Development of Oil and Gas Mobile Source Inventory in the Barnett Shale in the 12-County Dallas-Fort Worth Area

Texas Commission on Environmental Quality Grant Number: 582-11-13174

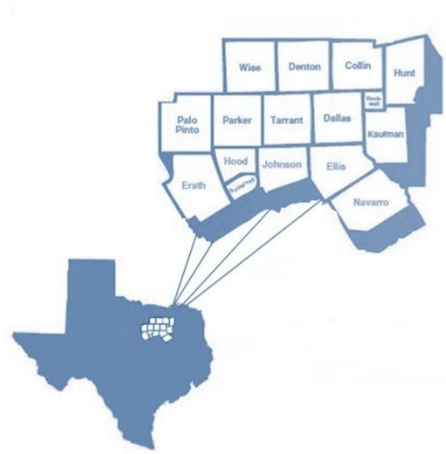
Final Report

North Central Texas Council of Governments
August 2012

What is NCTCOG?

The North Central Texas Council of Governments is a voluntary association of local governments established in 1966 to assist local governments in planning for common needs, cooperating for mutual benefit, and coordinating for sound regional development. NCTCOG's purpose is to strengthen both the individual and collective power of local governments and to help them recognize regional opportunities, eliminate unnecessary duplication, and make joint decisions.

NCTCOG serves a 16-county region of North Central Texas, which is centered on the two urban centers of Dallas and Fort Worth. Currently, NCTCOG has 240 member governments including 16 counties, 170 cities, 24 school districts, and 30 special districts.



Abstract

TITLE:	Development of Oil and Gas Mobile Source Inventory in the Barnett Shale in the 12-County Dallas-Fort Worth Area
DATE:	August 2012
AUTHORS:	Lori Clark Principal Transportation Planner Shannon Stevenson Program Manager Chris Klaus Senior Program Manager
SUBJECT:	Oil and Gas Mobile Source Emissions Inventory
SOURCES OF COPIES:	Transportation Department North Central Texas Council of Governments P.O. Box 5888 Arlington, Texas 76005-5888 (817) 640-3300
NUMBER OF PAGES:	47
ABSTRACT:	The North Central Texas Council of Governments developed an emissions inventory for on-road mobile sources serving the oil and gas industry operating in the Barnett Shale. Emissions were estimated for three analysis years: 2006, 2012, and 2018 for the 12-county Metropolitan Planning Area, which includes Collin, Dallas, Denton, Ellis, Hood, Hunt, Johnson, Kaufman, Parker, Rockwall, Tarrant, and Wise counties. This work will aid the Texas Commission on Environmental Quality in refining emissions inventories used in State Implementation Plan development and planning for potential future control measures.

Acknowledgements

The authors would like to thank the following individuals for their invaluable assistance in preparing this report.

Michael Morris, P.E.	Director of Transportation
Dan Kessler	Assistant Director of Transportation
Arash Mirzaei, P.E.	Transportation System Modeling Manager
Jenny Danieau	Senior Transportation Planner
Jody Loza	Air Quality Operations Analyst III
Kathleen Yu	Senior Transportation System Modeler
Behruz Paschai	Transportation System Modeling Manager
Hua Yang	Transportation System Modeler II
Zhen Ding	Transportation System Modeler II
Syeda Haque	Transportation System Modeler I
Roxann Nayar	Transportation Planner II
Cecile Grady	Administrative Assistant II
Cecilia Howard	Administrative Assistant II
Lisa Key	Administrative Assistant II
Peter Ogbeide	Texas Commission on Environmental Quality, Project Manager
Cesar Quiroga, P.E.	Senior Research Engineer and Manager, Texas Transportation Institute
Yingfeng (Eric) Li, Ph.D.	Assistant Research Scientist, Texas Transportation Institute
Darren Groth, AICP, REP	Gas Well Administrator, City of Denton

The North Central Texas Council of Governments (NCTCOG) would also like to thank operator and trucking contractor companies who responded to NCTCOG surveys and provided insight into the oil and gas industry, including Anchor Trucking, LLC; Mr. Bill Woodward of Buena Vista Transportation, Inc.; Mr. Brian Boerner of Chesapeake Energy Corporation; L&R Tank Trucks, Inc.; Lonestar Ranch & Outdoors; Superior Well Services; Thurman Transportation, Inc.; and Mr. Troy Rockey.

Table of Contents

List of Exhibits

Glossary of Abbreviations

CAAA	-	Clean Air Act Amendments
CBD	-	Central Business District
Chesapeake	-	Chesapeake Energy Corporation
CO	-	Carbon Monoxide
CO_2	-	Carbon Dioxide
DFW	-	Dallas-Fort Worth
DFX	-	Dallas-Fort Worth Regional Travel Model for the Expanded Area
EPA	-	Environmental Protection Agency
GPS	-	Geographic Positioning System
HDDV	-	Heavy-Duty Diesel Vehicle
IH	-	Interstate Highway
LBS	-	Pounds
MOVES	-	MOtor Vehicle Emission Simulator
MPA	-	Metropolitan Planning Area
MPO	-	Metropolitan Planning Organization
NAAQS	-	National Ambient Air Quality Standards
NCT	-	North Central Texas
NCTCOG	-	North Central Texas Council of Governments
NO_X	-	Nitrogen Oxides
O&G	-	Oil and Gas
PM	-	Particulate Matter, 10 microns
SIP	-	State Implementation Plan
SWD	-	Saltwater Disposal Well
TCEQ	-	Texas Commission on Environmental Quality
RRC	-	Texas Railroad Commission/Railroad Commission of Texas
TPD	-	Tons per Day
TPY	-	Tons per Year
TSZ	-	Traffic Survey Zone
TxDMV	-	Texas Department of Motor Vehicles
TxDOT	-	Texas Department of Transportation
VMT	-	Vehicle Miles of Travel
VOC	-	Volatile Organic Compounds

Executive Summary

Under this contract, the North Central Texas Council of Governments (NCTCOG) staff completed a study to improve the accuracy of activity and emissions estimates for on-road mobile sources serving the Barnett Shale natural gas exploration and production industry. The scope of the study included the 12-county NCTCOG Metropolitan Planning Area (MPA), which includes Collin, Dallas, Denton, Ellis, Hood, Hunt, Johnson, Kaufman, Parker, Rockwall, Tarrant, and Wise counties, and is limited to heavy-duty diesel vehicles (HDDVs) which perform work or deliver materials to the sites. Results can be used by the Texas Commission on Environmental Quality to refine State Implementation Plan (SIP) modeling and inform assessment of control strategies, and can also used by NCTCOG in developing future emissions inventories. The information provided from this project will advance current knowledge of the activities and emissions for heavy-duty trucks hauling equipment, water, and other material to and from well sites. This improved understanding will provide insight into possible emission control measures.

The Barnett Shale is a large natural gas reserve which encompasses more than 5,000 square miles and provides approximately six percent (6%) of all domestic natural gas (1). The shale also stretches across 20 counties in North Central Texas. Since the advent of horizontal drilling, coupled with hydraulic fracturing processes, production activity in the Barnett Shale area has experienced substantial growth. Within the NCTCOG MPA, significant production occurs within Denton, Johnson, Hood, Parker, Tarrant, and Wise counties. Between 2006 and 2012, the number of completed wells in these six counties grew from approximately 5,900 to approximately 14,700 (2). The growth in drilling and well production activity has led to an increase in trucking activity required to support the oil and gas (O&G) industry.

NCTCOG collected data from a variety of sources, including existing research/studies; the Texas Railroad Commission; the Texas Department of Motor Vehicles; surveys distributed to both natural gas operators (e.g. Chesapeake Energy) and trucking contractors working in the Barnett Shale; and phone calls, meetings, and site visits with industry participants.

NCTCOG staff developed an on-road mobile source emissions inventory for three analysis years: 2006, 2012, and 2018. To accomplish this, two major tasks were undertaken: quantification of HDDV activity in terms of vehicle miles of travel (VMT), and quantification of emissions based upon the Environmental Protection Agency (EPA) MOtor Vehicle Emission Simulator (MOVES) model. Truck VMT was quantified in two ways. For water trucks, which serve gas wells throughout the production phase, NCTCOG staff developed a synthetic module of the Dallas-Fort Worth Regional Travel Model for the Expanded Area through which truck traffic VMT was modeled by routing trips from gas wells (origins) to saltwater disposal wells (destinations) using a multiple shortest path methodology. However, this approach was not appropriate for truck trips that occurred during the drilling and completion phases, as these phases are high-intensity but short duration. NCTCOG developed a post-process equation to quantify this VMT. Results of truck activity estimation are outlined in Exhibit 1.

Exhibit 1: Estimated Daily Oil and Gas Truck VMT

Analysis Year	2006	2012	2018
Drilling Phase	2,466	411	411
Completion Phase	7,875	1,313	1,313
Production Phase	50,915	103,457	103,508
Total Daily VMT	**61,256**	**105,181**	**105,232**

In 2012, total VMT associated with drilling and completion phases is significantly lower than that experienced in 2006. This is due to the fact that the rate at which new O&G wells are being drilled in the Barnett Shale is much lower in 2012 than it was in 2006. However, between these two years, there was significant growth in the number of wells completed. Total VMT associated with the production phase grew accordingly and leads to an increase in overall VMT. Analysis year 2018 is presumed to be largely the same as 2012 as most assumptions about future activity rates were held constant from 2012.

The second major task was development of an emissions inventory for this on-road mobile source activity. Per the contract, five pollutants were quantified: nitrogen oxides (NO_X), volatile organic compounds (VOCs), carbon monoxide (CO), particulate matter (PM), and carbon dioxide (CO_2). To complete this task, NCTCOG staff again pursued two processes. First, emissions associated with VMT estimates were completed by multiplying miles traveled by emission factors produced using the EPA MOVES 2010a model. Second, staff estimated emissions associated with extended idling that occurs during loading and unloading of cargo, such as equipment, water, or sand. Idling emissions for VOCs and CO were quantified based upon MOVES 2010a emission factors adjusted to reflect emissions in grams per hour. However, idling-specific emission rates were available or calculated for NO_X, PM, and CO_2 based upon EPA sources. As these rates are more truly reflective of idle time and required no adjustment, they were considered preferable to MOVES emission factors for these three pollutants. Exhibit 2 illustrates total estimated emissions for on-road HDDVs serving the Barnett Shale O&G industry. Note that due to rounding, daily and annual numbers may appear to vary slightly.

Exhibit 2: Estimated Daily and Annual Oil and Gas Truck Emissions

Pollutant	NO_X (lbs/day)	VOC (lbs/day)	CO (lbs/day)	PM (lbs/day)	CO_2 (lbs/day)
Analysis Year 2006					
Drilling Phase	87.39	4.95	66.43	6.50	12,381.75
Completion Phase	279.08	15.80	212.13	20.77	39,541.30
Production Phase	1,749.49	101.30	1,356.31	128.58	251,027.40
Extended Idling	2,967.28	473.89	2,953.43	78.96	177,068.02
Total Emissions	**5,083.24**	**595.94**	**4,588.30**	**234.82**	**480,018.47**
Total Emissions (tpd)	**2.54**	**0.30**	**2.29**	**0.12**	**240.01**
Total Emissions (tpy)	**927.69**	**108.76**	**837.36**	**42.85**	**87,603.37**

Pollutant	NO_X (lbs/day)	VOC (lbs/day)	CO (lbs/day)	PM (lbs/day)	CO_2 (lbs/day)
Analysis Year 2012					
Drilling Phase	7.20	0.45	5.36	0.45	2,117.69
Completion Phase	22.99	1.45	17.12	1.45	6,762.86
Production Phase	1,760.11	112.46	1,332.99	109.64	528,394.08
Extended Idling	6,346.73	753.98	4,224.07	140.79	521,733.90
Total Emissions	**8,137.03**	**868.35**	**5,579.54**	**252.33**	**1,059,008.52**
Total Emissions (tpd)	**4.07**	**0.43**	**2.79**	**0.13**	**529.50**
Total Emissions (tpy)	**1,485.01**	**158.47**	**1,018.27**	**46.05**	**193,269.06**
Analysis Year 2018					
Drilling Phase	1.55	0.08	0.47	0.09	1,094.75
Completion Phase	4.96	0.25	1.51	0.28	3,496.10
Production Phase	380.40	19.25	117.61	21.71	274,691.55
Extended Idling	3,951.70	144.92	598.12	43.28	521,733.90
Total Emissions	**4,338.61**	**164.50**	**717.71**	**65.36**	**801,016.30**
Total Emissions (tpd)	**2.17**	**0.08**	**0.36**	**0.03**	**400.51**
Total Emissions (tpy)	**791.80**	**30.02**	**130.98**	**11.93**	**146,185.47**

lbs/day = pounds per day tpd = tons per day tpy = tons per year

As illustrated in Exhibit 2, approximately 4.07 tons per day (tpd) NO_X can be attributed to HDDVs serving this industry in 2012, based on the results of this study. The majority of these emissions can be attributed to extended idling activity which occurs during loading and unloading of cargo, such as water. Between 2006 and 2012, overall emissions increase; this is due to increases in emissions from extended idling activity as well as VMT-related emissions during the production phase. It should be noted that this increase in total emissions occurred despite anticipated fleet turnover which results in use of lower emission factors in 2012. Emissions from the drilling and completion phases declined, which reflects the decline in overall activity. It should also be noted that since assumptions regarding activity rates from 2012 were held constant to 2018, the reduction in emissions in 2018 is reflective of lower emission factors based upon fleet turnover.

NCTCOG developed the on-road mobile source emission inventory for the Dallas-Fort Worth ozone nonattainment area, which the Texas Commission on Environmental Quality combined with emission inventories for other sectors to develop the total emissions inventory used in the Dallas-Fort Worth Attainment Demonstration SIP Revision for the 1997 8-Hour Ozone Standard Nonattainment Area. This SIP Revision indicates that the total NO_X emissions inventory for the Dallas-Fort Worth nonattainment area in 2012 is 370 tpd. Therefore, the addition of these emissions in 2012 would increase the total NO_X emissions inventory by one percent (1%), and increase the on-road emissions inventory by approximately two percent (2%). For comparison, diesel transit buses and diesel school buses contribute approximately 2.68 tpd and 3.27 tpd NO_X, respectively (3).

It should be noted that numerous assumptions were made throughout the study due to unavailable data. It is NCTCOG's standard practice in developing emission inventories to be conservative in developing estimates unless data is available to suggest otherwise. Therefore, the emission estimates in Exhibit 2 are likely conservative. Several opportunities exist to refine key data assumptions that could impact the overall emissions inventory.

Chapter 1: Introduction

Oil and gas (O&G) exploration and development have increased significantly in recent years. By 2012, approximately 14,700 completed oil and gas wells existed within the western portion of the North Central Texas Council of Governments (NCTCOG) Metropolitan Planning Area (MPA), including in Denton, Hood, Johnson, Parker, Tarrant, and Wise counties. As the O&G industry has grown, concerns have arisen about the potential impacts of associated truck traffic to both the roadway system and regional air quality.

This report documents the methodology and results of the development of an emissions inventory for on-road mobile sources, or truck traffic, serving the O&G industry in the Barnett Shale. Chapter 1 of this report provides an overview of the North Central Texas region, the Barnett Shale, study objectives, and relationships between this study and other completed or ongoing research. Chapter 2 describes different phases involved in Barnett Shale exploration and production and the characteristics of truck traffic involved in each phase.

Chapter 3 details the process utilized to develop vehicle miles of travel estimates by phase, which fulfills the objective of refining on-road mobile source activity estimates. Mileage estimates by phase are also included. Emissions estimation and results are provided in Chapter 4. Chapter 5 discusses accomplishments and limitations of this study. NCTCOG provides recommendations for further study or research in Chapter 6. Appendices provide detail on various input parameters, calculations, and results.

1.1 Background

1.1.1 Air Quality in North Central Texas

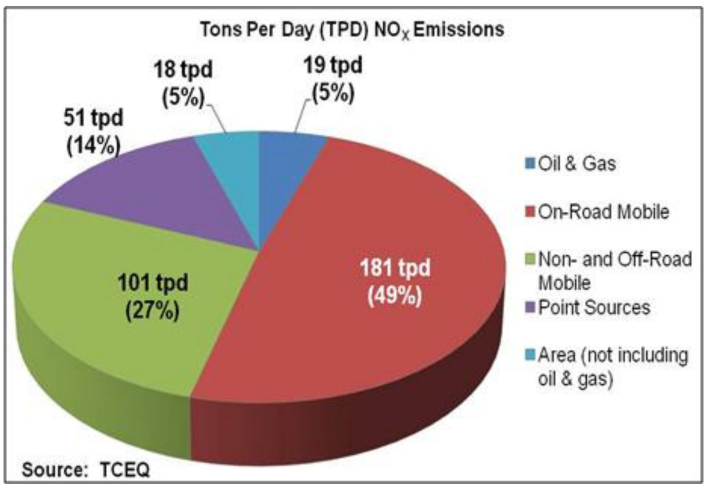
The Clean Air Act Amendments of 1990 (CAAA) require the Environmental Protection Agency (EPA) to set National Ambient Air Quality Standards (NAAQS) for widespread pollutants considered harmful to public health and the environment. The EPA has set NAAQS for six principal pollutants: Ozone (O_3), Particulate Matter (PM), Carbon Monoxide (CO), Sulfur Dioxide (SO_2), Nitrogen Oxides (NO_X), and Lead (Pb).

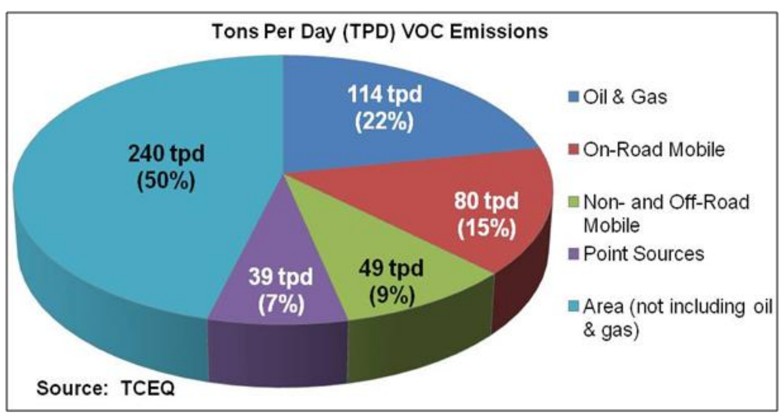
When the CAAA were signed into law, Collin, Dallas, Denton, and Tarrant counties were designated as nonattainment under the 1-Hour NAAQS for the pollutant ozone. Upon completion of a scientific review of the 1-Hour NAAQS, the EPA determined that this standard was insufficient to protect human health. As a result, the EPA developed the 1997 8-Hour NAAQS to place greater emphasis on prolonged exposure to pollutants. In 2004, under this more stringent standard, the Dallas-Fort Worth nonattainment area expanded to include nine counties: Collin, Dallas, Denton, Ellis, Johnson, Kaufman, Parker, Rockwall, and Tarrant counties. These nine counties received a “Moderate” ozone classification, which gave the region until June 15, 2010 to reach attainment. As a result of not reaching attainment by June 2010, the North Central Texas region was classified as “Serious” with a new attainment date of June 2013.

In 2008, the EPA again revised the ozone NAAQS to enact a stricter standard based upon newer scientific evidence. As in 2004, this stricter standard resulted in an expansion of the nonattainment area in North Central Texas. On July 20, 2012, the EPA designated Collin, Dallas, Denton, Ellis, Johnson, Kaufman, Parker, Rockwall, Tarrant, and Wise counties as "Moderate" nonattainment under the 2008 8-Hour NAAQS for ozone with an attainment date of December 2018.

Under the CAAA, the Texas Commission on Environmental Quality (TCEQ) is required to develop a State Implementation Plan (SIP) detailing how the nonattainment area will achieve the NAAQS. The SIP contains a collection of regulations and measures to reduce emissions from stationary, area, and mobile (both on- and non-road) sources in an effort to demonstrate attainment of the air quality standards. Exhibit 1.1 outlines emissions accounted for in the Dallas-Fort Worth Attainment Demonstration SIP Revision for the 1997 8-Hour Ozone Standard Nonattainment Area as adopted by TCEQ on December 7, 2011 (3).

Exhibit 1.1: Emissions Inventory from the Dallas-Fort Worth Attainment Demonstration SIP Revision for the 1997 8-Hour Ozone Standard Nonattainment Area





Accurate emission inventories are critical for planning purposes if areas are to attain and then maintain the NAAQS established by the EPA under the CAAA. TCEQ typically funds mobile source inventory and control strategy research and development work in support of attaining the NAAQS. Texas emission inventory assessment work includes inventory development, methodology updates, data gathering, analysis and assessment, and planning for future requirements to develop highly detailed on-road mobile inventories to meet EPA reporting requirements and to support SIP development.

For this study, vehicle emissions have been generated from the newly released EPA model, the MOtor Vehicle Emission Simulator (MOVES), as it will soon replace the current MOBILE6 model and will, therefore, be the required tool for estimating emissions from on-road vehicles (4), (5). Based on analysis of emission test results and considerable advances in understanding of vehicle emissions, the EPA has determined that MOVES is the best available tool for quantifying criteria pollutant and precursor emissions, as well as for other emissions analysis of the transportation sector. Fleet characteristics and activity data collected on heavy-duty vehicles operating in the Dallas-Fort Worth Barnett Shale area can be used to update inputs to current emissions and activity models in MOVES.

1.1.2 Oil and Gas Production in the Barnett Shale

The Barnett Shale is a large natural gas reserve that encompasses more than 5,000 square miles and provides approximately six percent (6%) of domestic natural gas (1). This shale formation stretches across 20 North Central Texas counties. Since horizontal drilling and hydraulic fracturing technologies have become economically viable, production activity in the Barnett Shale area has experienced substantial growth. In addition to growth in the number of gas wells located in the North Central Texas area, there has been an increase in the number of saltwater disposal wells (SWDs) drilled to accommodate disposal of produced water.

Within the NCTCOG MPA boundary, six counties have significant Barnett Shale production: Denton, Hood, Johnson, Parker, Tarrant, and Wise counties. Throughout this report, these counties will be referred to as “Barnett Shale counties within the MPA”. Exhibits 1.2 and 1.3 illustrate the expansion of O&G drilling activity, as well as the growth in SWD sites, in the NCTCOG MPA between study analysis years 2006 and 2012.

As drilling activity has increased, the amount of truck activity that serves these well sites has also increased. NCTCOG staff began to notice a change in truck activity in the western portion of the MPA by observing historical changes in vehicle mix composition through Texas Department of Transportation (TxDOT) vehicle classification data (6). Vehicle classification data is used in combination with overall volumes to develop a percent of vehicle types. A vehicle classification report is published annually, generally at the end of the fiscal year. This report summarizes the number of vehicles by type at each count location.

Exhibit 1.2: 2006 Oil and Gas Activity in the NCTCOG Metropolitan Planning Area

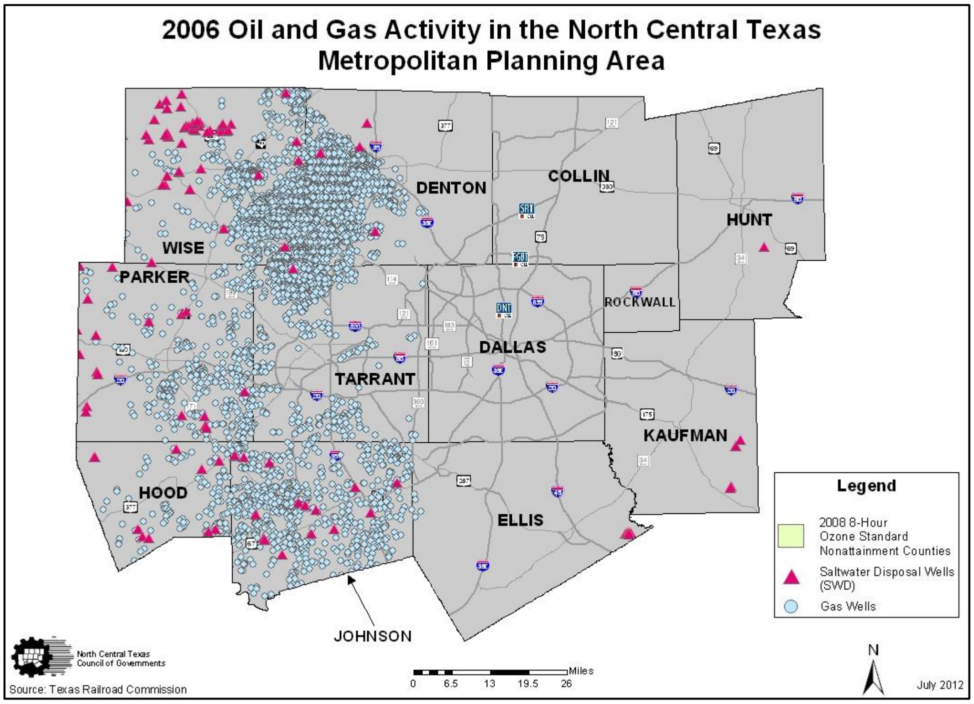
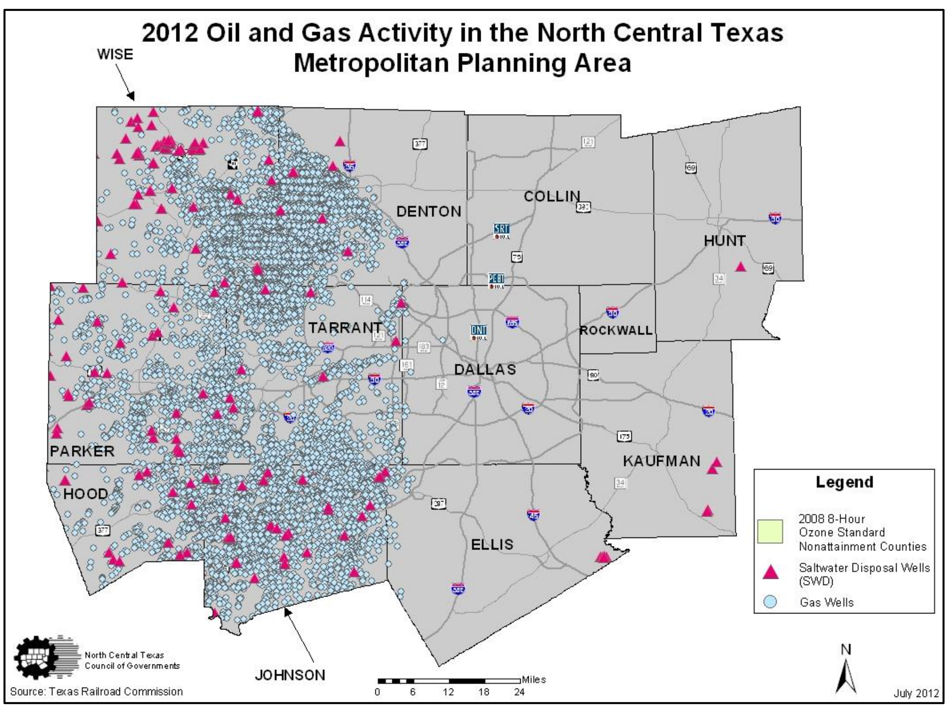


Exhibit 1.3: 2012 Oil and Gas Activity in the NCTCOG Metropolitan Planning Area

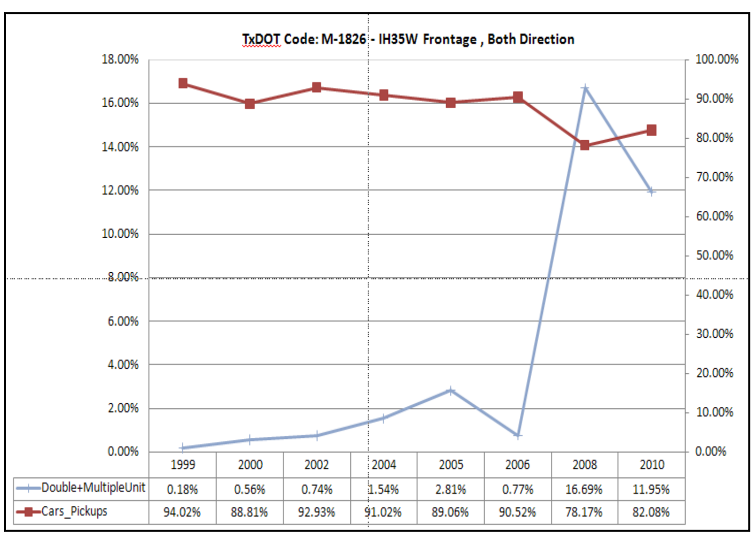


Vehicle classification data locations are limited. However, NCTCOG staff compared a sample of these vehicle classification data locations from different years and found that from around the 2005 timeframe, certain data collection points within the Barnett Shale area have recorded significant increases in trucks. For example, numerous SWDs are situated along Interstate Highway (IH) 35W in Johnson County near Alvarado, Texas. The following image provides an aerial view of an active SWD in this area.

SWD along IH 35W, Southwest Quadrant of IH 35W and County Road 405E

TxDOT also has a vehicle classification data location located in this area on IH 35W. Exhibit 1.4 provides results for this particular location, which show that the share of double and multiple unit trucks increased significantly from less than two percent (2%) in 2004 to a high of 16.7 percent (16.7%) in 2008. Although this statistic on its own cannot be conclusively tied to the O&G industry, it does underscore that something in this area has driven a significant growth in these types of vehicles during this time, which warrants further investigation.

Exhibit 1.4: Traffic Counts at TxDOT Data Location M-1826, IH 35W Frontage near CR 602



	1999	2000	2002	2004	2005	2006	2008	2010
Double+MultipleUnit	0.18%	0.56%	0.74%	1.54%	2.81%	0.77%	16.69%	11.95%
Cars_Pickups	94.02%	88.81%	92.93%	91.02%	89.06%	90.52%	78.17%	82.08%

Truck activity has been of growing concern due largely to the volume and weight of loads being carried on roads which are often not designed to support this magnitude and weight of traffic. Significant damage has been reported and observed on roadways that lead to Barnett Shale drilling sites, as depicted by the image below. TxDOT has estimated that the unanticipated maintenance need is up to $2 billion (7).

Pavement Damage
on Levy County Line Road

In addition to concerns over damage to roadways and pavement, there is speculation that the increase in heavy-duty truck traffic associated with this industry is contributing additional ozone-forming emissions in the Dallas-Fort Worth ozone nonattainment area which, to date, would not have been accurately accounted for in past emissions estimates due to rapid growth of the industry.

1.2 Objectives

Through this study, NCTCOG committed to improve the accuracy of on-road activity and emissions estimates of the Dallas-Fort Worth nonattainment area due to the O&G development in the Barnett Shale. Results can be used by TCEQ to develop SIP modeling and assessment of control strategies and used by NCTCOG in developing emissions inventories in the future. Information provided from this project will advance current knowledge of the activities and emissions for heavy-duty trucks hauling equipment and material to and from well sites. An improved understanding of activity and emissions rates will provide insight into possible emission control techniques. It should be noted that this study is limited to heavy-duty diesel vehicles (HDDVs) and does not include light- and medium-duty vehicles that visit well sites for administrative purposes or which provide transport to site workers.

NCTCOG serves as the Metropolitan Planning Organization for transportation in the Dallas-Fort Worth area and is responsible for developing and maintaining on-road mobile source emission inventories for the region. Traditionally, NCTCOG has assisted TCEQ with on-road emission inventory development activities that include inventory production; methodology updates; data gathering, analysis, and assessment; and planning for future requirements.

1.3 Relationship to Other Research

Much research has been devoted to the topic of natural gas exploration and production in recent years, particularly in regard to natural gas which is recovered through use of hydraulic fracturing processes. A relatively small subset of this research has been directed at the issue of truck traffic associated with the O&G industry. One key study, *Energy Developments and the Transportation Infrastructure in Texas: Impacts and Strategies,* was recently completed by the Texas Transportation Institute (TTI) under contract with TxDOT (8). This research focused on characterizing pavement impacts associated with heavy truck activity traveling among various energy industry facilities, including gas wells and SWDs. As a part of this study, TTI estimated the number of truck trips associated with various phases of natural gas exploration and production. TTI truck trip estimates were a key data point for use or corroboration of trip estimates used in this study, which is considered to be a complementary effort by furthering the discussion of truck activity to include emissions.

In addition, NCTCOG followed TTI methodology to estimate the total volume of produced water which a water truck could carry to an injection/disposal well; this volume was used to estimate a maximum number of truck trips, or capacity cap, which may be allowed to travel to a given site (9). However, the capacity cap was ultimately not utilized in this particular study as it was determined that the number of trips assigned to a given SWD by the synthetic module of the Dallas-Fort Worth Regional Travel Demand Model for the Expanded Area was less than the proposed capacity caps.

Chapter 2: Characterization of Barnet Shale Mobile Sources

Gas wells in the Barnett Shale typically come into being through three major phases. In all phases, HDDVs are involved in bringing equipment and materials to and from the well site. This chapter provides a brief overview of the major steps associated with each phase, estimated duration, and estimated number of truck trips by phase. It should be noted that the scope of this study is limited to heavy-duty trucks that perform work or make deliveries to well sites and SWDs; light- and medium-duty vehicles that serve administrative functions or belong to employees working at the sites are not included.

2.1 Information Sources

To develop estimates of truck activity by phase, NCTCOG staff gathered data from multiple sources including existing research, literature, and presentations; the Texas Railroad Commission (RRC); visits to Chesapeake Energy well sites and SWDs; and conversations, emails, and phone calls with industry participants. NCTCOG staff also developed two surveys for the industry.

2.1.1 Operator Survey

NCTCOG developed one survey for O&G operators, such as Chesapeake Energy Corporation (Chesapeake). The survey for operators was designed to gather information primarily on the number of wells drilled and hydraulically fractured in 2011 and the frequency of truck trips by phase for those operators' facilities. Questions included items such as the number of wells drilled in 2011, number of wells frocked in 2011, number of trucking contractors hired, and an estimate of the number of daily truck trips to a single well site by phase, etc. Contacts were sourced from the RRC Oil and Gas Directory (10). More than 150 operator surveys were sent, but only eight responses were received by June 2012. Therefore, it was difficult for staff to rely on this data as representative of the industry. The information from the surveys was used largely to corroborate data available from other reports or sources. A blank copy of this survey and summary of responses is included in Appendices A and C.

2.1.2 Truck Contractor Survey

A second survey was developed for trucking contractors that serve the industry (e.g. Alan Ritchey, Anchor Trucking, LLC, etc.). The truck contractor survey focused more on truck fleet characteristics and operating patterns. Questions included items such as type of material hauled, counties in which operations occurred, number of trucks in fleet, age of trucks, typical shift start and end times, and names of SWDs visited, as applicable. A contact list was obtained through a public records request for oversize-overweight permit data for trucks operating in Denton, Johnson, Parker, and Tarrant counties who were also hauling divisible loads, as Texas Department of Motor Vehicle (TxDMV) staff indicated that companies meeting these criteria were likely working in the Barnett Shale. As with the operator survey, only a small proportion of surveys were returned. As of June 2012, NCTCOG staff had received only 30 surveys out of more than 1,000 that were sent. Again, this caused difficulty in utilizing survey data for analysis due to concerns over whether the data could be considered representative of the entire industry, particularly as the 30 responses were divided among different types of service providers (water haulers, sand haulers, equipment carriers, etc.) who have different types of operation. Consequently, this data was also used primarily to corroborate information found in other sources. A copy of the survey and summaries of responses received are included in Appendices B and C.

2.2 Regional Activity Rates

Several existing sources express activity rates in terms of trips, trucks, or days per location. To develop a regional emissions inventory, NCTCOG staff first had to determine how many locations would be expected to generate this activity in a single day or year. To develop this estimate, NCTCOG utilized reports of how many unique rigs were located in the six Barnett Shale counties within the MPA. In June 2006, a total of 179 unique rigs were reported in these counties (11). From this total, staff estimated that approximately six sites were drilled throughout the region each day. This is considered to be a conservative count, as it is possible that one rig drilled multiple sites within the same county in that month, but would only be reported once unless it crossed county lines.

A similar exercise was undertaken to estimate the number of sites drilled region wide during 2012. NCTCOG staff reviewed three consecutive weeks of Fort Worth Star-Telegram Rig Reports from June to July 2012 (12). Based upon this information, it was estimated that approximately one site is drilled per day within the six-county region.

Future drilling activity is difficult to predict, as activity varies with the price of natural gas, supply availability in other shale formations in the country, and various other factors. Therefore, it is not appropriate to forecast future drilling activity. For 2018, NCTCOG staff held the number of sites drilled at one per day region wide, consistent with the 2012 estimate. This approach follows the standard process used in regional emission inventories for SIPs and transportation conformities. Conformity regulations require use of the most recent planning assumptions in force at the time the analysis begins (13). Use of future forecasts is based on the Interagency Consultation Group's discretion. To ensure future emission inventories are based on most sound assumptions, many future year datasets are held constant to latest observed data. This ensures minimal manipulation and maintains a level of credibility to future emission estimates as it is impossible to determine how future parameters will trend. Likewise, due to current volatility of the O&G industry, it is impossible to accurately and precisely understand what operations will be in 2018. Therefore, in keeping with standard practice for development of emission inventories for a variety of purposes, the latest observed drilling activities available at the time of this study will be appropriately incorporated.

2.3 Drilling Phase

Drilling is by far the most visible phase in the life of a natural gas well. Since the growth of O&G activity in the Barnett Shale region, images similar to the photograph below have become a familiar sight for many North Central Texas area residents. Major steps in this phase include preparation of the well site, delivery and assembly of rig equipment, drilling of the wellbore, and disassembly and removal of rig equipment. Although it attracts the most attention, it is also a relatively short phase and typically lasts approximately two to three weeks per wellbore. On occasion, this phase may appear to last longer because multiple wellbores are being drilled on a single well site before the rig is removed.

Drilling Rig

Truck traffic during this phase is associated with site preparation, rig and drilling equipment transport (both for setup and removal), delivery of cement and water used for drilling operations, and removal of water and mud produced during drilling operations. The following photos depict trucks transporting drilling rig equipment which would be needed during this phase.

Trucks Hauling Drilling Rig Equipment

In order to estimate emissions, key variables had to be determined for each phase, including duration, number of truck trips, and the average length of each truck trip. Exhibit 2.1 outlines the major assumptions made for this phase for the purposes of performing vehicle miles of travel calculations in Chapter 3. One assumption made in this study is that these variables are constant across all analysis years. Therefore, the number of truck trips for the drilling phase in 2006 will be the same as the number assumed for 2012 and 2018.

Exhibit 2.1: Summary of Data Sources and Assumptions: Drilling Phase

Variable	Data Points		Final Assumptions
	Source	Estimate	
Duration (D)	Chesapeake (14)	17-24 days	22.75 days, average of Chesapeake and TxDOT estimates
	TxDOT (15)	25 days	
Number Truck Trips (T)	Chesapeake (14)	62 for equipment	187, based upon TxDOT data, which was more detailed
	TxDOT (15)	187 (70 for site preparation, 52 for equipment, 67 for water/mud/cement)	
Miles per Trip (M)	L&R Tank Trucks	Water hauler; travel approximately 30 miles for freshwater, approximately 50 miles for produced water; trucks travel approximately 200-500 miles per day	50 Miles
	Thurman Transportation	Water hauler; travel less than 60 miles	
	Mr. Troy Rockey, Trucking Contractor	Rock and equipment hauler; travel anywhere from 100-500 miles per day	

It should be noted that for this study, a simplifying assumption was made that each well site includes a single wellbore. If multiple wellbores are included on a single well site, and all were drilled at the same time, the number of water trucks would may increase. However, the number of equipment trucks would not be expected to change much. Due to lack of readily available information, this level of detail is not captured in this inventory.

2.4 Completion Phase

The most significant element of this phase is the hydraulic fracturing of the well which is done by pumping a mix of water, sand, and hydraulic fracturing chemicals under high pressure into the wellbore to create fissures in the shale formation. These fissures enable the gas to escape the shale rock in which it has been trapped (16). The quantity of water needed to hydraulically fracture a well can vary from site to site, but has been estimated to range from two to six million gallons (8). Once the shale rock has been fractured, the water mixture comes back up out of the wellbore to make way for the flow of natural gas. This process is often referred to as flowback, and the water is known as flowback water or produced water. This phase also includes other steps needed to put the well into production, including installation of wellhead, meters, and pumps, and aesthetic elements as required by local ordinances (14).

Aerial View of Hydraulic Fracturing Job

A significant amount of truck traffic occurs during this phase, primarily associated with delivery of large tanks used to hold fresh water for hydraulic fracturing, unless water is available by pipeline, and transport of produced water after the hydraulic fracturing is completed. In the aerial photograph of a hydraulic fracturing job, these tanks are visible lining the perimeter of the well site. In addition, trucks are needed to supply fracturing sand, chemicals, and a series of engines mounted on flatbed trailers is required to generate necessary high pressure to push the needed mix of water, sand, and additives into the wellbore to create fissures. Existing estimates of the number of truck trips needed to hydraulic fracture a wellbore can vary greatly, as illustrated in Exhibit 2.2. NCTCOG determined that much of this discrepancy is due to whether the source assumed use of pipelines to supply freshwater needed for fracturing. According to TxDOT, most production companies suggest that approximately 50 percent (50%) of fresh water needed for fracturing is piped in to the area (15). Assuming that the Fort Worth and Chesapeake estimates reflect this as standard practice, variability across information sources is greatly reduced. As Exhibit 2.2 shows, NCTCOG used estimates from Chesapeake for calculations in this study, as these figures were a moderate estimate compared to the other two sources. As in the drilling phase, NCTCOG assumed that these variables are constant across all analysis years. Therefore, the number of truck trips in 2006 will be the same as the number assumed for 2012 and 2018.

Ground View of Hydraulic Fracturing Job

Sand Trucks for Hydraulic Fracturing

Exhibit 2.2: Summary of Data Sources and Assumptions: Completion Phase

Variable	Data Points		Final Assumptions
	Source	Estimate	
Duration (D)	Chesapeake (14)	3-5 days	16 days
	City of Fort Worth (17)	Approximately 1 month	
	TxDOT (15)	Approximately 14 days	
Number Truck Trips (T)	Chesapeake (14)	Up to 400 water trucks, another 20 truckloads for other items	420 truckloads, based on Chesapeake information which is a moderate assumption compared to other two sources
	City of Fort Worth (17)	Ranges from 105-400 truckloads	
	TxDOT (15)	997 truckloads; can be reduced to 655 truckloads if half of freshwater needed for hydraulic fracturing is piped in	
Miles per Trip (M)	L&R Tank Trucks	Travel approximately 30 miles for freshwater, approximately 50 miles for produced water; trucks travel approximately 200-500 miles per day	50 miles
	Thurman Transportation	Travel less than 60 miles	
	Troy Rockey, Trucking Contractor	Rock and equipment hauler; travel anywhere from 100-500 miles per day	

As with the drilling phase, a simplifying assumption was made that each well site includes a single wellbore. The presence of multiple well bores on a single site would definitely impact the activity rates in this phase. For the purposes of this study, all activity rates provided for a site assume a single well bore.

Survey responses from operators indicated that during 2011, the number of wells hydraulically fractured was consistent with the number of wells drilled, or slightly more. Therefore, for the purpose of generating vehicle miles of travel and emissions estimates in this study, it is assumed that the number of sites hydraulically fractured is the same as the number of sites drilled. As discussed in Section 2.2, NCTCOG estimated six sites per day region wide in 2006, and one site per day region wide in both 2012 and 2018.

2.5 Production Phase

Once a well is drilled and completed, it shifts into the production phase, which has comparatively low on-site activity relative to the first two phases. A typical well is expected to produce gas for 20 to 40 years (1). As the well produces gas, additional water from the shale

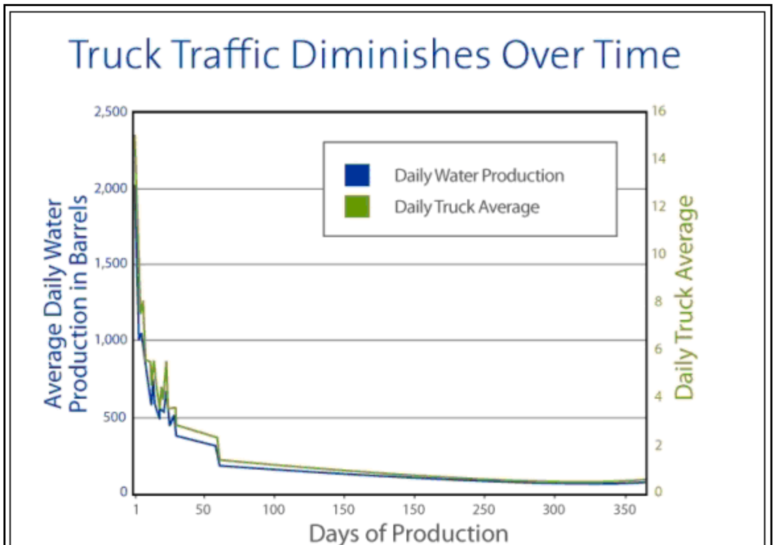
Producing Well Site

formation continues to travel up the wellbore. This produced water is collected in on-site storage tanks and eventually must be hauled away by water tankers to be disposed of at SWDs. Although there is relatively little site activity, this is the phase that introduces the most long-term truck traffic impacts due to water tanker trips. As with the hydraulically fracturing phase, the number of truck trips associated with the production phase can vary greatly depending upon whether pipelines are available to carry produced water to SWDs. Although a few projects are underway to pipe produced water to a SWD, such as the Chesapeake Brentwood SWD in Fort Worth, these sites are generally pilot or demonstration projects (14). Although this practice may become more common in the future, the extent to which transport will shift to piping cannot be predicted. As noted in Section 2.2, when this type of future forecast cannot be accurately estimated, latest observed planning assumptions are utilized for future scenarios. Therefore, for purposes of this study, it is assumed that all produced water in this phase is transported by truck for all analysis years.

Water Truck Leaving SWD

The amount of well water produced declines sharply once the well is put into production. Therefore, the number of truck trips needed to serve these wells will also decline sharply once a well is put into production. Exhibit 2.3 illustrates this relationship.

Exhibit 2.3: Decline in Water Truck Trips during Operating Life of a Well



Source: Chesapeake Energy, 2012

In order to incorporate a trip rate into the model, an average daily trip rate was needed. As noted before, since the limited survey information could not be relied upon as representative of the industry, NCTCOG established a moderate, standard estimate utilizing existing sources. Exhibit 2.4 illustrates various Barnett Shale-specific estimates available.

Exhibit 2.4: Summary of Data Sources and Assumptions: Production Phase

Source	Estimate	Equivalent Trips/Day	Final Assumption
Chesapeake (14)	13-17 trips on the first day of production, approximately 8 trips/day during the second week of production, approximately 4 trips/day after 60 days, less than one trip/day after 90 days	Less than 1 per day for lifetime of well	0.33 trips/day per well
City of Fort Worth (17)	219-2,847 lifetime trips	0.03-0.39	
TTI (8)	88 trips/year	0.24	
TxDOT (15)	353 trips/year	0.97	

As Exhibit 2.4 shows, estimated daily truck trips during the production phase ranged from 0.03 to 0.97. The high degree of variability in information proved difficult in making an assumption for modeling purposes. Since only a single number would be applied in the model, it was determined that the assumption should be representative of the long-term truck trip pattern, which is less frequent, rather than assuming the high truck trip rates that occur only in the first few months of well production as noted by Chesapeake. This approach is reinforced by the fact that most wells in this analysis were completed more than a year prior to 2012 and, therefore, trip rates have already degraded significantly. To be conservative, NCTCOG ultimately assumed an average trip rate of one truck every three days or 0.33 truck trips per day per gas well. Note that this estimate is per wellbore; a well site with multiple wellbores would generate this rate of trips for each wellbore.

Chapter 3: Quantification of Mobile Source Activity

Mileage for Barnett Shale trucks was forecasted in two ways, depending upon the well phase. For drilling and hydraulically fracturing, which are high-intensity, low-duration phases, mileage was estimated through a post-process methodology. For the production phase, which has long-term impacts, vehicle miles of travel was developed through use of a synthetic travel demand modeling module.

3.1 Drilling and Completion Phases

For both of these phases, estimated VMT was quantified using the following basic equation:

VMT_D = (T) x (M) x (S),

Where:

VMT_D = Daily VMT in the NCTCOG MPA
T = Trips per phase, per site
D = Average duration of the phase, in days
M = Miles per trip
S = Sites being drilled or frocked per day throughout the NCTCOG MPA

Values and assumptions for each variable are described in detail for each phase in Chapter 2. Annual VMT results were obtained by simply multiplying VMT_D by 365 days per year. Results are illustrated in Exhibit 3.1. Detailed spreadsheets for these calculations are provided in Appendices D through F.

Exhibit 3.1: Estimated Regional Drilling and Completion Phase VMT

Analysis Year	2006	2012	2018
Drilling Phase	2,466	411	411
Completion Phase	7,875	1,313	1,313
Total Daily VMT	**10,341**	**1,724**	**1,724**
Annual VMT	**3,774,465**	**629,260**	**629,260**

3.2 Production Phase

The majority of NCTCOG staff effort in this study was focused on estimating total VMT for truck traffic occurring during this phase of the life of a gas well. This is due to the fact that although drilling and hydraulically fracturing phases are associated with high volumes of truck activity, the phases are short-lived and the truck traffic only occurs in a short amount of time at the beginning of the life of a well. Once exploration in the Barnett Shale matures, truck traffic associated with these phases will no longer exist.

On the contrary, truck traffic that occurs during the production phase is a long-term on-road mobile source impact, as water trucks will continue to be needed to dispose of produced water as long as the well is operational. Most wells are expected to produce for 20 years or more (1). Due to the chronic and repetitive nature of this traffic, it was appropriate to evaluate this impact through use of travel demand modeling. In order to estimate total mileage of water trucks associated with Barnett Shale facilities within the MPA, NCTCOG modelers developed a synthetic module of the Dallas-Fort Worth Regional Travel Model for the Expanded Area (DFX), which will be referred to as the DFX-Barnett Shale Module. Development of this module was necessary because truck VMT activity is virtually nonexistent in the current DFX due to a current model validation/calibration of 2004, when little Barnett Shale operations existed. Use of a travel demand model of this same year would not properly reflect activity, as underscored by the change in vehicle classification counts illustrated in Exhibit 1.4. Thus, a synthetic travel demand model was created to generate VMT appropriately for regionally significant roadways, rural, and local roadways. Then, a post-process, manual TransCAD approach was applied to adjust the VMT for rural and local roadways based on the modeled result. The benefit of this module is that it uses traditional activity based modeling steps to generate VMT. Exhibit 3.2 outlines the datasets that were programmed into this module for each of the three analysis years (2006, 2012, and 2018):

Exhibit 3.2: Datasets Used in DFX-Barnett Shale Module Development

<table>
<tr><th>Dataset</th><th>Source</th><th>Key Assumptions</th></tr>
<tr><td rowspan="2">Gas Well Locations</td><td rowspan="2">RRC (2)</td><td>2006 and 2012: Reliable information regarding wells that had been closed or were no longer operational was not readily available. Therefore, it was assumed that all wells that were completed by the analysis year were still in use for that year.</td></tr>
<tr><td>2018: The number and location of gas wells was held constant from 2012 with no new wells assumed. This is consistent with historical emission inventories for use in SIP modeling and transportation conformity analysis (see Section 2.2 for further explanation).</td></tr>
<tr><td rowspan="2">SWD Locations</td><td rowspan="2">RRC, Obtained through TTI</td><td>All years: Private and commercial locations treated the same for modeling purposes. This likely produces conservative estimates because it allows the nearest SWD to attract the most trips regardless of whether it is a private or commercial well.</td></tr>
<tr><td>2006: Reliable information regarding SWDs that had been closed or were no longer operational was not available. Therefore, it was assumed that all SWDs completed by 2006 were still in use.</td></tr>
</table>

Dataset	Source	Key Assumptions
		2012: Reliable information regarding SWDs that had been closed or were no longer operational was not available. Therefore, it was assumed that all SWDs completed by 2006 were still in use. In addition, at the time RRC data was obtained by TTI, which was in 2011, 11 SWDs were "expected" due to newly obtained permits. NCTCOG staff located records in the RRC H-10 Filing system for 4 of these 11 locations, suggesting they had become operational (18). Therefore, these four sites were included in the 2012 dataset.
		2018: Same as 2012, except all 11 "expected" SWDs were assumed to be operational, for a net increase of seven SWDs.
DFX Roadway Network	NCTCOG DFX Model	2006 and 2012: Roadway networks are coded in DFX for travel demand modeling.
		2018: The 2018 roadway network is not yet available in DFX. However, the 2020 roadway network is already coded properly. Since differences between these two years' roadway networks are considered to be minor and insignificant, the 2020 roadway network was used to represent the 2018 roadway network.
Demographic Data	NCTCOG Demographics	2006 and 2012: Demographic data is programmed in DFX.
		2018: To be consistent with the use of 2020 roadway network data, 2020 demographic data is applied in this project.

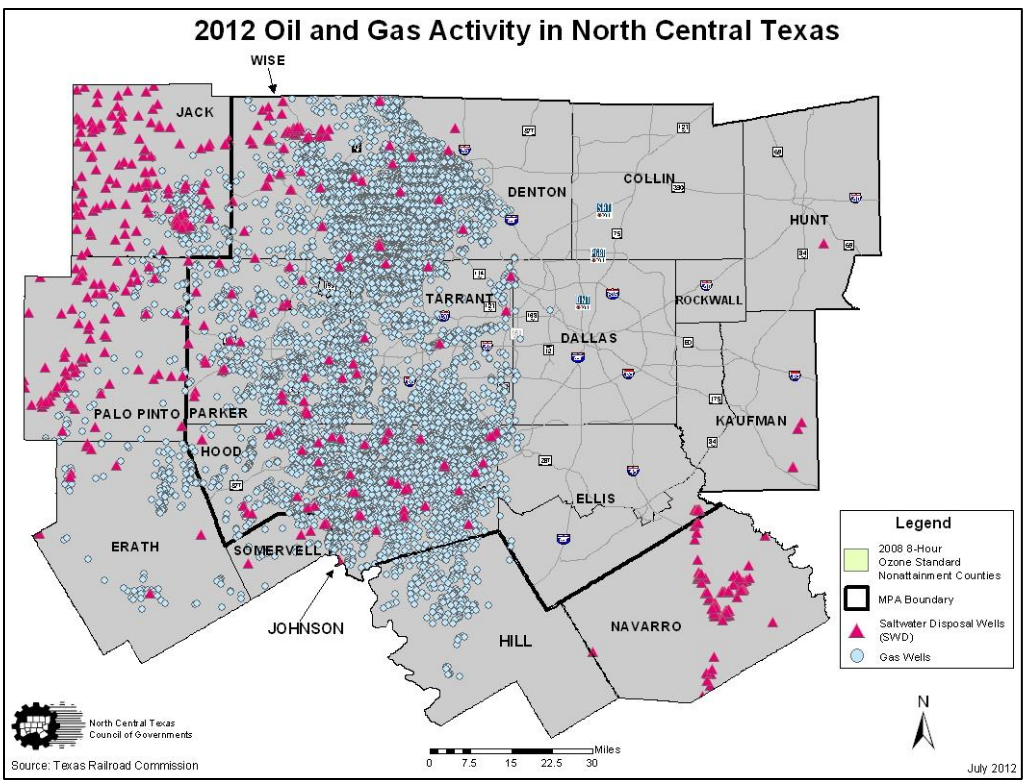
As discussed in Section 2.5, a daily water truck trip rate of 0.33 truck trips per day per well was assumed for the lifetime of each gas well. This assumption was kept constant across all three analysis years. In the DFX-Barnett Shale Module, these trips were routed from the origin (well location) to destination (SWD). Due to lack of detailed information about the path of truck trips, two key assumptions were used:

- Each trip traveled from a single gas well to a single SWD (as opposed to visiting multiple gas wells prior to visiting one or more SWDs)
- Drivers are assumed to prefer the shortest distance path. Therefore, the path of each truck trip is achieved through a multiple shortest path methodology in the synthetic module. The multiple shortest path is first achieved based on the shortest distance between gas wells and SWDs. All O&G truck trips are then distributed based on a general gravity-based distribution model, which means all O&G truck trips are distributed by shortest distance between gas and SWDs (weight by distance). In this process, the attractiveness of a given SWD is a function of the inverse of the square of its network-based distance between the gas well and the SWD. It should be noted that this is a

conservative estimate since many factors may determine trip pattern, including congestion, truck capacity, expense, etc.

A significant number of SWDs fall outside the NCTCOG MPA, as exemplified in Exhibit 3.3. In fact, in 2006, 367 of the 483 SWDs in the Barnett Shale, or 76 percent (76%), were outside the MPA. In 2012, this percentage dropped slightly to 72 percent (72%). The DFX modeling domain does not include roadways in the non-MPA counties, nor were these counties a part of the scope of the contract. The modeling methodology considered SWDs outside the MPA boundary to be located in external stations, while the gas wells outside the MPA boundary were disregarded. However, trips from gas wells within the MPA to SWDs in external stations, as dictated by the multiple shortest path methodology, are likely and needed to be captured as best as possible. To accomplish this, NCTCOG modeling staff utilized external stations. External stations are a set of specified traffic survey zones (TSZs) along the boundary of the MPA. Since they represent points outside of the MPA boundary, they serve as the destination for a trip which begins in the MPA but leaves the modeling area. All trips to SWDs within non-MPA counties were assigned to one of the existing external stations in the model for the purpose of attracting trips.

Exhibit 3.3: Full Extent of Oil and Gas Activity in North Central Texas, Analysis Year 2012



3.2.1 Capacity Cap

In reality, the number of truck trips that go to a given SWD vary and/or are limited based upon several factors, including the permitted injection capacity for that location, whether that location is a private or commercial site, the rate of disposal fees charged by that location, and the length of time a driver may have to wait to dispose of their load due to the number of trucks already in the queue. As these factors could not be programmed into the DFX-Barnett Shale Module, the use of the Multiple Shortest Path methodology could route an excessive number of truck trips to a single destination. Therefore, staff utilized a capacity cap to limit the number of trips allowed to arrive at a single destination before the model forced trips to travel further to the next-closest well.

To develop a capacity cap, staff followed TTI methodology in estimating the maximum volume of water that could be carried by a truck, assuming 100 percent (100%) compliance with standard 80,000 gross vehicle weight rating limits (9). Staff then analyzed the volume of produced water that had been disposed at 66 SWDs for the year 2011 (18). The maximum reported injection volume from any well for any month was used to calculate the total possible number of truck trips that could be expected to arrive at a single location. This number was estimated to be between 150 and 200 trips, depending upon whether water trucks were assumed to be partially or completely full when traveling to a SWD. These calculations are illustrated in Appendix AC. However, when the DFX-Barnett Shale Module was run using shortest path method, no SWDs received more than 150 truck trips. Therefore, there was no need to utilize the capacity cap in any of the analysis years. However, this is a feature that should be considered in possible future studies.

3.2.2 VMT Results

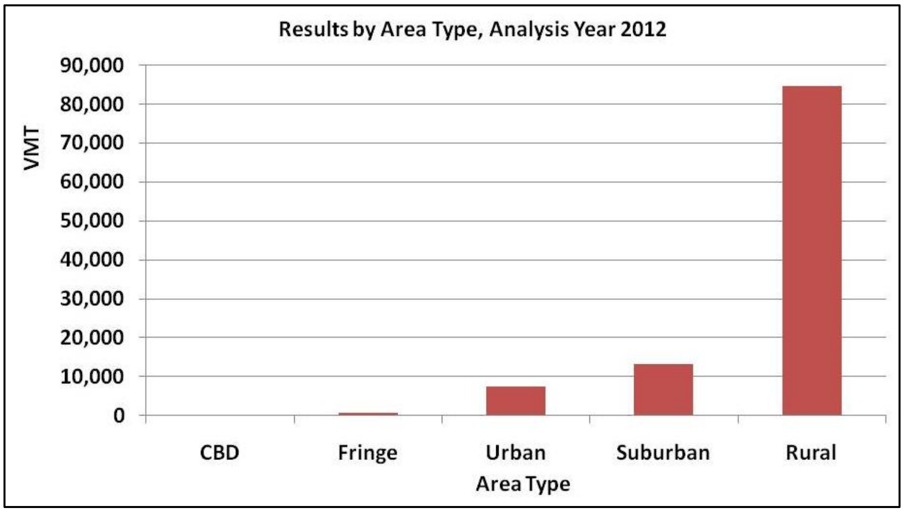
Based upon the multiple shortest path methodology, truck trips and truck VMT were assigned to links (roadways) in the model. The majority of resulting truck trip activity occurs within the six Barnett Shale counties within the MPA: Denton, Hood, Johnson, Parker, Tarrant, and Wise counties. A negligible amount of VMT occurred in Dallas and Ellis counties, but was not determined to warrant further analysis. A summary of results is outlined in Exhibit 3.4. Detailed results for truck trip volume (number of trips) and VMT for each analysis year are outlined in Appendices D through F.

Exhibit 3.4: Summary of Oil and Gas Truck Daily VMT by Analysis Year

Analysis Year	2006	2012	2018
Estimated Trip Length (miles)	26	22	22
On-Network VMT	856	2,037	2,037
Off-Network VMT	50,969	103,769	103,804
Total Gas Truck VMT	51,825	105,806	105,841
Total VMT (all vehicle types)	166,308,477	198,352,711	244,266,048
VMT %	0.03%	0.05%	0.04%

Total VMT was generated based upon both county and area type (e.g. central business district, urban, rural, etc.), as outlined in Exhibit 3.5.

Exhibit 3.5: Daily Oil and Gas Truck VMT Distribution by Area Type and County for Analysis Year 2012



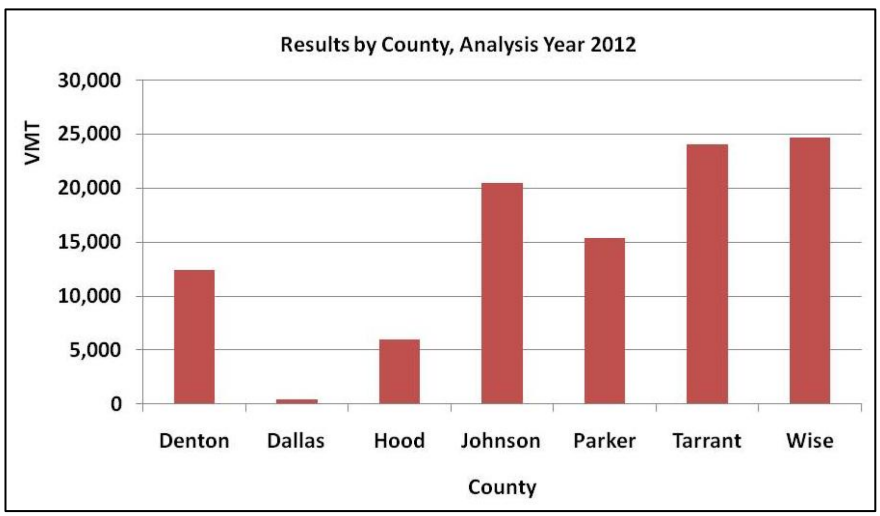
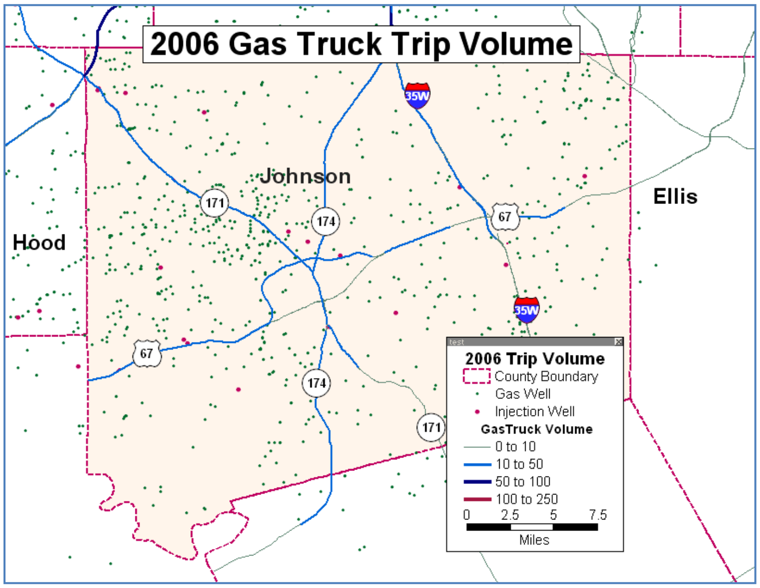


Exhibit 3.6 illustrates the change in trip volume over time in Johnson County. Note that in these graphics, the volume of trips is reflective of link-based trips along the roadways and should not be interpreted to reflect the total number of origin to destination trips. These graphics do, however, illustrate growth in magnitude of travel. For clarity, only freeways and highways are illustrated. Note the growth in truck trip volume for 2006 to 2012. Results for 2018 are not shown as they are nearly identical to 2012 volume.

Exhibit 3.6: Comparison of Oil and Gas Truck Trip Volumes from 2006 to 2012, Johnson County



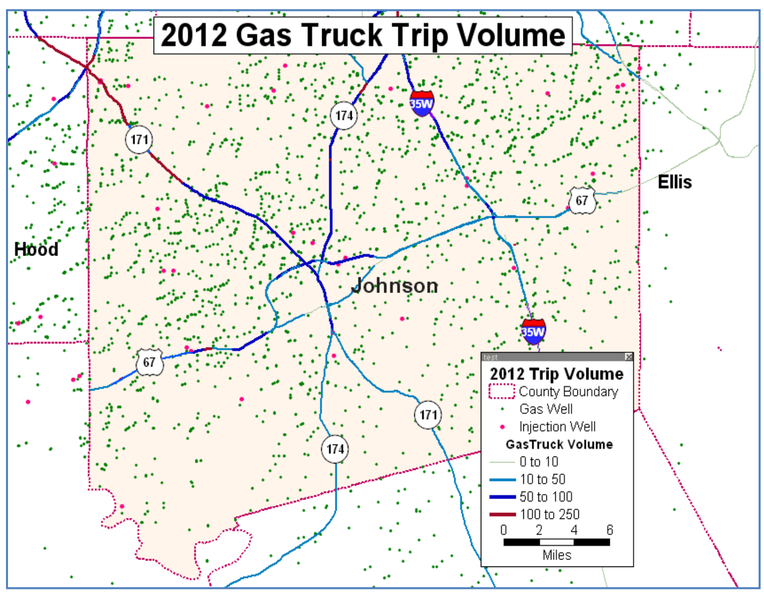
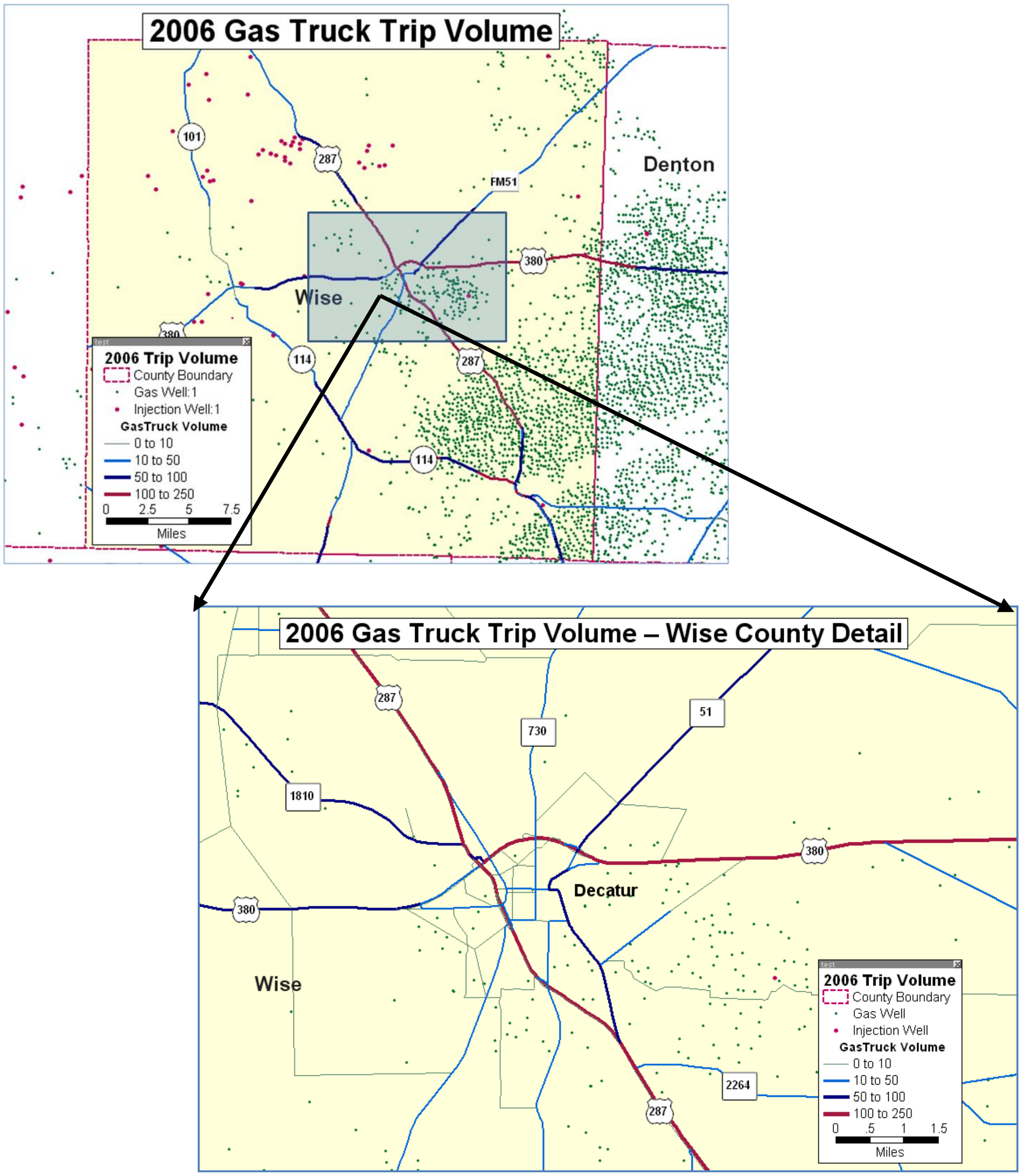
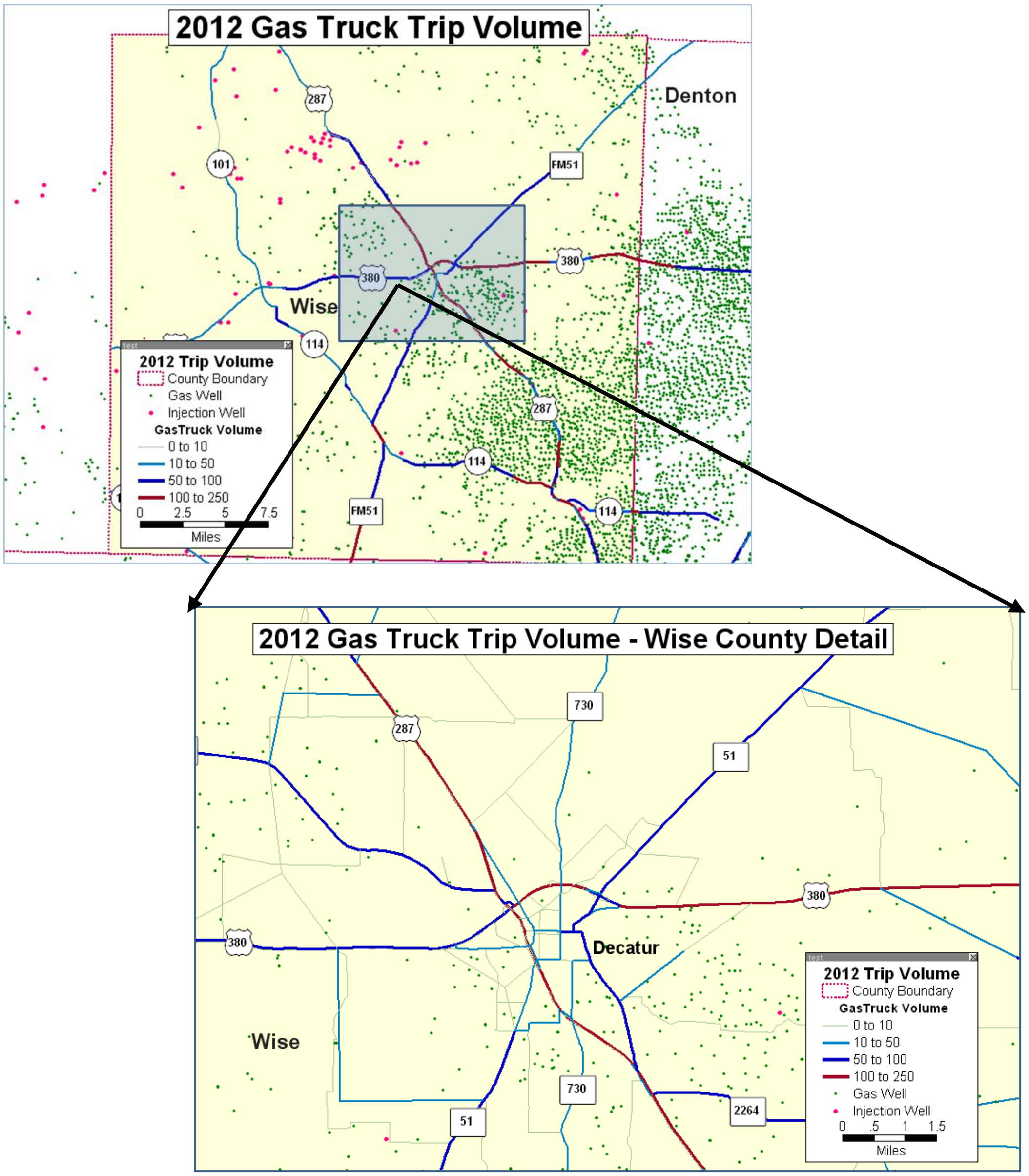


Exhibit 3.7 provides a similar illustration of how trips were distributed in Wise County over the three analysis years. However, for 2006 and 2012, blue boxes outline areas of greater detail which are blown up into larger graphics. The areas of greater detail depict all roadway types which are coded into the DFX model, including local roads. Detail of analysis year 2018 is not provided as it is forecasted to be nearly identical to 2012, based upon use of the same gas well locations and minor changes in SWD locations. Note the growth in the number of truck trips on local roads in the area surrounding the city of Decatur from 2006 to 2012. This indicates growth in activity on smaller local roads.

Exhibit 3.7: Comparison of Oil and Gas Truck Trip Volumes for 2006 and 2012, Wise County

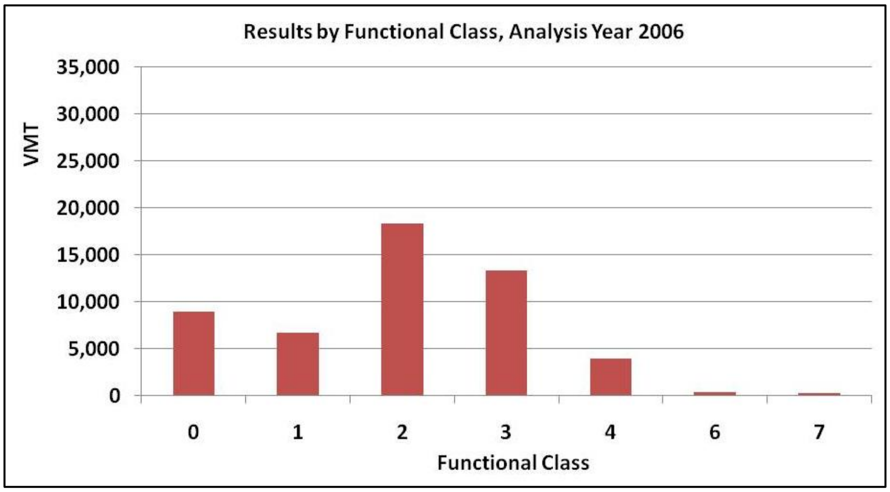


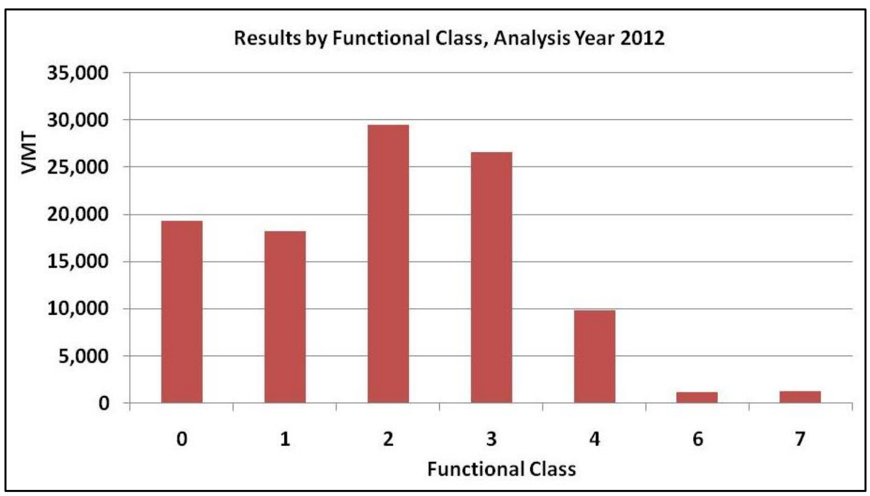


3.2.3 Off-Network VMT Adjustment

Often times, gas wells and SWDs are not located near a roadway coded in the DFX. Many of the roadways utilized by the industry are rural or local Farm to Market or County Roads, as these are the roadways which access gas wells. DFX networks generally contain "regionally significant" roadways and often do not include these smaller roadway types, particularly in more rural areas. All roadways coded in DFX are assigned to a functional class based upon roadway type. To capture the off-road and off-network fraction of the VMT, a sample analysis was conducted to identify the ratio between the off-network path length and the captured (centroid connector path length) in-network path length of each TSZ in TransCAD. Based upon analysis of four counties, an average adjustment factor of 1.28 was developed, which indicates that 28 percent of total VMT is estimated to occur off-network. Therefore, VMT results which occur on the functional class that captures local roads (known as the centroid connector, or functional class 0) were multiplied by this factor to produce final VMT estimates for that roadway type. Staff developed a distribution of truck trips and VMT by functional class, as outlined in Exhibit 3.8.

Exhibit 3.8: Comparison of Oil and Gas Truck VMT by Functional Class





Definitions of each functional class are provided in Exhibit 3.9, along with a summary of the percentage of gas truck VMT in each county by roadway type. In this table, the off-network VMT associated with local and rural roads is incorporated into the portion of VMT on functional class 0. As Exhibit 3.9 shows, in most counties, a majority of VMT travels on lesser road types, such as functional class 0 (which includes local roads not coded in DFX), and minor arterials. Distribution by functional class is significant because different functional classes are associated with different speeds, which impacts emission factors. Speeds associated with each functional class are included in Appendices D through F.

Exhibit 3.9: County-Level Distribution of Oil and Gas Truck VMT by Functional Class

2006		Percent of VMT by Functional Class (FUNCL)					
FUNCL	**Definition**	**Denton**	**Hood**	**Johnson**	**Parker**	**Tarrant**	**Wise**
0	Centroid Connector	28%	12%	23%	14%	7%	17%
1	Freeway	7%	0%	8%	15%	52%	1%
2	Principal Arterial	16%	41%	36%	43%	11%	51%
3	Minor Arterial	35%	41%	22%	19%	21%	26%
4	Collector	13%	5%	9%	9%	7%	5%
6	Freeway Ramp	0%	0%	1%	0%	2%	1%
7	Frontage Road	1%	0%	1%	0%	1%	1%
Total		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
2012		**Percent of VMT by Functional Class (FUNCL)**					
FUNCL	**Definition**	**Denton**	**Hood**	**Johnson**	**Parker**	**Tarrant**	**Wise**
0	Centroid Connector	26%	18%	24%	17%	8%	19%
1	Freeway	9%	0%	10%	13%	51%	1%
2	Principal Arterial	13%	36%	26%	38%	11%	46%
3	Minor Arterial	35%	37%	28%	20%	17%	27%
4	Collector	14%	8%	11%	11%	8%	7%
6	Freeway Ramp	1%	0%	1%	0%	3%	0%
7	Frontage Road	3%	0%	1%	0%	2%	1%
Total		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Note: Due to rounding, not all percentages may add up to 100%

3.2.4 Adjustment for VMT Already Captured in DFX

One concern in conducting this study was that O&G truck VMT may be double-counted in the existing DFX model, as DFX already includes VMT associated with HDDVs. However, the DFX model which the synthetic module was based upon has a validation year of 2004. Since the growth in Barnett Shale industry activity within the MPA did not begin in earnest until after this date, the assumption is that no industry-specific VMT is already included in DFX. This assumption is reinforced by vehicle classification counts illustrated in Exhibit 1.4.

3.3 Idling Activity

Throughout the drilling, completion, and production phases, HDDVs are often observed idling for extended periods of time. NCTCOG requested information on typical shift length, idle time, and reason for idling from several of the trucking contractors who submitted surveys. Seven different contractors responded with details about their idling patterns, which were repeatedly reported to be due to loading and unloading of cargo. Although this was a small sample size, staff was confident in utilizing this data point due to the high degree of consistency in responses, both in regard to the duration and reason for extended idle time. From these responses, staff estimated that on average, each truck idles for approximately six hours. Although most respondents were water haulers, an assumption was made that loading and unloading activity is consistent regardless of the type of cargo (e.g. water, rock, mud, or equipment), so this estimate of six hours per day was held constant across all phases and for all analysis years. Exhibit 3.10 summarizes the number of idling hours estimated for each phase, by analysis year.

Exhibit 3.10: Estimated Regional Idling Time, in Hours

Analysis Year	2006	2012	2018
Drilling Phase	296	49	49
Completion Phase	945	158	158
Production Phase	11,737	29,167	29,167
Daily Total	**12,978**	**29,374**	**29,374**
Annual Total	**4,737,098**	**10,721,583**	**10,721,583**

3.4 Summary

As Exhibits 3.1 and 3.10 illustrate, the level of activity of O&G trucks associated with the drilling and completion phases is significantly lower in 2012 than in 2006. This is reflective of the decline in new drilling activity that has been observed in the Barnett Shale in recent years compared to a peak in activity just a few years ago. However, the level of activity associated with the production phase has significantly increased in accordance with the growth in number of completed wells which require ongoing service, largely from water trucks. The magnitude of the increase in VMT and idling associated with truck traffic in the production phase overshadows the decline from the drilling and completion phases, leading to a net increase in overall truck activity.

Chapter 4: Quantification of Mobile Source Emissions

To develop a full emissions inventory, NCTCOG staff calculated emissions associated with VMT estimated in Chapter 3 for the drilling, completion, and production phases. In addition, staff estimated idling emissions associated with wait time at a well site or SWD. Both daily emission estimates, in tons per day (tpd), and annual estimates in tons per year (tpy), were calculated. The contract also required staff to develop a spatial and temporal profile of emissions. Details on each step are outlined throughout this chapter.

For this study, NCTCOG developed emission factors (EFs) using MOVES 2010a for each of the three analysis years. First, NCTCOG evaluated available data sources, including TxDMV oversize-overweight permit data and trucking contractor survey responses, to determine if evidence suggested that the truck fleet used in the O&G industry is significantly older or newer than the "average" heavy-duty truck fleet. If this was found to be the case, input parameters would have been adjusted to reflect a shifted fleet mix. However, available information did not support any claim that the trucks are appreciably different than other industry sectors. Therefore, NCTCOG utilized TxDMV registration data, following the standard practice in emissions inventory development, to develop composite EFs for HDDV classes. The TxDMV registration data which was utilized in MOVES 2010a for the purpose of developing emission factors for this study is included as Appendix AE; note that registration data from 2006, 2010, and 2011 was utilized for analysis years 2006, 2012, and 2018, respectively.

To develop a composite EF for all HDDVs, both commercial long-haul trucks and commercial short-haul trucks were taken into account. A summary of MOVES 2010a input parameters and adjustments is included in Appendix G. A set of run specifications, which reflect user-selected inputs chosen in MOVES 2010a, is also included as Appendix AD. Emission factors for the six Barnett Shale counties within the MPA were averaged together to develop regional average emission factors. Exhibits 4.1 through 4.3 provide examples of MOVES 2010a emission factors developed for the analysis year 2012 for three pollutants: NO_X, VOC, and CO.

Exhibit 4.1: HDDV NO_X Emission Rates by Speed, Analysis Year 2012

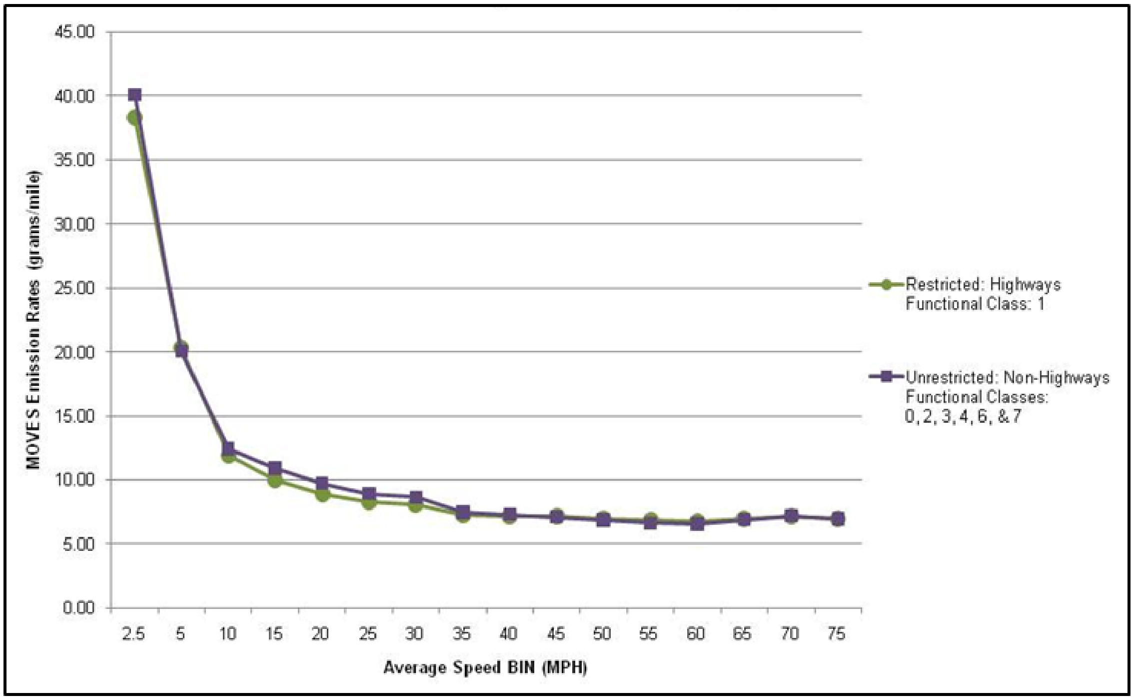


Exhibit 4.2: HDDV VOC Emission Rates by Speed, Analysis Year 2012

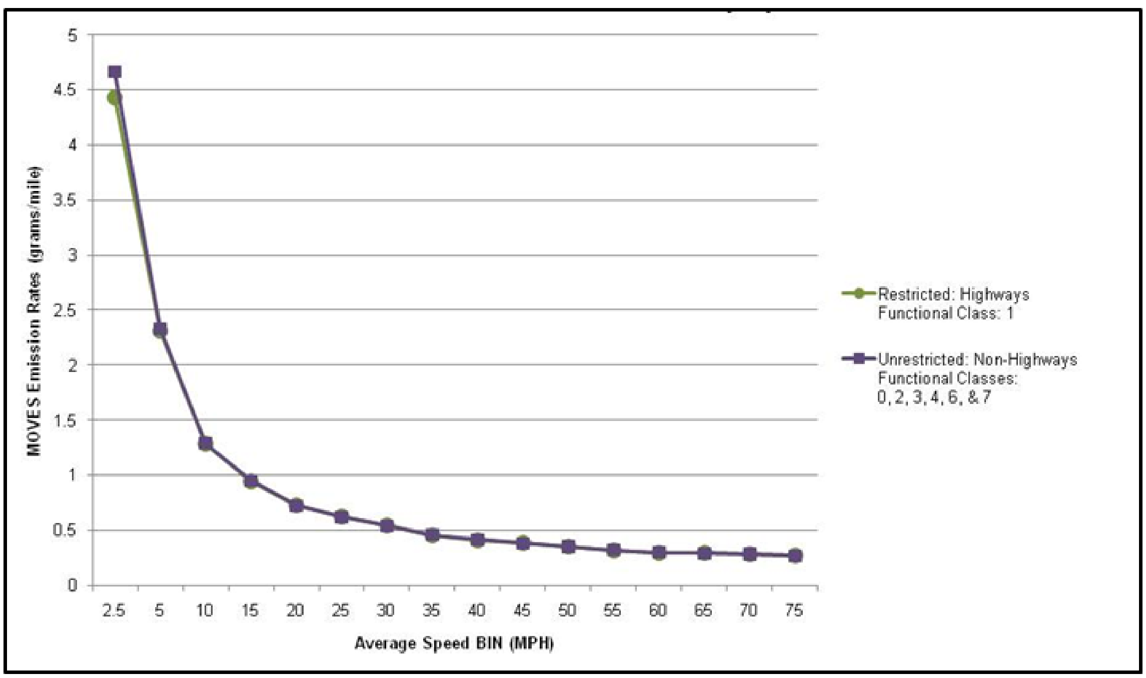
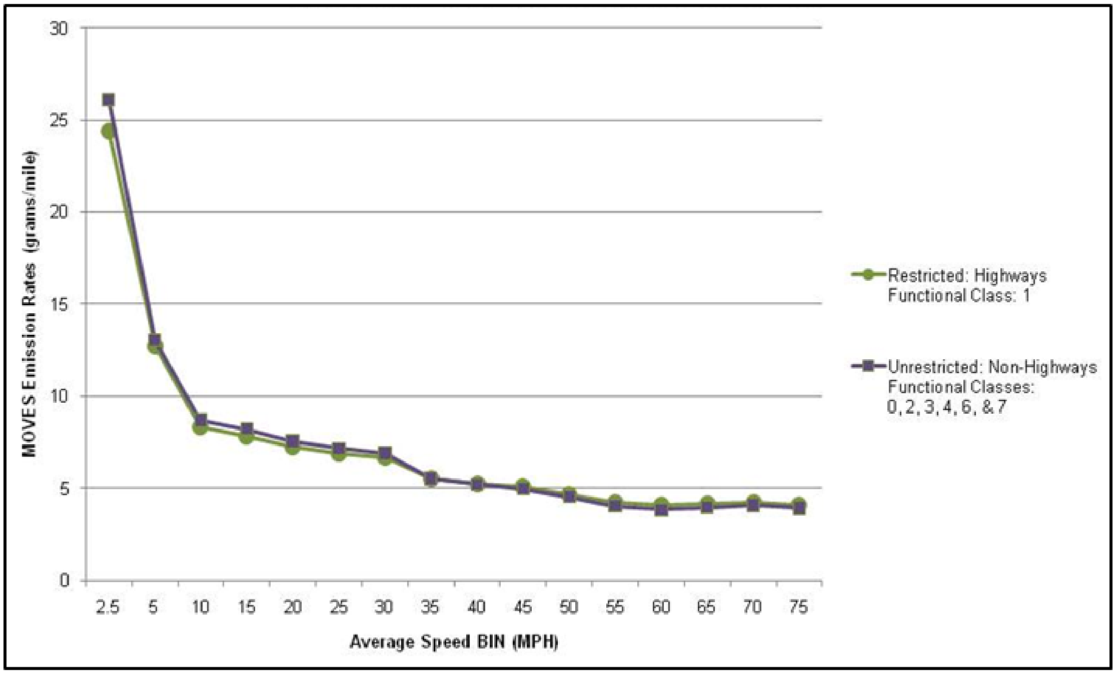


Exhibit 4.3: HDDV CO Emission Rates by Speed, Analysis Year 2012



Typically, NCTCOG develops regional emissions inventories by inputting VMT results from DFX and EF results from the MOBILE model into a separate module called EMILINK which serves to multiply the VMT results by EFs and provides emissions outputs. However, due to current validation of the DFX model, NCTCOG estimated emissions by performing post-processing calculations. As explained in Section 3.2, a synthetic module was developed for estimation of VMT, which was completed through a split process. Unfortunately, this methodology was not compatible with use of EMILINK to calculate emissions. Therefore, a manual approach was utilized.

4.1 VMT-Based Emissions

The emissions discussed in this section are produced while trucks are traveling, which includes processes such as evaporative permeation, evaporative fuel vapor venting, evaporative fuel leaks, and crankcase running exhaust. These emissions are directly related to VMT and are calculated based upon the following basic equation:

Emissions_D = (VMT) x (EF),

Where:

Emissions	**=**	**TPD in the NCTCOG MPA**
VMT	**=**	**Daily Miles Traveled**
EF	**=**	**Emission Factor per Mile Traveled**

Exhibits 3.8 and 3.9 illustrated how VMT is divided among functional classes. This is a critical element of emissions calculations because MOVES 2010a EFs are speed-based and speed varies

based upon functional class. Each functional class has an average regional speed based upon DFX output that varies based upon analysis year. These speeds were used to select the appropriate speed-based EF for that functional class. Speed-based EFs from MOVES 2010a were used for quantification of all phases and are outlined in Appendices H, I, and J.

County-specific VMT results were apportioned across functional classes in order to apply the appropriate speed-based EF to that portion of VMT. Detailed emissions calculations are provided in Appendices K through U. Exhibit 4.4 summarizes estimated emissions by phase. Note that due to rounding, daily and annual numbers may appear to vary slightly for all tables.

Exhibit 4.4: VMT-Based Oil and Gas Truck Emissions

Pollutant	NO_X (lbs/day)	VOC (lbs/day)	CO (lbs/day)	PM (lbs/day)	CO_2 (lbs/day)
Analysis Year 2006					
Drilling Phase	87.39	4.95	66.43	6.50	12,381.75
Completion Phase	279.08	15.80	212.13	20.77	39,541.30
Production Phase	1,749.49	101.30	1,356.31	128.58	251,027.40
Total 2006 Emissions	**2,115.97**	**122.05**	**1,634.87**	**155.86**	**302,950.45**
Total 2006 Emissions (tpd)	**1.06**	**0.06**	**0.82**	**0.08**	**151.48**
Total 2006 Emissions (tpy)	**386.16**	**22.27**	**298.36**	**28.44**	**55,288.46**
Analysis Year 2012					
Drilling Phase	7.20	0.45	5.36	0.45	2,117.69
Completion Phase	22.99	1.45	17.12	1.45	6,762.86
Production Phase	1,760.11	112.46	1,332.99	109.64	528,394.08
Total 2012 Emissions	**1,790.29**	**114.37**	**1,355.47**	**111.55**	**537,274.63**
Total 2012 Emissions (tpd)	**0.90**	**0.06**	**0.68**	**0.06**	**268.64**
Total 2012 Emissions (tpy)	**326.73**	**20.87**	**247.37**	**20.36**	**98,052.62**
Analysis Year 2018					
Drilling Phase	1.55	0.08	0.47	0.09	1,094.75
Completion Phase	4.96	0.25	1.51	0.28	3,496.10
Production Phase	380.40	19.25	117.61	21.71	274,691.55
Total 2018 Emissions	**386.91**	**19.58**	**119.59**	**22.08**	**279,282.40**
Total 2018 Emissions (tpd)	**0.19**	**0.01**	**0.06**	**0.01**	**139.64**
Total 2018 Emissions (tpy)	**70.61**	**3.57**	**21.83**	**4.03**	**50,969.04**

4.2 Idling Emissions

In addition to emissions produced while traveling during the drilling, completion, and production phases, HDDVs produce emissions during idling time. These emissions are quantified from the following basic equation:

$Emissions_D$ = (T) x (EF),

Where:

Emissions	**=**	**TPD in the NCTCOG MPA**
T	**=**	**Daily Trips**
EF	**=**	**Emission Factor per Mile Traveled**

As discussed in Section 3.3, each trip is assumed to include six hours of idle time for cargo (e.g. water, sand, equipment) loading and unloading. This was multiplied by the estimated number of trips for each phase, which was then multiplied by an idling EF.

4.2.1 Idling EFs for VOC and CO

Typically, to quantify idling emissions or emissions reductions associated with idle reduction, NCTCOG utilizes the grams per mile EFs at the slowest MOVES 2010a output speed, which is 2.5 miles per hour (mph), and then multiplies by 2.5 mph to get units of grams per mile. This is the standard methodology which has been followed by staff for quantification of transportation control measures in the SIP and transportation emissions reduction measures in conformity. This same methodology was applied in this study to develop “idling” EFs for VOCs and CO.

4.2.2 Idling EFs for NO_X, PM, and CO_2

“Idling” EFs for NO_X, PM, and CO_2 were also available following the methodology described in Section 4.2.1. However, idling emission rates for CO_2 can be calculated based upon estimates of CO_2 emissions per gallon diesel fuel and the quantity of diesel fuel consumed per hour (19). In addition, the EPA has provided guidance on quantifying idling emissions for NO_X and PM (20). As these emission rates are more reflective of true idle operation, they were determined to be preferable to using an emission factor at 2.5 mph.

EPA idling EFs for PM are different for 2006 and older model year vehicles compared to 2007 and newer vehicles. Therefore, NCTCOG staff evaluated registration data to determine what percentage of the fleet in the six Barnett Shale counties was older or newer than 2007. This percentage was applied to the total number of idling hours quantified for 2012. For 2018, staff extrapolated future fleet penetration of 2007 and newer trucks, assuming that fleet turnover continues at the same rate. Calculations outlining this process, along with associated registration data, are included in Appendix W.

Following EPA guidance, a default idling emissions factor of 135 grams NO_X per hour was used. However, in 2008 many engine manufacturers began producing Certified Clean Idle engines, which are certified by the California Air Resources Board (CARB) to not emit more than 30 grams per hour NO_X (21). Although this was a special CARB provision, Certified Clean Idle engines became common nationwide, as manufacturers found it easier to produce one engine configuration that could be used nationwide (22). Data regarding the actual proportion of model year 2008 and later engines which are Certified Clean Idle versus those which are not is not available. Therefore, to be conservative, NCTCOG assumed that all model year 2008 and later vehicles are equipped with Certified Clean Idle engines. As with PM calculations, NCTCOG used registration data to attribute idling EFs to total idling hours in analysis year 2012 based upon the percentage of the fleet which was 2008 or newer and therefore assumed to be Certified Clean Idle. For 2018, future fleet penetration of 2008 and newer trucks was again extrapolated assuming a constant rate of turnover. Registration data and fleet extrapolation calculations are provided in Appendix X.

Detailed calculations for idling emissions quantification are available in Appendices Y, Z, and AA. Exhibit 4.5 summarizes idling emissions estimated by phase and by analysis year.

Exhibit 4.5: Idling Emissions from Oil and Gas Trucks

Pollutant	NO_X (lbs/day)	VOC (lbs/day)	CO (lbs/day)	PM (lbs/day)	CO_2 (lbs/day)
Analysis Year 2006					
Drilling Phase	88.07	14.07	87.66	2.40	5,255.40
Completion Phase	281.25	44.92	279.94	5.74	16,783.20
Production Phase	2,597.96	414.91	2,585.84	70.82	155,029.42
Total 2006 Emissions	**2,967.28**	**473.89**	**2,953.43**	**78.96**	**177,068.02**
Total 2006 Emissions (tpd)	**1.48**	**0.24**	**1.48**	**0.04**	**88.53**
Total 2006 Emissions (tpy)	**541.53**	**86.49**	**539.00**	**14.41**	**32,314.91**
Analysis Year 2012					
Drilling Phase	10.64	1.26	7.08	0.24	875.02
Completion Phase	33.99	4.04	22.62	0.75	2,794.40
Production Phase	6,302.10	748.67	4,194.36	139.80	518,064.47
Total 2012 Emissions	**6,346.73**	**753.98**	**4,224.07**	**140.79**	**521,733.90**
Total 2012 Emissions (tpd)	**3.17**	**0.38**	**2.11**	**0.07**	**260.87**
Total 2012 Emissions (tpy)	**1,158.28**	**137.60**	**770.89**	**25.69**	**95,216.44**
Analysis Year 2018					
Drilling Phase	6.63	0.24	1.00	0.07	875.02
Completion Phase	21.17	0.78	3.20	0.23	2,794.40
Production Phase	3,923.91	143.90	593.91	42.98	518,064.47
Total 2018 Emissions	**3,951.70**	**144.92**	**598.12**	**43.28**	**521,733.90**
Total 2018 Emissions (tpd)	**1.98**	**0.07**	**0.30**	**0.02**	**260.87**
Total 2018 Emissions (tpy)	**721.19**	**26.45**	**109.16**	**7.90**	**95,216.44**

4.3 Temporal Distribution

To develop a diurnal distribution of emissions, NCTCOG staff utilized automatic traffic recorder (ATR) data which distributes volume of trips across 24 hours in a day. Use of this data is standard NCTCOG process for travel demand modeling.

NCTCOG staff did not expect industry operating patterns to vary depending on school or summer seasons. Indeed, survey results did not indicate any seasonal variation in operation. Therefore, Annual Average Daily adjustment factors were applied with no seasonal adjustment. The diurnal distribution is derived from vehicle classification counts of multi-unit trucks from year 2004; detailed information is provided in Appendix V.

4.4 Spatial Distribution

For this study, emissions results are distributed spatially at the county level. For on-road emissions, regional VMT estimates for the drilling and completion phases were adjusted by county proportional to the number of sites drilled in each county for that analysis year based upon RigData information (11). The DFX-Barnett Shale Module produced VMT results by county and by functional class. The functional class distribution from the production phase was applied to county-specific VMT from the drilling and completion phases in order to distribute VMT by functional class, as it is reasonable to assume similar distribution across roadway types as trucks must travel to the same well sites in all phases. Exhibit 4.6 illustrates county-level emissions for the six Barnett Shale counties within the MPA boundary.

Exhibit 4.6: Oil and Gas Truck Emissions by County, lbs/day

Pollutant	NO_X	VOC	CO	PM	CO_2
Analysis Year 2006					
Denton County	1,575.87	215.96	1,492.45	60.52	123,034.10
Hood County	212.34	22.88	186.75	10.65	21,621.41
Johnson County	484.47	44.16	409.51	27.18	55,659.85
Parker County	637.09	70.56	571.61	32.16	62,245.15
Tarrant County	445.42	37.87	366.78	26.11	54,188.15
Wise County	1,728.06	204.52	1,561.20	78.20	160,269.80
Analysis Year 2012					
Denton County	1,512.96	167.46	1,026.62	43.16	172,353.65
Hood County	433.25	45.46	297.74	13.90	58,828.82
Johnson County	1,911.64	206.87	1,303.25	57.91	235,503.41
Parker County	826.17	84.34	582.05	29.34	128,213.93
Tarrant County	1,862.40	199.26	1,273.91	55.67	240,589.77
Wise County	1,590.61	164.96	1,095.97	52.36	223,518.94
Analysis Year 2018					
Denton County	850.18	31.87	136.34	11.67	140,513.17
Hood County	224.94	8.59	37.78	3.52	43,298.58
Johnson County	1,039.74	39.25	169.80	15.18	183,228.66
Parker County	407.15	15.84	71.29	7.16	88,800.47
Tarrant County	1,005.37	37.83	164.76	14.74	183,609.64
Wise County	811.22	31.12	137.74	13.10	161,565.78

4.5 Emissions Summary

Exhibit 4.7 summarizes total emissions for all phases of drilling. Consistent with trends in overall O&G truck activity, emissions from the drilling and completion phases are lower in 2012 than in 2006. However, emissions associated with the production phase are significantly higher and offset the reduction from the first two phases. The majority of emissions for each analysis year are associated with extended idling of HDDVs.

The rate of activity in 2018 is forecasted to be nearly identical to that from 2012, consistent with conformity regulations and planning assumptions as outlined in Section 2.2. However, estimated NO_X emissions decrease significantly, which is a reflection of lower emission rates in future years which reflect fleet turnover and use of cleaner engines. For VMT-based emissions, this is based upon MOVES 2010a emission factors. For idling emissions, this is due to significant growth in the proportion of trucks powered by Certified Clean Idle engines and is predicated on the assumption that fleet turnover will continue to occur at the same pace as has been observed in recent years.

Exhibit 4.7: Summary of Oil and Gas Truck Emissions, TPD and TPY

Pollutant	NO_X	VOC	CO	PM	CO_2
Analysis Year 2006					
Total 2006 Emissions (tpd)	2.54	0.30	2.29	0.12	240.01
Total 2006 Emissions (tpy)	927.69	108.76	837.36	42.85	87,603.37
Analysis Year 2012					
Total 2012 Emissions (tpd)	4.07	0.43	2.79	0.13	529.50
Total 2012 Emissions (tpy)	1,485.01	158.47	1,018.27	46.05	193,269.06
Analysis Year 2018					
Total 2018 Emissions (tpd)	2.17	0.08	0.36	0.03	400.51
Total 2018 Emissions (tpy)	791.80	30.02	130.98	11.93	146,185.47

As illustrated in Exhibit 4.7, approximately 4.07 tpd NO_X can be attributed to HDDVs serving this industry in 2012, based on the results of this study. This is considered to be a conservative estimate of emissions based upon the fact that numerous assumptions were made throughout the process of developing VMT estimates. When pressed to make an assumption due to lack of or conflicting data, NCTCOG used conservative estimates.

For comparison, diesel transit buses and diesel school buses contribute approximately 2.68 tpd and 3.27 tpd NO_X, respectively (3). NCTCOG developed the on-road mobile source emission inventory for the Dallas-Fort Worth ozone nonattainment area, which TCEQ combined with emission inventories for other sectors to develop the total emissions inventory used in the Dallas-Fort Worth Attainment Demonstration SIP Revision for the 1997 8-Hour Ozone Standard Nonattainment Area. This SIP Revision indicates that the total NO_X emissions inventory for the Dallas-Fort Worth nonattainment area in 2012 is 370 tpd. Therefore, the addition of these emissions in 2012 would increase the total NO_X emissions inventory by one percent (1%), and increase the on-road emissions inventory by approximately two percent (2%).

Chapter 5: Accomplishments and Limitations of Work

NCTCOG accomplished several key items outlined below. Through improved methodologies and the development of a synthetic module, NCTCOG was able to develop an emissions inventory for truck traffic serving the O&G industry in the Barnett Shale. While this study proved challenging at times due to the lack of accurate or incomplete data available, it provided the opportunity to enhance NCTCOG's understanding of O&G operations and build better relationships with industry partners.

5.1 Data Collection and Analysis

Data acquisition is an important component of inventory development. NCTCOG followed quality assurance/quality control requirements consistent with the applicable elements of ANSI/ASQ E4-2004: Specifications and Guidelines for Quality Systems for Environmental Data Collection and Technology Programs (23). NCTCOG collected a significant amount of data from a variety of sources including the following:

- TxDMV Registration Data (Appendices W and X) and Oversize Overweight Permit Data
- Existing Shale Industry Reports/Studies
    - TTI Study: *Energy Developments and the Transportation Infrastructure in Texas: Impacts and Strategies* (8)
    - TxDOT Presentation: Barnett Shale Gas Exploration Impact on TxDOT Roadways: Fort Worth District (Richard Schiller, P.E.) (7)
    - City of Fort Worth Presentation: Local Land and Transportation Controls (Rick Trice, P.E.) (17)
    - Chesapeake Presentation: Barnett Shale: A Powerful Drive for North Texas (Julie Wilson) (14)
- RigData Reporting: Rig Counts (11) (Appendix AB)
- RRC Data: Gas Well and SWD Sites (2)
- NCTCOG DFX Model: DFX Roadway Network
- NCTCOG Demographics: Demographic Data
- Survey Reponses from Industry Participants (Appendix C)
    - Surveys of Natural Gas Operators (Appendix A)
    - Surveys of Industry Trucking Contractors (Appendix B)
- Phone Calls/Meetings
    - Industry Participants
    - RRC Staff

The data that was available was often fragmented, which resulted in a significant amount of staff time and resources expended simply for compilation of existing information. In turn, this limited the amount of time and resources available to collect additional data needed to fill the data holes.

NCTCOG staff included the following data quality objectives when analyzing data: precision, completeness, and comparability. Where sufficient information existed, NCTCOG staff worked with O&G producers, water hauling company personnel, and other agencies to ensure that Barnett Shale specific parameters employed represented local activity and conditions. Staff ensured methodologies used in calculating emissions were accurate and consistent with those used in emission inventory development for other purposes. Emissions inventories were compared to most recent inventories developed for the region for reasonableness of emission estimates for each pollutant type.

5.2 Synthetic Module Development

A critical element to this study was the development of the DFX-Barnett Shale Module, which set up a process through which the trip activity and emissions generated by the O&G industry can be captured. Since the process and methodology has now been established, refinements can easily be done in the future to incorporate revised assumptions or add further detail to improve accuracy. In addition, NCTCOG staff was able to translate the assumed site-specific activity trip rates into trips and VMT levels distributed region wide. Details on the module development can be found in Chapter 3.

Incomplete datasets or lack of data also negatively impacted the ability to refine the DFX-Barnett Shale Module and forced staff to make numerous simplifying assumptions. Changes in key variables, particularly trip pattern and trip length have the potential to significantly impact total VMT and emissions results. Among the assumptions, the most critical lack of data surrounded the following:

Trip Origins: As discussed in Chapter 3, the DFX module developed assumes all water hauler trips travel from a single gas well (origin) to different SWDs (destination) by following a trip distribution based upon multiple shortest paths. It is quite likely that a truck travels to multiple origins before arriving at a destination; however, no conclusive information was available to help derive a specific assumption regarding trip chaining between different gas wells.

Trip Destinations: Due to lack of information, trip paths and their corresponding trip lengths for the production phase was driven solely by the DFX module based upon the results of multiple shortest path methodology applied in a multi-modal/multi-class user-equilibrium traffic assignment. In reality, many factors likely play into driver choice of SWD. These may include, but are not limited to, distance, disposal fees, contractual obligations, and private versus commercial access.

5.3 Estimated Emissions Inventory

NCTCOG staff calculated emissions associated with VMT estimated for the drilling, completion, and production phases. In addition, staff estimated idling emissions associated with loading and unloading time at a well site or SWD. NCTCOG staff created an on-road mobile source emissions inventory for three analysis years: 2006, 2012, and 2018 by developing emission factors using MOVES 2010a. Exhibit 5.1 summarizes emissions for the region by pollutant.

Exhibit 5.1: Summary of Oil and Gas Truck Emissions, TPD and TPY

Pollutant	NO_X	VOC	CO	PM	CO_2
Analysis Year 2006					
Total 2006 Emissions (tpd)	2.54	0.30	2.29	0.12	240.01
Total 2006 Emissions (tpy)	927.69	108.76	837.36	42.85	87,603.37
Analysis Year 2012					
Total 2012 Emissions (tpd)	4.07	0.43	2.79	0.13	529.50
Total 2012 Emissions (tpy)	1,485.01	158.47	1,018.27	46.05	193,269.06
Analysis Year 2018					
Total 2018 Emissions (tpd)	2.17	0.08	0.36	0.03	400.51
Total 2018 Emissions (tpy)	791.80	30.02	130.98	11.93	146,185.47

Chapter 4 provides details on methodology and results. The results will help in the development of SIP modeling and also aid with the assessment of control strategies.

As previously discussed, a key limitation with this study was the numerous assumptions NCTCOG staff had to make. In regard to quantification for the drilling and completion phases, a major challenge was the fact that many companies that work in these segments of the industry work across Texas and even into other states, as they may work in various shale formations. This poses obstacles in identifying a “typical” route, trip length, or operating pattern. For example, one respondent indicated that their trucks pick up rock at one of three yards in the state, deliver to one or more sites, and return by the end of the day to leave the truck overnight. Therefore, their trucks may travel a great distance within a single trip. However, because the scope of this study was confined to the NCTCOG MPA, the proportion of mileage within the MPA would need to be determined.

5.4 Partnerships Established

The ability to thoroughly understand activities associated with an industry is an essential element to any analysis and NCTCOG would not have been able to complete this study without the participation and input from key players from the O&G sector. This was an important obstacle to overcome because in general, the industry is concerned about the possibility of future regulation, which may have led to hesitation in sharing information and been a factor in the low survey response rate. Despite this obstacle, the connections NCTCOG was able to establish with O&G partners including producers, trucking contractors, and other industry experts will prove to be helpful in facilitating future collaboration. NCTCOG will foster these new partnerships and seek input as appropriate as the region works to meet attainment.

5.5 Discovery of Incomplete Data

Finally, an important accomplishment not to be overlooked is gaining a greater understanding of what key pieces of information are not readily available and need further investigation. Although this is also a limitation, an improved grasp of what remains unknown or uncertain is still an important step. NCTCOG anticipates working with the state and industry alike to close these data gaps to refine future estimates.

Chapter 6: Recommendations for Future Studies

This study opens the door to numerous possibilities for further investigation and analysis which can improve upon the estimates in this report. One of the most important elements would be revising some of the major assumptions made in this report, particularly those outlined in Chapter 4. In order to accomplish this, NCTCOG recommends a few key opportunities for data collection which are outlined in this chapter.

6.1 Data Collection

Assumptions were made throughout the report due to lack of reliable observed data. These assumptions could be further refined to improve accuracy, and changes to several key data points has the potential to significantly impact VMT and emissions results. NCTCOG believes that the greatest information gaps surround assumptions made for the drilling and completion phases, outlined in Exhibits 2.1 and 2.2, as these crews frequently operate outside the MPA working in other shales and/or oilfields. One of the best ways to gather comprehensive, reliable data regarding these phases of O&G activity would be to enter into agreements with a few trucking contractors who work in these segments of the industry and have the companies install geographic positioning systems (GPS) equipment on their trucks in order to monitor routes traveled and distance. Use of GPS would have the added benefit of providing further insight on idle time, etc.

In regard to the production phase, the greatest opportunity for improvement is centered upon refining the model used to estimate VMT. However, this model cannot be refined without the presence of concrete data on which to base revised assumptions. Use of GPS systems as described previously would be invaluable in providing information. Other opportunities may be useful in this phase as well. Additional surveys or interviews, specifically with water haulers, would be helpful in addressing some of the data gaps regarding trip pattern and trip length. If a standard trip pattern and trip length was better understood, then a minimum number of stops and minimum trip length could be coded into the DFX-Barnett Shale Module to improve representation of total VMT. In addition, surveys of SWD owners and operators would be helpful in better understanding wait times and volume of trips arriving at a given site in a day.

Additional opportunities to improve upon available data may exist through coordination with appropriate state agencies. For example, the RRC maintains an extensive database of information on gas wells and SWDs, much of which is accessible online. However, online access is limiting as information must be gathered on a site-by-site basis. Availability of this type of information in a comprehensive database would be helpful, as information could be analyzed much more readily. However, obtaining this type of information may require a memorandum of agreement with the Railroad Commission (RRC).

6.2 Model Refinement

With additional time and resources, the DFX-Barnett Shale module may be further improved mainly in three aspects as listed below.

The current assumption that a gas well has a trip rate of 0.33 per day was made as a simplifying assumption for all well sites. However, some wells may be closed. Additional detail from the RRC could help differentiate between active and inactive wells. In addition, different trip rates could be applied to each gas well during the production phase based upon age of the well to more truly reflect the deterioration of activity levels over time. Therefore, the trip generation may be fine-tuned if more comprehensive survey data becomes available.

The water hauler trips from gas wells to SWDs are assumed to be distributed based on a general gravity-based trip distribution model, where the attractiveness of SWDs is a function of the inverse of the square of their network-based distance between the gas well and the SWD. This is simply suggesting that the farther a gas well is from an injection well, the less likely a trip is generated between the two. However, with more detailed, observed information, an assumption that is closer to the reality may be applied. For instance, a gas well may send water haulers to any injection wells within 40 miles, or an injection well may only receive, at most, 100 water haulers per day. Once the appropriate data becomes available, these conditions may be easily implemented in the module as well. With more comprehensive information, more advanced methods such as choice theory, can be used to model the selection process of SWDs by water haulers or the trip-chaining process between several gas wells.

Another factor that may impact the distribution of water hauler trips from gas wells to SWDs is the capacity of produced water that is allowed to be disposed of at a given SWD or its permitted capacity. Each SWD has a specific permitted capacity defined by the RRC. This information is available online but must be collected well by well, which requires significant staff time and resources. In future work, if this complete dataset could be provided by the RRC, each SWD could be programmed with its permitted capacity to ensure that the model does not assign too many truck trips to a single SWD.

Due to the nature of travel demand forecasting, the model does not include all local roads in the region. Instead, centroid connectors are used as a representative of those roads. Therefore, as discussed in Section 3.2.3, it was decided to apply a factor of 1.28 to the O&G truck VMT on the centroid connectors to better account for the lower density of local roads in the travel demand model. In future studies, more local roads can be coded into DFX, reducing or eliminating the need for an adjustment factor and more accurately capturing VMT.

An important step in any model development is model validation, which gauges how accurately results were predicted by comparing modeled results against observed data. Due to the short duration of this project, model validation was not possibly within the contracted timeframe. However, in future work, NCTCOG staff could take steps to validate the DFX-Barnett Shale Module and make adjustments to various inputs based upon feedback gained during the validation effort.

To summarize, the module structure and procedures are implemented based on the current modeling practices at NCTCOG, making reasonable assumptions due to the lack of a comprehensive survey dataset regarding the detail activities in the gas industry. In the future, with sufficient resources and data, these assumptions may be adjusted to better reflect the actual situation and predict the future travel pattern without resulting in drastic changes in the current module design.

6.3 Enhanced Vehicle Classification Counts on Non-Regionally Significant Roadways

This study confirmed the need for improved vehicle classification counts on rural roads in and around areas of significant O&G activity, distributed by time of day, given the discovery of the increased amount of truck traffic traveling on local roadways (e.g. county roads) that are not captured as regionally significant in travel demand modeling. There is a persistent lack of information about exactly where these trucks travel and what paths they take which results in the need for numerous assumptions to be made. These assumptions have the potential to significantly impact estimates of resources needed for roadway maintenance and safety issues. In addition to the Barnett Shale activity in North Central Texas, other areas of the state are also impacted by recent growth in the O&G industry. Significant activity is also occurring in the Eagle Ford Shale in south Texas, Permian Basin in west Texas, and western edge of the Haynesville Shale in east Texas. These areas could benefit from this type of improved data. Benefits could be reaped by a variety of TxDOT and local government interests, aside from emissions inventory development, including safety planning, roadway maintenance planning, and budget planning for jurisdictions which oversee areas of O&G development.

References

1. American Petroleum Institute. Freeing Up Energy: Hydraulic Fracturing: Unlocking America's Natural Gas Resources. *www.api.org.* [Online] July 19, 2010. http://www.api.org/~/media/Files/Policy/Exploration/HYDRAULIC_FRACTURING_PRIMER.ashx.
2. Railroad Commission of Texas. Geodatabase of Barnett Shale Wells. January 2012.
3. Texas Commission on Environmental Quality. Dallas-Fort Worth Attainment Demonstration SIP Revision for the 1997 Eight-Hour Ozone Standard Nonattainment Area. *www.tceq.texas.gov.* [Online] 2011. www.tceq.texas.gov/assets/public/implementation/air/sip/dfw/ad_2011/10022SIP_ado_111811.pdf.
4. Official Release of the MOVES2010 Motor Vehicle Emissions Model for Emissions Inventories in SIPs and Transportation Conformity: Notice of Availability. s.l. : 75 Federal Register 40, 2 March 2010.
5. Guidance on the Use of MOVES 2010 and Subsequent Minor Revisions for State Implementation Plan Development, Transportation Conformity, and Other Purposes. [Online] April 2012. www.epa.gov/otaq/models/moves/documents/420b12010.pdf.
6. Texas Department of Transportation. Traffic Data and Analysis Manual. [Online] September 2011. http://onlinemanuals.txdot.gov/txdotmanuals/tda/manual_notice_tda.htm.
7. Schlachter, Barry. Drilling trucks have caused an estimated $2 billion in damage to Texas roads. *Fort Worth Star-Telegram.* July 3, 2012.
8. Quiroga, Cesar, Fernando, Emmanual and Oh, Jeongho. *Energy Developments and the Transportation Infrastructure in Texas: Impacts and Strategies.* Austin : Texas Transportation Institute, 2012. Research Report FHWA/TX-12/0-6498-1.
9. Texas Transportation Institute. Underground Injection Control System. 2012.
10. Railroad Commission of Texas. Oil and Gas Directory - Operator Contact Information. *www.rrc.state.tx.us.* [Online] http://www.rrc.state.tx.us/data/operators/ogdirectory/index.php.
11. RigData Reporting. Information Request. July 7, 2012.
12. Barnett Shale Rig Reports. *Fort Worth Star-Telegram.* June, July 22, 30, and 7, 2012.
13. U.S. Environmental Protection Agency. Transportation Conformity Regulations as of April 2012. [Online] April 2012. www.epa.gov/otaq/stateresources/transconf/regs/420b12013.pdf.
14. Wilson, Julie. Barnett Shale: A Powerful Driver for North Texas. s.l. : Chesapeake Energy, January 2012.
15. Schiller, Richard. Barnett Shale Gas Exploration Impact on TxDOT Roadways. s.l. : Texas Department of Transportation, Fort Worth District, August 2010.
16. Barnett Shale Energy Education Council. What is Hydraulic Fracturing? *www.bseec.org.* [Online] [Cited: July 24, 2012.] www.bseec.org/sites/default/files/BSEEC-FactSheet-HydraulicFracturing.pdf.
17. Trice, Rick. Local Land and Transportation Controls. s.l. : City of Fort Worth, March 8, 2012.
18. Railroad Commission of Texas. H-10 Record Search. [Online] [Cited: December 17, 2011.] http://webapps.rrc.state.tx.us/H10/h10PublicMain.do.

19. U.S. Department of Energy. Carbon Dioxide from Gasoline and Diesel Fuel. *Vehicle Technologies Program.* [Online] June 22, 2009. www1.eere.energy.gov/vehiclesandfuels/facts/2009_fotw576.html.
20. U.S. Environmental Protection Agency. *Guidance for Quantifying and Using Long Duration Truck Idling Emission Reductions in State Implementation Plans and Transportation Conformity.* Office of Transportation and Air Quality. January 2004. EPA420-B-04-001.
21. California Air Resources Board. Manufacturers Advisory Correspondence 2007-03. [Online] August 2007. www.arb.ca.gov/msprog/macs/mac0703/mac0703.pdf.
22. Morasch, Charlie. CARB: California certified clean idle may be short lived. [Online] February 2008. www.truckflix.com/news_article.php?newsid=5466.
23. American National Standard Institute. *Specifications & Guidelines for Quality Systems for Environmental Data Collection & Environmental Technology Programs.* ANSI/ASQC E4-1994.

Appendices

All appendices are provided electronically.

Appendix A: Operator Survey
Appendix B: Final Truck Contractor Survey
Appendix C: Survey Responses
Appendix D: 2006 DFX Module Results
Appendix E: 2012 DFX Module Results
Appendix F: 2018 DFX Module Results
Appendix G: MOVES Emission Factor Inputs and Adjustments
Appendix H: 2006 Regional Emission Factors
Appendix I: 2012 Regional Emission Factors
Appendix J: 2018 Regional Emission Factors
Appendix K: 2006 Drilling Emission Calculations
Appendix L: 2006 Completion Emission Calculations
Appendix M: 2006 Production Emission Calculations
Appendix N: 2012 Drilling Emission Calculations
Appendix O: 2012 Completion Emission Calculations
Appendix P: 2012 Production Emission Calculations
Appendix Q: Texas Department of Motor Vehicles Registration Data
Appendix R: 2018 Drilling Emission Calculations
Appendix S: 2018 Completion Emission Calculations
Appendix T: 2018 Production Emission Calculations
Appendix U: Emission Summary
Appendix V: Diurnal Distribution of Truck Activity
Appendix W: Heavy-Duty Diesel Vehicles, 2007 or Newer by County
Appendix X: Heavy-Duty Diesel Vehicles, 2008 or Newer by County
Appendix Y: 2006 Idling Emissions Calculations
Appendix Z: 2012 Idling Emissions Calculations
Appendix AA: 2018 Idling Emissions Calculations
Appendix AB: Rig Count Data
Appendix AC: Injection Well Capacity Calculations
Appendix AD: MOVES 2010a Run Specifications