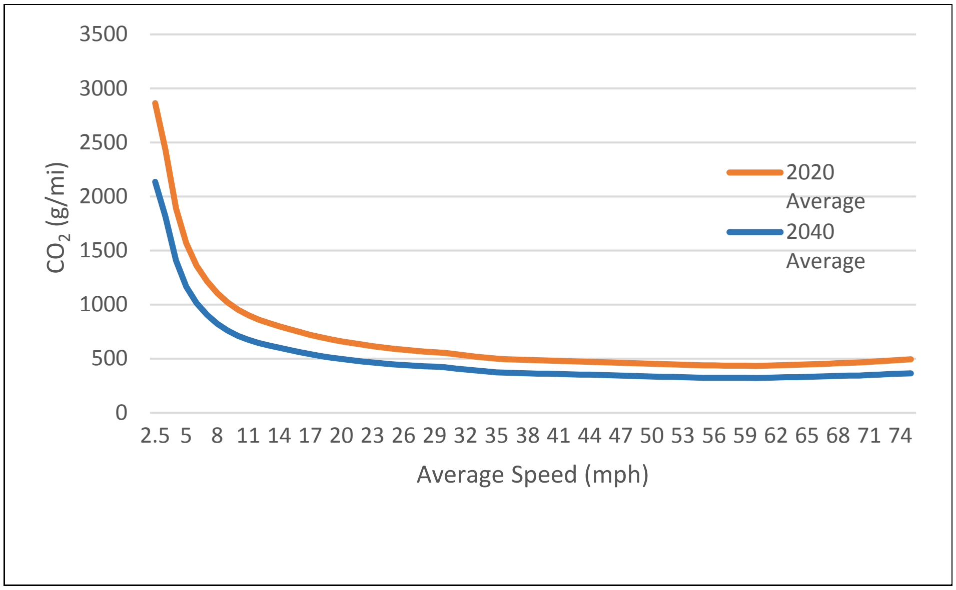
Figure 10: Estimated U.S. Surface Transportation Investment Gap



Source: (USDOT)

Based on EPA MOVES-generated emission rates for Texas, improvements in travel speed will provide reductions to operational GHG emissions. These rates represent the average rates for all vehicle and roadway types in Texas. Rates for 2040 show an overall average decrease of 25 percent from the 2020 rates based on benefits from federal CAFE standards. Figure 11 illustrates the relationship between speed and emission rates for the 2020 and 2040 analysis years. The most congested roadways and bottlenecks have stop-and-go traffic during peak traffic times. Stop-and-go traffic is represented in Figure 11 at the lowest speeds (0–10 miles per hour), which have the highest emission rates. For example, five mph has three times higher emissions than 20 mph. Reducing congestion on roadways would provide further emissions reductions statewide.

Figure 11: Emission Rates by Speed



Source: (TxDOT 2017) Emissions Rate Lookup Tables (ERLT)

7.3 Mitigation Measures

Mitigation measures were not required under the rescinded CEQ guidance, and no national control requirements exist beyond federal CAFE standards; however, several reduction initiatives exist in the U.S. and Texas. Because GHG is a global issue, these programs are focused on achieving incremental reductions, which can contribute to long-term meaningful reductions when combined with similar initiatives around the world. Clean construction and operation activities and other TxDOT efforts contribute to incremental GHG emission reductions across the Texas transportation system.

Strategies that reduce on-road GHG operational emissions fall under four major categories:

- federal engine and fuel controls under the Clean Air Act implemented jointly by EPA and U.S. Department of Transportation (USDOT), which includes CAFE standards;
- “cash for clunker” programs which remove older, higher-emitting vehicles from roads;
- traffic system management (TSM) which improves the operational characteristics of the transportation network (e.g., traffic light timing, pre-staged wrecker service to clear accidents faster, or traveler information systems); and
- travel demand management (TDM) which provides reductions in VMT (e.g., transit, rideshare, and bicycle and pedestrian facilities).

The majority of on-road emission reductions has been achieved through federal engine and fuel controls. Lesser reductions have been achieved through the other three options. USDOT-NHTSA and EPA have jointly established new, more stringent fuel economy as well as the first-ever GHG emissions standards for model-year 2012 to 2025 passenger cars and light-duty trucks and model-year 2014 to 2029 for medium- and heavy-duty vehicles. The 2025 standards are currently being reviewed for technological feasibility and may be subject to change. The fuel economy for 2025 model-year vehicles is 54.5 miles per gallon for cars and light-duty trucks, compared to the 35.5 miles per gallon for the 2016 standard and 25.5 miles per gallon for the 2009 standard. The 2025 model-year vehicles should reduce fuel used by more than 50 percent, compared to fuel used in vehicles purchased in 2009. The objective of this group of strategies is to use less fuel and generate fewer GHG emissions.

NHTSA issued EISs for the CAFE standards. Each EIS has substantial discussion of GHGs and climate change and include modeling of alternative future GHG emissions and climate stressor scenarios. NHTSA estimates of the impact of the standards on global GHG emissions and climate change are summarized in **Table 6**.

Table 6: Estimated Climate Impacts for the NHTSA CAFE Standards

Vehicle Model Years	Lifetime National GHG Reductions (million metric tons)	Annual GHG Reductions (million metric tons)	Lifetime Fuel Reduction (billion gallons)	Annual Fuel Reduction (billion gallons)	Reduction in Global Temperature Change in 2100 Compared to No Action	Reduction in Global Sea Level Rise in 2100, Compared to No Action (inches)
2012–2016 (1)	20,700 – 47,300 (1)	232–543 (2)	NA	25.5–59.6 (2060)	0.016°F to 0.027°F	0.02–0.06 inches
2017–2025 (2)	29,800 – 53,300 (3)	NA	200–1,767(4)	NA	0.002°F to 0.027°F	.016 to 0.06 inches
2014–2018 (3)	6,700–12,500 (5)	11–63	46.7–189.4 (6)	NA	0.0005 °F to 0.0037 °F	max of 0.008 inches
2018–2029 (4)	5,000 – 14,200 (7)	NA	85.9–287.1 (8)	NA	0.004°F to 0.009°F	max of 0.04 inches

Sources: (1) (NHTSA 2010, S-5, S-13, 3-85, 3-109)
(2) (NHTSA 2012, S-12, S-43, S-47, 2-41)
(3) (NHTSA 2011, S-6, S-19, S-20, 3-91, 3-114)
(4) (NHTSA 2016, S-7, S-23, S-24, S-26)

Other initiatives intended to reduce emissions include the following.

- The U.S. Department of Energy's (DOE) Clean Cities program which supports local actions to cut petroleum use in transportation. Dallas/Fort Worth, Austin, San Antonio and Houston/Galveston Clean Cities programs work with vehicle fleets, fuel providers, community leaders, and other stakeholders to reduce petroleum use in transportation. TxDOT works collaboratively with these local programs.
- Texas State Energy Conservation Office researches and assists public and private entities in securing grants to encourage the use of alternative fuels.
- TxDOT is participating in the federal alternative fuels corridors program and is increasing the number of alternate-fueled vehicles in the TxDOT fleet. Nine corridors already have signage for electric vehicles, ten corridors have signage for propane and/or natural gas and two corridors are pending signage for hydrogen-fueled vehicles.
- Texas Transportation Funding, Project Selection and Operational Programs:
    - TxDOT provides approximately $150,000,000 per year in nonattainment areas for federally funded Congestion Mitigation Air Quality (CMAQ) improvement projects (e.g., bicycle/pedestrian facilities).
    - Project selection: TxDOT gives preference for alternatives that reduce congestion (and emissions) and improve safety including but not limited to TDM and TSM.
    - Transportation sector fees fund the TCEQ Texas Emission Reduction Program (TERP), a program used by many TxDOT contractors to reduce diesel on-road and construction equipment emissions. TERP provides grants for alternative fuel and advanced technology demonstration and infrastructure projects under the New Technology Research and Development (NTRD) Program. While CO_2 emission reductions are not part of the TERP reported benefits, use of newer, cleaner technology also reduces fuel consumption, which reduces CO_2 emissions from construction. For the 2016–2017 biennium, approximately $236 million is appropriated to the TERP program.
    - TxDOT's Clean Construction and Operation initiatives are intended to improve sustainability of pavements.
    - The Drive Clean Texas (DCT) program encourages driving habits that reduce emissions.
    - TxDOT's Clean Air Plan encourages its 12,000 employees statewide to reduce emissions.

Examples of these programs are provided below.

<u>Congestion Mitigation Air Quality Projects</u>

Annual funding for 2006 Congestion Mitigation Air Quality (CMAQ) projects resulted in reducing 1,116 tons/year of volatile organic compounds (VOC); 5,326 tons/year of CO; and 2,107 tons/year of nitrogen oxides (NOx). Converting VOC and CO to CO_2 reductions is equivalent to reducing approximately 1.52 to 1.94 MMT of CO_2.[45] In other words, CMAQ reductions were equivalent to removing annual emissions from approximately 320,373–409,981 passenger vehicles per year, or saving approximately 170,662,541–218,396,422 gallons of gasoline, or powering 160,156–204,951 homes per year.[46]

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[45] Based upon 2017 TTI generated 85% upper/15% lower range conversion factors for VOC to CO2 and CO to CO2 from TCEQ Emission Trends report.

[46] (EPA 2017)

Clean Construction and Operation

TxDOT has specifications for sustainable pavements that reduce energy consumption, increase recyclable use, and reduce air emissions. Examples include:

- Warm Mix Asphalt (WMA)
- Recycled Asphalt Pavement (RAP)
- Recycled Asphalt Shingles (RAS)
- Coal and Other Combustion By-Products (e.g., flyash)
- Recycled Tires
- Recycled Concrete
- Standard specifications for purchasing light emitting diode (LED) lighting
- Solar sign boards replacing diesel-powered sign boards
- Other additional technologies to further reduce energy consumption are under evaluation

The recycling program provides energy reductions as well reducing emissions to air, water and land (**Table 7**). The use of recycled material (without warm mix asphalt reductions) is estimated to reduce approximately 202,472 to 211,529 metric tons of CO_2E.[47] This reduction is equivalent to removing CO_2 emissions from approximately 42,769–44,682 passenger vehicles per year, or saving 22,782,941–23,802,070 gallons of gasoline, or powering 21,380–22,337 homes per year.[48]

Table 7: Clean Construction and Operation

Recycled Product	Recycled Amount (U.S. Tons Per Year)		Avoided CO2E (Metric Tons Per Year)	
	Amount or Low	High	Amount or Low	High
Recycled Asphalt Shingles	20,000		1,813	
Recycled Asphalt Product	620,000		50,414	
Warm Mix Asphalt	3,200,000		Variable (1)	
Fly Ash	153,134		132,855	
Recycled Concrete	1,000,000		7,957	
Recycled Tires	2,000	3,000	752	1,128
Scrap Metal	2,000	4,000	8,681	17,362
Totals			**202,472**	**211,529**

Source: TxDOT, 2017, Recycled concrete was last tracked in 2010, other data is 2016, or low and high for recent year averages.
(1) The emissions vary, although warm mix asphalt is estimated to reduce energy consumption approximately 8% over hot mix asphalt, but emission estimates are not possible due to variabilities in energy consumption across the state.

In 2001, TxDOT, in partnership with the TCEQ, developed the nation's first and only comprehensive *statewide* public outreach and education campaign aimed at getting individual drivers to reduce tailpipe

[47] (EPA 2017)and (EPA 2017)
[48] (EPA 2017)

emissions by changing driving habits. TxDOT spends approximately $1.4 million annually on the campaign. Research shows that more than one-fifth of all Texas drivers have adopted at least one of the five DCT core messages to change their driving habits: maintain your vehicle, drive less, buy a "cleaner" vehicle, drive the speed limit and/or avoid idling.

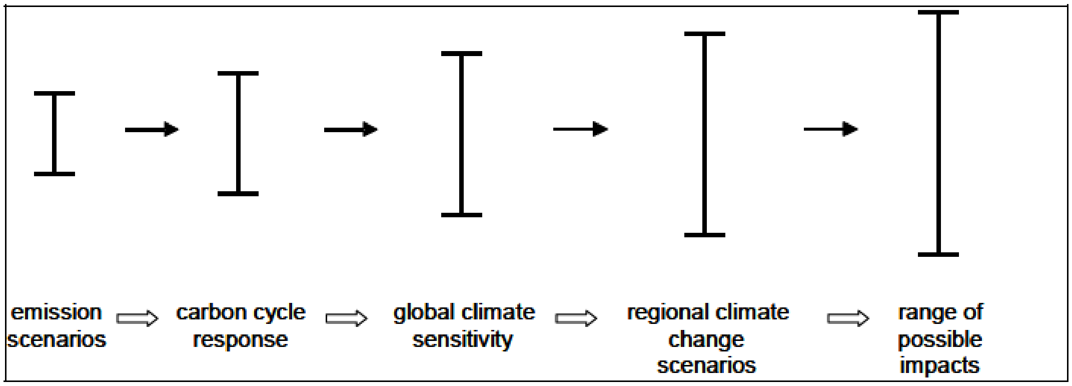
The Clean Air Plan focuses on employee vehicle travel reduction and business operational changes in support of air quality goals for five months/year during the ozone season, consistent with the Drive Clean Program. The travel reduction portion of this program removes between 2,000,000–5,300,000 vehicles miles of commute travel by employees and saves 90,000–270,000 gallons of gasoline. This equals CO_2E reductions of 800 to 2,399 metric tons per year.[49]

8.0 Incomplete or Unavailable Information for Specific Climate Change Impacts Analysis (40 CFR Section 1502.22)

This analysis is based on relevant available data; however, gaps and uncertainties in the data and the tools used to generate outcomes limit their accuracy. This section describes key limitations to this analysis.

Figure 12 provides a visual display of how uncertainties amplify as variable ranges are multiplied to provide a range of future consequences. In other words, increasing the number of variables expands the amount of uncertainty. The uncertainty bands broaden with each successive step in the analytic chain, with the mid-range values having the highest likelihood and the outer ranges having less likelihood. For example, sea level rise has a higher likelihood of being a mid-range of 2–3 feet rise rather the highest projection of 8 feet. **Figure 13** contains confidence levels that were used in the 2014 NCA study. In particular, note that confidence levels do not equate with the same data terminology. For example, "high confidence" is associated with "moderate data evidence," "moderate confidence" is associated with "suggestive data evidence," and "low confidence" is associated with "inconclusive data evidence."

Figure 12: Cascade of Uncertainty in Climate Change Simulations



Source: (Moss 2000) "Cascade of uncertainties typical in impact assessments showing the 'uncertainty explosion' as these ranges are multiplied to encompass a comprehensive range of future consequences, including physical, economic, social and political impacts and policy responses.

[49] (EPA, 2017)

Figure 13: National Climate Assessment Confidence Levels

Very High Confidence Level
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus
High Confidence Level
Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus
Medium Confidence Level
Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought
Low
Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Source: (Melillo, 2014)

Limitations of GHG Analysis

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 emission factor modeling. Travel demand estimates based on fuel use, population or travel models is used to forecast traffic volumes and diversions related to transportation projects. Uncertainty surrounds the travel choices, demographic futures, and other parameters that serve as the foundation of the traffic projections. The estimation of travel speeds remains an important step in the process, as emissions vary significantly by vehicle operation; however, such data is not readily available on a statewide basis, so EPA MOVES national default values were used. In addition, average, design, or posted speed is what is typically available for most projects, with only a few of the largest projects having detailed speed data for a reasonably accurate congested and free-flow speed analysis. 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 the present or in future projections. Although EPA's MOVES emission factor model provides the best available tool for conducting different types of transportation GHG analyses, there is some uncertainty with many of the model's input files many of which are based on 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 may dramatically change emissions in ways not accounted for by EPA MOVES model.

In addition, the pace and effects of technological changes in the transportation sector and other sectors that emit GHGs are difficult to predict with accuracy. For example, the DOE Joint Center for Artificial Photosynthesis (JCAP) was established in 2010 to find new and effective ways to produce fuels using only sunlight, water and carbon dioxide as inputs.[50] JCAP has made progress towards solar hydrogen generation systems that are both efficient and robust and is now turning its focus towards carbon dioxide reduction to produce energy dense fuels.[51] Carbon dioxide reduction research includes artificial nanoparticle photosynthesis. Scientific advances and success in this area could ultimately drive commercial development of solar-fuel systems designed from inception to be easily deployable almost

[50] (DOE 2017)
[51] (DOE 2017)

anywhere.[52] Such changes may dramatically change GHG emissions in the U.S. as well as worldwide. Electric and hydrogen fueled vehicles are available that emit no CO_2 tailpipe emissions. Autonomous and connected vehicles or future technologies such as Hyperloop systems[53] may transform both travel and travel patterns in ways we cannot predict with accuracy today. Technological advances may transform the transportation system just as the internal combustion engine changed horse, buggy, bike, and rail travel in the early 1900s as shown in **Figures 14–15**.

Figure 14: Austin, Congress Avenue (1910)[54]

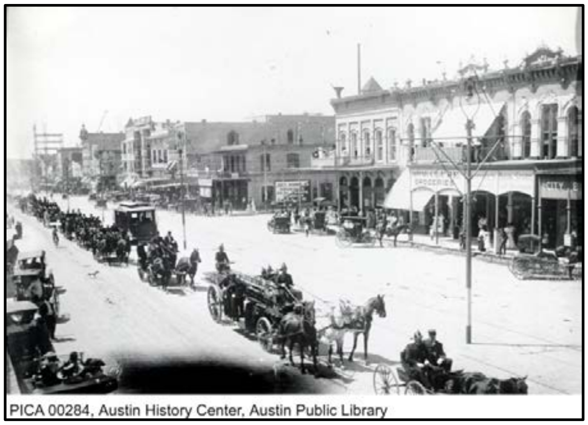


Figure 15: Austin, Congress Avenue, (current)[55]

Limitations of Climate Models

Climate science is highly complex and evolving, and climate models incorporate many different assumptions. Most models rely on past patterns to calibrate results; however, one of the challenges associated with climate change is that the future is not expected to follow the patterns of the past, which makes it difficult to assess the accuracy of the models. For example, it is unknown what the sensitivity of climate is to increased GHG concentrations, the rate of change in climate system in response to changing GHG concentrations, or the potential existence of thresholds and their levels in the climate system, all of which impact the accuracy and precision of predicted or simulated future scenarios. Additionally, the models are intended to analyze the global climate, and results must be scaled down to assess climate predictions at a more local level. The combination of assumptions, uncertainty of model results, and scaling mean that it is not possible to credibly assess climate impacts directly attributable to GHG emissions associated with proposed UTP on-road transportation projects in Texas.

The USGCRP identifies three main sources of uncertainty within climate models:

1. Natural climate variability affects the initial conditions input into models, and variability built into the models may also affect the results. This is the dominant source of uncertainty for projecting temperature and precipitation on shorter timeframes (up to decades).
2. Results are based on the model structure and the parameters used, which are affected by the state of the science at the time the model is designed. This is the dominant source of uncertainty affecting projections of global temperature through mid-century and for regional temperature and precipitation through the end of the century.
3. Human decision making around the world will affect the level and timeframe of increased GHG emissions, and may not follow any of the scenarios modeled. It is impossible to predict which, if

[52] (DOE, 2017)
[53] (Schneider 2016)
[54] ([Austin Volunteer Fire Department], photograph 1910 n.d.)
[55] (Wikipedia: Congress Avenue Historic District 2017)

any, of the scenarios analyzed in the model is the most likely. This source of uncertainty affects projections of global temperatures by the end of the century.

Scaling the model results also may affect their accuracy for predicting local conditions. While global climate models yield important scientific insights, they may not be as fine as the end-use application requires. Therefore, the global climate models are downscaled using one of two main methods. Dynamical downscaling uses regional simulations to assess how global processes affect regional or local climates. This method accounts for local physical conditions that are not expected to be affected by climate change, but it may be sensitive to bias introduced at the large scale. The second method is statistical downscaling, which uses statistics-based techniques to define relationships between large-scale climate patterns and observed local climate responses. This method requires an assumption that the relationships will not be affected by the anticipated changes.

Limitations on Predicting Personal Decisions

It is unknown what personal decisions will be made in the future and what conditions may alter those decisions. In the recent past, individuals have increased purchases of pickup trucks, sport utility vehicles and crossover purchases. Such purchases may alter the ability to achieve the 2025 CAFE standards, which are based on a higher proportion of smaller more fuel efficient or alternative fueled vehicles being purchased. Safety concerns may factor into consumer choices on vehicle purchases. The 2007 data from the Insurance Institute for Highway Safety indicate a correlation of 250–500 fatalities per year per mile per gallon increase.

> "A 2003 NHTSA study estimated that every 100 pounds of weight taken off a car weighing more than 3,000 pounds increases the accident death rate slightly less than 5%, and the rate increases as vehicles become lighter than that. Two years earlier a National Academy of Sciences study estimated that CAFE standards at that time were responsible for as many as 2,600 highway deaths in a single year. A 1999 study conducted by USA Today applying federal government Fatality Analysis Reporting System Data attributed deaths of 7,700 people for each additional mile-per-gallon (mpg) mandated to meet CAFE regulations."[56]

Limitations in Using the Data

Future uncertainties are real and pose challenges to engineering as evidenced by the findings in the FHWA *Assessment of Key Gaps in the Integration of Climate Change Considerations into Transportation Engineering.* According to the study, the four primary gaps facing state DOTs/ metropolitan planning organizations (MPOs) are:

- Translation of climate data to terms that resonate with transportation practitioners;
- Engineering solutions for preparing for climate change;
- Methods for evaluating efficacy and costs/benefits of implementation adaptation measures, and
- Organization process/decision-making.

Limitations Regarding Impacts on Human Health

Impacts of climate change on human health are also an area of uncertainty. The USGCRP *The Impacts on Climate Change on Human Health in the United States A Scientific Assessment* includes a discussion of potential health impacts and identified uncertainties with measures of likelihood and confidence.

[56] (Bell 2011)

9.0 Conclusion

Climate change or extreme weather events may alter final project design following conclusion of the environmental process, especially in areas subject to excess flooding and in coastal areas subject to potential storm surge or sea-level rise. For example, TxDOT has already made changes to reduce bridge scouring from flood-prone areas and bridge height to address potentially higher coastal storm surge. Climate change or extreme weather events may result in additional changes to TxDOT transportation planning, design, emergency response, maintenance, and asset management operations. Maintenance and pavement design operations currently address severe weather issues (heat, drought and flooding) with elasticity to adapt to a changing environment. USDOT and TxDOT implementation of the FAST Act will result in additional enhancements to transportation planning, asset management, design, and maintenance programs.

Climate change impacts within a typical roadway lifespan are not generally anticipated to alter the selection of NEPA project alternatives. Exceptions to this include consideration of the location of a project alternative that could be particularly subject to extreme rain events or sea level rise. While TxDOT considers potential climate change and severe weather events such as flooding or increased storm surge as we maintain existing or design and build new infrastructure, the “rule of reason” must be applied so that repetitive NEPA reviews of any and all potential impacts are not necessary, especially those which cannot be reasonably anticipated with current tools, analytical methods and reasonable assumptions. From recent participation in FHWA Climate Change Resilience Pilots, both the Capital Area Metropolitan Planning Organization (CAMPO, serving greater Austin) and the North Central Texas Council of Governments (NCTCOG, serving greater Dallas-Fort Worth area) determined that the outcome of their analyses could be used for future scenario planning but that the uncertainty in future climate projections precluded the use of the information for individual project funding decisions in their transportation plans. Such uncertainties also limit what data is reasonable for use under NEPA analyses.

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Appendix A: Methodology for Greenhouse Gas and Climate Change Analysis

This section identifies methodologies used for the statewide CO_2E emissions estimate and an assessment of projected climate stressors for the state of Texas.

A.1 Greenhouse Gas Analysis Methods

A quantitative estimate of state on-road (both on- and off-system) operational emissions and upstream fuel cycle CO_2E emissions was conducted by TxDOT. The operational CO_2E emissions were calculated based on annual operational emission projections for a base year of 2010 through a design year of 2040 using TCEQ Emission Trends Report. The year 2040 is consistent with the design year (final year) of the current TxDOT statewide long-range transportation plan. **Table A-1** describes the methods employed for CO_2E emission calculations for Texas.

For the TCEQ Emission Trends Report, the Texas A&M Texas Transportation Institute (TTI) developed and produced Highway Performance Monitoring System (HPMS)-based annual emissions estimates for each of the 254 Texas counties. The level of detail in the final emissions estimates were aggregate emissions by county and vehicle class.

Table A-1: GHG Emission Methodology Matrix

Traffic Data/Inputs		
Source of Traffic Data	Texas A&M Texas Transportation Institute VMT for 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
Fuel Cycle	Emissions generated by extracting, shipping, refining, and delivering fuels.	EPA Multiplier of Operational Emissions (1.27 or 27%)
Conversion of CO_2 to CO_2E	EPA conversion factor for CO_2 to CO_2E, from Greenhouse Gases Equivalencies Calculator–Calculations and References for Mobile Sources	EPA Multiplier for CO_2 to CO_2E: (CO_2, CH_4, and N_2O)/0.986 CO_2

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

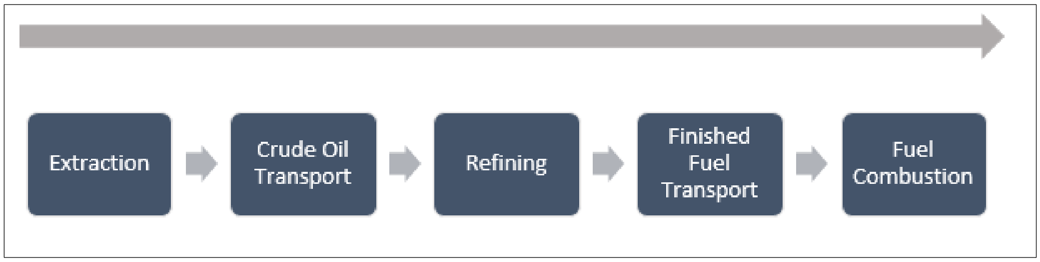
- Carbon dioxide (CO_2) was estimated. TxDOT converted this to CO_2E and added fuel-cycle emissions by using the EPA multipliers listed in **Table A-1**.
- The emissions factor model used in developing inventories for this task was the most recent version of the EPA's MOVES on-road emissions model: MOVES2014.
- Emissions inventories were developed for each of the 254 Texas counties.
- The analysis years include 2010 to 2040.
- MOVES default weekday average speed distributions were used.
- Temperature and humidity inputs used were provided by TCEQ.
- The VMT mixes were consistent with the EPA MOVES source use types (SUTs).
- Locality-specific MOVES vehicle age distributions input for historical and future years were based on available and suitable local vehicle registration data in conjunction with MOVES default age distributions as needed.

- The level of detail for the development methodology in the final emissions estimates was aggregate emissions by county and vehicle class, based on 24-hour HPMS activity.
- Fuel parameter inputs were used as defined in the CFR Title 40–Protection of the Environment, Part 80–Regulation of Fuels and Fuel Additives, Section 27–Controls and Prohibitions on Gasoline Volatility. Federal- and state-regulated summer Reid Vapor Pressure (RVP) levels were modeled consistent with assumptions allowed for refiner compliance safety margins.
- The effects of the oxygenated fuel program for El Paso County were modeled.
- Federally regulated gasoline and diesel sulfur levels were modeled.
- Reformulated gasoline (RFG) was modeled for the four Dallas-Fort Worth (DFW) and the eight Houston-Galveston-Brazoria (HGB) ozone nonattainment counties, which use RFG.
- The effects of all the federal motor vehicle control programs that are included as defaults in the MOVES model were modeled.
- The Austin-Round Rock, DFW, HGB, and El Paso County inspection and maintenance (I/M) programs were modeled.
- VMT by county was forecast for future years using historical TxDOT VMT data and U.S. Census Bureau population statistics and projections, consistent with the current practice for virtual-link applications. The VMT projections vary from 1.13% to 1.76% per year.
- Year-specific Texas Low Emissions Diesel (TxLED) adjustment factors were developed using the reduction benefit information described in EPA's Memorandum on Texas Low Emission Diesel Fuel Benefits.
- The activity and fleet characterization tables included: VMT; VMT distributions (monthly, day-of-the-week, hourly); source type populations; and source type age distributions.

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 the vast majority of proposed projects, which prohibits the ability to accurately analyze free flow and congestion emissions of project-level build and no-build scenarios. A qualitative discussion on congestion trends is provided in the GHG analysis section.

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 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 Approach

A qualitative assessment was completed to evaluate the potential vulnerability of the Texas on-road transportation system to potential climate change impacts, typically projected between the years 2070 to 2100, unless otherwise specified. Shorter-term projections (including for the period of the TxDOT long-range transportation plan through 2040) were not consistently available among the data reviewed. The analysis incorporates available information on historic and projected climate change impacts for the state of Texas (**Section 6.2**). Data was reviewed from several sources, including: the 2014 NCA; USGS National Climate Change Viewer; the Assessments from the IPCC; NOAA Global and Regional Sea Level Rise Scenarios; USACE Procedures to Evaluate Sea Level Change; and the TxWRAP. It should be noted that **Section 8** discusses several major sources of uncertainty inherently included in the data source projections regarding climate change, such as the effects of natural variability, future human emissions, sensitivity to GHG emissions, and natural climate drivers.

The climate change projections used herein were based on RCPs. RCPs are GHG concentration trajectories used for climate modeling and research and are based on assumptions relating to the level of GHG emissions now and into the future. The high and low CO_2E concentration RCP options were chosen for the TxDOT analysis. RCP8.5 (high emissions estimated to be approximately 1370 parts per million [ppm] CO_2E in 2100) is a business as usual case with little to no additional worldwide GHG control measures. RCP4.5 (low emissions estimated to be approximately 650 ppm CO_2E in 2100) refers to a high level of GHG controls recommended to keep temperature rise below 2^{o} C in 2100.

Where information was available in the data reviewed, the current state of each climate stressor was disclosed, and then low and high future projections based upon RCP4.5 and RCP8.5 were summarized for the state of Texas (**Section 6.2**). This includes evaluating how climate stressors may impact the transportation system design, maintenance or operation and identifying the transportation system vulnerability to those stressors. Considerations of resiliency and adaptation are addressed through a combination of: existing and evolving state and local transportation planning activities, TxDOT asset management, TxDOT design standards, TxDOT maintenance programs, the TxDOT Design Manual, the TxDOT Maintenance Manual, and ongoing state and national technical research (**Section 6.3**).

Appendix B: Glossary

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 a number of 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). CAFE was enacted by Congress 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 against which other greenhouse gases are measured. (IPCC).

Carbon dioxide (CO_2) equivalent Greenhouse gas emissions are often measured in carbon dioxide (CO_2) equivalent. To convert emissions of a gas into CO_2 equivalent, its emissions are multiplied by the gas's global warming potential (GWP). The GWP takes into account 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 period of time 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). Climate change may be caused by natural internal processes or external forcing or by persistent anthropogenic changes in the composition of the atmosphere or land use. (IPCC).

Climate stressor 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 stressor for forests and crops. Rising sea level is another climate stressor. (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 found all over 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).
Emissions	The term used to describe the gases and particles which are put into the air or emitted by various sources. (EPA).
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. The Environmental Protection Agency’s (EPA’s) lifecycle analysis includes significant indirect emissions as required by the Clean Air Act. (EPA).
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 as a result of 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).
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	A process which warms the Earth’s atmosphere due to the absorption of radiation energy by several trace gases. These greenhouse gases allow solar radiation to reach the Earth’s surface but then absorb the energy as it is redeemed as infrared radiation, acting to contain the heat within the atmosphere. This occurs naturally and is increased by human activity. (NOAA).
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).

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 different 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.
Reasonably foreseeable effects	Under NEPA, reasonably foreseeable effects include effects that are likely to occur or probable, rather than those that are merely possible. (FHWA).
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).

Appendix C: Abbreviations and Acronyms

CAFE	Corporate Average Fuel Economy
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
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
ERLT	Emissions Rate Lookup Table
FAST	Fixing America's Surface Transportation Act
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
GCM	General circulation model
GHG	Greenhouse gas
GWP	Global warming potential
HGB	Houston-Galveston-Brazoria
HPMS	Highway Performance Monitoring System
HURDAT	Atlantic Hurricane Database
IPCC	Intergovernmental Panel on Climate Change
I/M	Inspection and maintenance
JCAP	Joint Center for Artificial Photosynthesis
LED	Light emitting diode
LRTP	Long Range Transportation Plan
MAP-21	Moving Ahead for Progress in the 21^{st} Century Act
MMT	Million metric tons
MOVES	Motor Vehicle Emissions Simulator

MPO	Metropolitan Planning Organization
NCA	National Climate Assessment
NCTCOG	North Central Texas Council of Governments
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
N_2O	Nitrous oxide
ppm	Parts per million
RAP	Recycled asphalt pavement
RAS	Recycled asphalt shingles
RCP	Representative Concentration Pathways
RFG	Reformulated gasoline
RVP	Reid Vapor Pressure
SUT	Source use type
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
TTC	Texas Transportation Commission
TTI	Texas A&M Texas Transportation Institute
TxDOT	Texas Department of Transportation
TxLED	Texas Low Emissions Diesel
TxWRAP	Texas A&M Wildfire Risk Assessment Portal
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