Drilling Rig Emission Inventory for the State of Texas

Final Report

Prepared for:

Texas Commission on Environmental Quality

Prepared by:

Eastern Research Group, Inc.

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LIST OF ACRONYMS

Acronym	Definition
API	American Petroleum Institute
CARB	California Air Resources Board
CO	Carbon Monoxide
DOE	U.S. Department of Energy
EIA	Energy Information Administration
ERG	Eastern Research Group
HAP	Hazardous Air Pollutant
hp	Horsepower
IADC	International Association of Drilling Contractors
MMBBL	Million Barrels
NEI	National Emissions Inventory
NIF	NEI Input Format
NO_x	Nitrogen Oxides
OSD	Ozone Season Daily
PM_{10}	PM with particle diameter less than 10 micrometers
$PM_{2.5}$	PM with particle diameter less than 2.5 micrometers
SCC	Source Classification Code
SIP	State Implementation Plan
SO_2	Sulfur Dioxide
TCEQ	Texas Commission on Environmental Quality
TexAER	Texas Air Emissions Repository
TIPRO	Texas Independent Producers and Royalty Owners Association
TOG	Total Organic Gases
TRC	Texas Railroad Commission
TxLED	Texas Low Emission Diesel
TXOGA	Texas Oil and Gas Association
US EPA	United States Environmental Protection Agency
VOC	Volatile Organic Compounds
WRAP	Western Regional Air Partnership

1.0 Executive Summary

The purpose of this study was to develop a comprehensive emissions inventory for drilling rig engines associated with onshore oil and gas exploration activities occurring in Texas in 2008. Oil and gas exploration and production facilities are considered some of the largest sources of area source emissions in certain geographical areas, dictating the need for continuing studies and surveys to more accurately depict these activities. A 2005 base year oil and gas emissions inventory developed for the Texas Commission on Environmental Quality (TCEQ) by Eastern Research Group (ERG) in 2007 (TCEQ, 2007) was comprehensive in coverage of all exploration and production facility and equipment types, including drilling rig engines. However, that project relied on data from secondary sources with assumptions applied to represent local activities. The Western Regional Air Partnership (WRAP) developed a comprehensive emissions inventory of oil and gas exploration and production facilities for the western states that did not include Texas, although the previous ERG study did make use of the WRAP results in terms of methodology and emission factors where practicable.

The current inventory effort built off of the previous 2007 study, focusing exclusively on drilling activities. The previous effort was expanded upon by improving both the activity data (well counts, types, and depths) used to estimate emissions, and through the development of updated drilling rig engine emission profiles. The improved well activity data was obtained through acquisition of the "Drilling Permit Master and Trailer" database from the Texas Railroad Commission (TRC), while the improved drilling rig emissions characterization profiles were obtained through a survey of oil and gas exploration and production companies. The activity data and emissions characterization data were then used to develop the drilling rig engine emissions inventory for a 2008 base year.

In order to survey drilling rig contractors and oil and gas operators across the state, ERG purchased contact information for companies that were active in well drilling activities that occurred in Texas in 2008 through a commercial vendor (RigData®). Through phone and email surveys, ERG obtained 45 drilling rig profiles representative of over 1,500 wells drilled in Texas in 2008.

The survey effort itself focused on collecting the following information from each respondent:

- The number of engines on a rig
- Engine make, model, model year, and size (hp)
- Average load for each engine

- Engine function (draw works, mud pumps, power)
- Actual engine hour data for each well (total hours)
- Actual engine fuel use data for each well (total fuel use)
- Total well drilling time (actual number of drilling days)
- Total well completion time (number of days needed for well completion activities)
- Well depth
- Number of wells represented by survey

Target pollutants for this inventory include nitrogen oxides (NO_X), volatile organic compounds (VOC), carbon monoxide (CO), particulate matter (PM_{10} and $PM_{2.5}$), sulfur dioxide (SO_2), and hazardous air pollutants (HAP). Emissions were calculated for each county in Texas where drilling occurred in 2008 and are provided in annual tons per year and by typical ozone season day. For planning purposes, the 2008 base year estimates were used to develop 2002 and 2005 prior year inventories, as well as projected inventories for 2009 through 2021. 2002 and 2005 prior year inventories were based on TRC records of oil and gas well completions during those years, and U.S Department of Energy (DOE), Energy Information Administration (EIA) oil and gas production growth estimates were used to develop the projections for future years 2009 through 2021.

Emissions estimates developed from this inventory project may be used for improved input data to photochemical air quality dispersion modeling, emissions sensitivity analyses, State Implementation Plan (SIP) development, and other agency activities. The final 2002, 2005, and 2008 base year inventory estimates are provided in National Emissions Inventory (NEI) Input Format (NIF) 3.0 to facilitate entry of the data into the state's TexAER (Texas Air Emissions Repository) database, and for the purposes of submittal to US EPA. For purposes of NIF preparation, Source Classification Code (SCC) 23-10-000-220 (Industrial Processes - Oil and Gas Exploration and Production - All Processes - Drill Rigs) was used as provided by TCEQ (TCEQ, 2009).

Table 1-1 summarizes the statewide annual emission estimates for 2002, 2005, and 2008 through 2021.

Table 1.1 Drilling Rig Estimates (tons/year)

Year	CO	NO_x	PM_{10}	$PM_{2.5}$	SO_2	VOC
2002	13,305	35,828	2,552	2,475	4,776	3,631
2005	15,878	42,854	3,036	2,945	5,977	4,337
2008	16,721	55,238	2,543	2,467	956	4,326
2009	16,769	55,457	2,550	2,474	961	4,340
2010	16,336	53,123	2,417	2,344	45	4,182

Table 1.1 Drilling Rig Estimates (tons/year) (Continued)

Year	CO	NO_x	PM_{10}	$PM_{2.5}$	SO_2	VOC
2011	15,117	48,462	2,319	2,249	44	3,806
2012	14,748	46,253	2,263	2,196	43	3,665
2013	12,008	39,793	1,378	1,337	38	3,413
2014	11,945	39,461	1,372	1,331	38	3,392
2015	11,755	38,837	1,350	1,310	37	3,349
2016	11,558	36,440	1,320	1,280	37	3,320
2017	8,915	34,771	1,118	1,085	36	2,800
2018	6,114	31,282	811	787	35	2,227
2019	6,073	31,127	805	781	35	2,215
2020	6,035	30,771	800	776	35	2,205
2021	3,299	26,063	448	435	33	1,504

2.0 Introduction

The purpose of this study was to develop a comprehensive emissions inventory for drilling rig engines associated with onshore oil and gas exploration activities occurring in Texas in 2008. Oil and gas exploration and production facilities are considered some of the largest sources of area source emissions in certain geographical areas, dictating the need for continuing studies and surveys to more accurately depict these activities. A previous study conducted by Eastern Research Group (ERG) in 2007 under TCEQ contract 582-7-84003, Work Order 01 was comprehensive in coverage of all the exploration and production facility and equipment types, including drilling rig engines, although this project relied on data from secondary sources with assumptions applied to represent local activities (TCEQ, 2007). The Western Air Regional Partnership (WRAP) developed a comprehensive emissions inventory of oil and gas exploration and production facilities for the western states that did not include Texas, although the previous ERG study did make use of the WRAP study in terms of methodology and emission factors where practicable.

While drilling activities are generally short-term in duration, typically covering a few weeks to a few months, the associated diesel engines are usually very large, from several hundred to over a thousand horsepower. As such, drilling activities can generate a substantial amount of NO_x emissions. While previous studies have focused more intently on quantifying the ongoing fugitive VOC emissions associated with oil and gas production, significant uncertainty remains regarding the shorter term NO_x emission levels associated with drilling activity.

In order to gain a more accurate understanding of emissions from drilling rig engines, data regarding typical rig profiles (number of engines, engine sizes, and engine load factors) were collected through phone and email surveys for drilling operations for the 2008 base year. These data were used to develop well drilling emissions profiles using US EPA's NONROAD emissions model.[1] To develop the statewide emissions inventory, the drilling rig emissions profiles developed as a result of the survey were applied to well drilling activity data for 2008 obtained from the Texas Railroad Commission (TRC).

The activity and drilling rig engine emissions profiles developed under this study were used to develop emissions estimates of volatile organic compounds (VOC), nitrogen oxide (NO_x), carbon monoxide (CO), particulate matter (PM_{10} and $PM_{2.5}$), sulfur dioxide (SO_2), and

[1] While the NONROAD model was used to calculate drilling activity emissions (in order to more accurately capture emission standard phase in impacts), these emissions are actually classified as area sources emissions and reported as such to the TCEQ.

hazardous air pollutants (HAP) for drilling rig engines across the state. Emissions are calculated on a county-level basis and provided in annual tons per year and by typical ozone season day. For planning purposes, the 2008 base year estimates were used to develop 2002 and 2005 prior year inventories, as well as projected inventories for 2009 through 2021.

Section 3.0 of this report provides the results of a review of existing literature as well as currently available data that could be used to develop the inventory. This discussion also provides an overview of the drilling process and identifies the types of activities and equipment that are commonly associated with drilling activity. Section 4.0 provides an overview of the data collection plan and the subsequent survey that was used to obtain the information needed to develop the model drilling rig emissions profiles. Section 5.0 presents the results of the survey, including a discussion of how the data was broken down into distinct “model” drilling rigs by well type and depth. Section 6.0 describes the development of the emissions inventory including how the activity data was compiled, how the model drilling rig emission profiles were developed, and how these model drilling rig emission profiles were combined with the activity data to develop the 2002, 2005, and 2008 through 2021 emission inventories.

3.0 Review of Existing Literature

At the start of this study ERG conducted a review of relevant literature, current studies, and available data that could be used in the development of a drilling rig engine emissions inventory for Texas. The results of this research are discussed below in Sections 3.1 through 3.3. Section 3.1 discusses the review of existing studies concerning estimating emissions from oil and gas drill rig operations, Section 3.2 covers the results of the review of existing Texas data available from government and industry websites and publications, and Section 3.3 includes a discussion of drilling rigs and the types of engines and activities occurring during a drilling operation.

3.1 Review of Existing Studies

Over the last several years numerous studies have been conducted in the western states to develop area source emission estimates for oil and gas exploration and production sources, with subsequent studies improving upon the data collection methodology and emission estimation approaches. Most of these studies addressed emissions from drilling rig engines to some degree. The relevant studies ERG identified are listed in Table 3-1.

Table 3.1 Existing Oil and Gas Exploration Emissions Studies

Report Title	Geographic Coverage	Publication Date
Oil and Gas Emission Inventories for the Western States (Russell, et al., 2005)	WRAP States	December, 2005
Ozone Precursors Emission Inventory for San Juan and Rio Arriba Counties, New Mexico (Pollack, et al., 2006)	San Juan and Rio Arriba Counties, New Mexico	August, 2006
Emissions from Oil and Gas Production Facilities (TCEQ, 2007)	Texas	August, 2007
WRAP Area Source Emissions Inventory Projections and Control Strategy Evaluation Phase II (Bar-Ilan, et al., 2007)	WRAP States	September, 2007
Development of Baseline 2006 Emissions from Oil and Gas Activity in the Denver-Julesburg Basin (Bar-Ilan, et al., 2008)	Denver-Julesburg Basin, Colorado	April, 2008
Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories (Bar-Ilan, et al., 2008a)	CENRAP States	November, 2008

Table 3.1 Existing Oil and Gas Exploration Emissions Studies (Cont.)

Report Title	Geographic Coverage	Publication Date
Development of Baseline 2006 Emissions from Oil and Gas Activity in the Piceance Basin (Bar-Ilan, et al., 2009)	Piceance Basin, Colorado	January, 2009

Based on a review of these studies, ERG developed a series of survey questions to obtain the types of data that would be needed to develop the 2008 base year emissions inventory. The resultant survey was developed using example survey questions and forms from several of these existing studies.

The studies identified in Table 3-1 were comprehensive in nature, inclusive of all emission sources found at oil and gas exploration and production locations. While drilling rig engines were typically included in these studies, this source category was not the primary focus of these efforts, as these inventories addressed emissions sources associated with both the exploration and production sides of the oil and gas industry. As such, many of the surveys used in these studies were sent to the oil and gas producers themselves, and not directly to the owners and operators of the drill rigs, who are typically contracted by the producers to drill the well. As described below in Section 5, ERG focused this survey effort on the drilling contractors themselves, who are most familiar with drilling equipment and activities, with less emphasis on the production companies.

3.2 Review of Existing Data

All exploratory oil and gas drilling in Texas requires a permit. These permits are processed and maintained through the TRC. The drilling permits are available for review through the TRC website, and include well-specific data such as approval date, location (county), well profile (vertical, horizontal, directional), well depth, start or "spud-in" date, and well completion date. On March 10, 2009, ERG obtained this data in electronic format through acquisition of the "Drilling Permit Master and Trailer" database. This database formed the basis of the activity data used to develop the 2008 base year emissions inventory.

In addition to the drilling permit data obtained through the TRC, many of the larger drilling contractors provide information about their drilling rig fleets in their on-line websites. Examples of these websites are provided in the approved Data Collection Plan, which is included as Appendix A of this report. ERG reviewed this on-line information in an effort to gain a better understanding of typical drilling rig engine profiles, including the size, number, and type of engines used on typical rigs. Additional information provided included make and model of the engines. Engine manufacturer websites were also reviewed and proved useful as a resource to obtain engine specifications and fuel usage data that could be used to gapfill the data obtained during the survey and needed to complete the emissions inventory. For example, engine fuel usage data could be used to determine load percentages for engines where the operator provided fuel use data but did not provide load estimates.

3.3 Drilling Rig Overview

Air pollutant emissions from oil and gas drilling operations originate from the combustion of diesel fuel in the drilling rig engines. The main functions of the engines on an oil and gas drilling rig are to provide power for hoisting pipe, circulating drilling fluid, and rotating the drill pipe. Of these operations, hoisting and drilling fluid circulation require the most power.

There are two common types of rigs currently in use – mechanical and electrical. In general, mechanical rigs have three independent sets of engines. The first set of engines (draw works engines) are used to provide power to the hoisting and rotating equipment, a second set of engines (mud pump engines) are dedicated to circulating the drilling fluid which is commonly referred to as "mud", and a third set of engines (generator engines) are used to provide power to auxiliary equipment found on the drill site such as lighting equipment and heating and air conditioning for crew quarters and office space. There may be one, two, or more draw works engines, depending on the input power required. There are typically two mud pumps for land rigs, with each mud pump independently powered by a separate engine. The mud pump engines are typically the largest engines used on a mechanical rig. Finally, there are typically two electric generator engines per mechanical rig, with one running continuously and the second serving as a stand by unit.

> **Draw Works engines** – used to power hoisting and rotating equipment
> **Mud Pump engines** – used to circulate drilling fluid
> **Generator engines** – used to power auxiliary equipment

Electrical rigs are typically comprised of two to three large, identical diesel-fired engine-generator sets that provide electricity to a control house called a silicon controlled rectifier (SCR) house. Electricity from the SCR house is then used to provide power to separate motors on the rig. In this configuration, there are dedicated electric motors used for the draw works/hoisting operations, the mud pumps, and other ancillary power needs (such as lighting). The generator engines are loaded as required to meet fluctuating power demands, with one unit typically designated for standby capacity. The trend in new rig design is almost exclusively towards electric rigs, except perhaps for the smallest rigs. This is probably due to the relative expense of engines versus motors, both in terms of initial cost and maintenance. Today, electrical rigs are common, especially for larger rigs (Bommer, 2008).

After drilling and casing a well, it must be "completed." Completion is the process in which the well is enabled to produce oil or gas. Once the desired well depth is reached, the geological formation must be tested and evaluated to determine whether the well will be completed for production, or plugged and abandoned. To complete the well production, casing is installed and cemented and the main drilling rig is dismantled and moved to the next site. A smaller rig, called a completion rig (also known as a workover rig), is then moved on site to bring the well into production, to perforate the production casing and run production tubing to complete the well. Typically, the completion rig is a carrier-mounted arrangement and may be on-site for several days to a week or more depending on well depth and other factors. The completion rigs hoist smaller loads and pump at lower rates than the drilling rigs, and therefore require much smaller engine capacity.

Increasingly, reservoir productivity is enhanced by the application of a stimulation technique called hydraulic fracturing. In this process, the reservoir rock is hydraulically overloaded to the point of rock fracture. The fracture is induced to propagate away from the well bore by pumping hydraulic fracturing fluid into the well bore under high pressure. The fracture is kept open after the end of the job by the introduction of a solid proppant (sand, ceramic, bauxite, or other material), by eroding the sides of the fracture walls and creating rubble by high injection rates, or for carbonate formations, by etching the walls with acid. The fracture thus created and held open by the proppant materials becomes a high conductivity pathway to the well bore for reservoir fluid.

In vertical wells a single fracture job per reservoir is commonly done. In high angle or horizontal wells, it is common to perform multiple fracturing jobs (multi stage fracturing) along the path of the bore hole through a reservoir. Fracturing jobs are often high rate, high volume, and high pressure pumping operations. They are accomplished by bringing very large truck-mounted diesel-powered pumps (e.g., 2,000 hp or more) to the well site to inject the fracturing fluids and material, and to power the support equipment such as fluid blenders. The measure of the power required is based on the hydraulic horsepower necessary to fracture the well. Although very short in duration (typically less than a day), fracturing activities may result in substantial NO_x emissions due to the very high horsepower requirements.

Oil and gas wells are commonly classified as vertical, directional, or horizontal wells, depending on the direction of the well bore. Vertical wells are the most common, and are wells that are drilled straight down from the location of the drill rig on the surface. Directional wells are wells where the well bore has not been drilled straight down, but has been made to deviate from the vertical. Directional wells are drilled through the use of special tools or techniques to ensure that the well bore path hits a particular subsurface target, typically located away from (as opposed to directly under) the surface location of the well. Horizontal wells are a subset of directional wells in that they are not drilled straight down, but are distinguished from directional wells in that they typically have well bores that deviate from vertical by 80 - 90 degrees. Horizontal wells are commonly drilled in shale formations. Once the desired depth has been reached (the well bore has penetrated the target formation), lateral legs are drilled to provide a greater length of well bore in the reservoir.

4.0 Data Collection Plan

ERG's Data Collection Plan identified the proposed approach for collecting the information needed to develop a comprehensive emissions inventory for land-based drilling rig engines in the state of Texas in 2008. The primary focus of the data collection survey was to obtain engine operating data from rig operators who were actively drilling in Texas in 2008. The goal of this survey was to obtain sufficient data to allow for the development of a series of "model" drilling rig emission profiles for different well types and/or depths to apply to the corresponding subsets of the TRC well activity data.

Details of the Data Collection Plan were subject to external peer review and approved by TCEQ. ERG conducted the data collection as per the approved Data Collection Plan, which is included as Appendix A.

4.1 Participant Recruitment

In order to encourage survey response rates, stakeholder support for the study was sought. In addition to consulting with contacts at the University of Texas, Southern Methodist University, and the Texas Railroad Commission for suggestions on implementing the survey and soliciting participants, the following trade associations were contacted to help encourage participation in the study:

- International Association of Drilling Contractors (IADC)
- Texas Independent Producers and Royalty Owners Association (TIPRO)
- Texas Oil and Gas Association (TXOGA)

ERG provided the trade associations with a draft copy of the survey materials and requested they distribute them to their membership for feedback. In addition, ERG requested these trade groups lend their support to the project through a letter of introduction about the study to be sent to their constituents. While these associations were supportive of the goals and appreciated the need for this study, ERG did not receive any feedback on the draft survey materials. However, both TIPRO and TXOGA recognized the importance of the project and agreed to allow ERG to reference their support in the survey transmittal letter (see Appendix B).

4.2 Phone/Email Surveys

Once the survey was developed, ERG obtained contact information for oil and gas well operators and drilling contractors in order to distribute the survey. The primary source of data used to identify target respondents was the commercial RigData® database. This database contains information for over 24,000 drilling permits issued in Texas between January 1, 2008 and March of 2009. For over 14,000 of these records, drilling contractor contact information was provided. The RigData® database used to develop the target respondent list has been provided to the TCEQ in electronic format

ERG attempted to contact each of the drilling contractors included in this listing through phone and/or email surveys. The survey effort itself focused on collecting the following information from each respondent:

- The number of engines on a rig
- Engine make, model, model year, and size (hp)
- Average load for each engine
- Engine function (draw works, mud pumps, power)
- Actual engine hour data for each well (total hours)
- Actual engine fuel use data for each well (total fuel use)
- Total well drilling time (actual number of drilling days)
- Total well completion time (number of days needed for well completion activities)
- Well depth
- Number of wells represented by survey

An example of the data collection form used to compile the results of the survey is presented in Appendix C. For those respondents who were contacted via email, an Excel file containing similar information was provided as an email transmittal. The results of the survey effort are described in Section 5.0.

4.3 Confidentiality

Confidentiality was stressed to survey participants, as evidenced in the survey letter. ERG is particularly sensitive to the privacy of individuals and businesses. Therefore all interviews and data collection efforts began with a guarantee of privacy, anonymity, and confidentiality. To ensure survey respondent's rights to privacy, respondents were informed of the research purpose, the kinds of questions that would be asked, and how the TCEQ may use the results of the study. Confidentiality was maintained by eliminating respondent names from the study datasets before provision to the TCEQ.

5.0 Data Collection Results

5.1 Survey Findings

Using the contact information in the RigData® dataset, ERG began implementation of the Data Collection Plan on April 30, 2009 and collected data through June 16, 2009. Initially, contacts were attempted with many of the oil and gas well operators themselves. As a rule, the operators were knowledgeable concerning general information about the drilling process including average depth, drilling days, number of engines used and gallons of fuel used per day. However, they typically did not have the specific information about the characteristics of the rig engines (model year, engine size, and load factors) needed to estimate emissions.

During phone interviews it was discovered that several of the operators also drilled their own wells. Based on these interviews, the strategy for the remainder of the data collection phase of the project was refined. In particular, factors such as depth of the well, the engine configurations used, the individual preferences of drilling superintendents to idle engines or to turn them off, and the difficulty of estimating load and operating hours over the entire drilling period made it difficult to collect the data via email or fax without being able to discuss the needed data directly with the respondent. The complexity of the drilling process and the lack of response from the operators to anything other than a verbal interview informed the collection process for the drilling contractors.

Therefore to obtain the information needed, a verbal interview with the actual drilling contractors was determined to be preferable in order to carefully walk the respondent through the survey questions.

The RigData® dataset included approximately 225 unique contact profiles for drilling contractors. However, many of these contacts were regional contacts for the same company, several had gone out of business, and others had recently consolidated into a single company. As a result, the final number of unique contacts for the drillers was approximately 190.

ERG attempted to contact each of the drilling companies at least four times, by phone and/or email. Based on the experience with contacting the operators, verbal contact was attempted with each respondent before distribution of the survey through email or fax. The strategy was designed to increase participation by explaining the purpose of the survey, to explain the data being requested, and thus avoid receiving incomplete or inaccurate surveys. For each targeted survey respondent, three attempts were made via phone to find someone to speak with before a voicemail was left or an email was sent. This strategy was intended to eliminate dead-end contacts such as unreturned voicemails or emails.

Because smaller companies generally had fewer administrative and management personnel, contact for companies with less than 50 wells generally consisted of a phone call answered by a receptionist who either took a message, transferred the call to a voicemail, or established direct contact with someone who could answer the survey questions. If there was no answer, a return call was scheduled. After three attempts without response, a short voice message was left. If no reply was received to this message, no further attempt was made to contact the respondent.

For the larger drilling companies (those that drilled over 100 wells in 2008), an enhanced contact strategy was used. Because some of the companies are quite large and represent a significant percentage of the wells drilled in the state, more extensive efforts were made to increase their participation. For several of these companies, an effort was made to encourage response by providing them with tailored Excel spreadsheets identifying their wells and asking about specific well types and locations. In addition, attempts were made to contact the company through multiple avenues, either through multiple contacts provided in the RigData® dataset, or through contact information available on-line. In one case, ERG collected data from one of the top 25 drilling contractors after an initial refusal from one drilling superintendent by requesting data through other contacts at the company.

Generally speaking, at least ten contacts through phone calls and emails were attempted for the larger companies, the medium sized companies required from 5 to 7 contacts, and the smaller companies required 3 to 4 contacts before identifying the appropriate person to talk to.

At the completion of the survey effort, 45 completed surveys with sufficient data to estimate emissions had been obtained from 39 different drilling rig contractors and/or oil and gas well operators. This figure reflects approximately a 15% response rate for complete surveys from the attempted contacts. One additional survey was received after the submittal cutoff date, but it was not received in time for incorporation into the inventory.

The surveys that were received and used in the inventory were representative of over 1,500 wells drilled in Texas in 2008 and covered 121 counties and all of the major oil and gas basins in the state (Andarko, East Texas, Ft. Worth/Bend Arch, Permian, and Western Gulf). An additional 17 survey responses were obtained, but the respondents for these surveys did not provide sufficient information to be used in the final model drilling rig emission profile development. Typically, these incomplete responses were those received from the oil and gas well operators and not the drilling contractors. Considering both the complete and incomplete survey responses, the overall response rate for the survey effort was approximately 21%. Table 5-1 presents the summary results for the survey effort.

Table 5.1 Survey Summary Statistics

Survey Activity/Results	Number of Respondents
Attempted Company Contacts	295
Refusal to Participate	24
Soft Refusal (did not return attempted contacts via phone calls or email)	209
Respondent Interviewed and provided sufficient data for inclusion in inventory dataset	45
Respondent Interviewed, but insufficient data provided for inclusion in inventory dataset	17

Figure 5-1 provides a county-level map of Texas providing a graphical representation of the geographic coverage of the survey results.

5.2 Model Rig Category Development

Upon completion of the survey and data collection task, the survey results were compiled into a spreadsheet database for evaluation in order to disaggregate the survey data into sub-categories for model drilling rig profile development. As each completed survey was received from the surveyor, identifying information for that survey was entered into a tracking spreadsheet, and the survey was prepared for data entry and forwarded to data entry personnel. Upon receipt of the survey, data entry personnel transferred the data in the survey form into the spreadsheet database, and updated the survey tracking spreadsheet with date of data entry and their initials. A QA check was then performed on the data entered into the spreadsheet database, and the tracking spreadsheet was updated to indicate the date of QA and the initials of the personnel performing the QA.

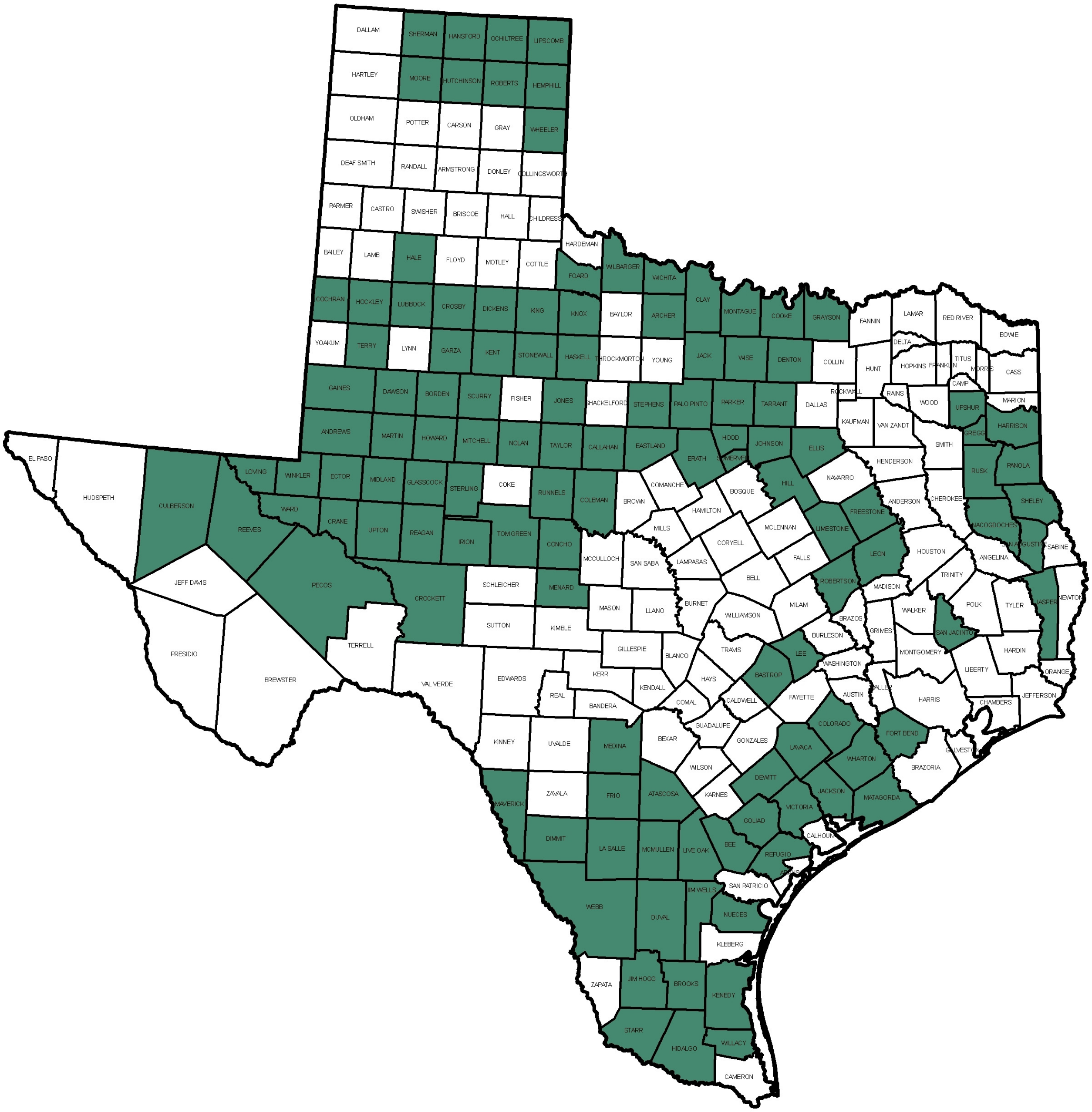

Figure 5.1 Counties with Survey Data

Survey results for vertical, directional, and horizontal well types were reviewed as described below.

A review of the 32 surveys completed for vertical drilling, representing 1,261 wells, provided a clear distinction between the engine profiles (number and size of engines) used to drill shallow vertical wells relative to deeper vertical wells. In particular, by separating the survey results into those representing wells at 7,000 feet of depth or less, and those representing wells deeper than 7,000 feet, the following differences were observed:

- The average drilling duration for the shallower wells was 8 days, with a maximum of 14 days;
- The average drilling duration for deeper wells was 27 days, with a maximum of 84 days;
- Only 1 of the 16 profiles for shallow wells was for an electrical rig, compared to 6 electrical rig profiles out of the 16 profiles for the deeper wells;
- The engine sizes were significantly different for the shallow and deep wells, with the survey results for the shallow wells containing no engines over 700 hp, while the engine population for surveys received for the deeper wells contained approximately 25 engines rated at over 1,000 hp.

For horizontal and directional wells, a total of 13 completed surveys were received representative of 288 wells. The average measured well depth of the wells covered under these surveys was approximately 11,000 feet, with a minimum of 8,000 feet and a maximum of 17,688 feet. All of the profiles for horizontal and directional wells were either for electrical rigs (6 profiles) with 2 or 3 engines, or for mechanical rigs (7 profiles) with 6 engines. Due to the limited number of surveys received for horizontal and directional wells, and the relative consistency of the profiles for these types of wells, it was determined to consolidate the survey results for horizontal and directional wells into one model rig category.

Table 5-2 provides a summary of the final survey statistics for each of the three model rig well type categories.

Table 5.2 Model Rig Category Statistics

Model Rig Well Type Category	Number of surveys included in profile	Number of respondents providing surveys	Number of Wells Represented	Number of Mechanical Rig Profiles	Number of Electrical Rig Profiles
Horizontal and Directional Wells	13	10	288	7	6
Vertical Wells <= 7,000 feet	16	16	900	15	1
Vertical Wells > 7,000 feet	16	13	361	10	6

Tables D-1 through D-3 in Appendix D contain the collected survey data for each of the three model rig well type categories.

5.3 Fracturing

During the data collection phase of this project, information was solicited from respondents regarding fracturing activities. While not specifically mentioned in the original work plan or data collection plan, a review of existing literature and studies showed fracturing activity to be increasing in Texas over the past several years. As part of their survey response, the drilling contractors and oil and gas exploration companies occasionally provided some qualitative or quantitative information regarding fracturing, but the responses were highly variable in content and format. In general, the indication was that fracturing was a short-term activity (less than one day in duration), and that pump trucks containing multiple, large diesel-fired engines could be used simultaneously to pump the fracturing fluids into the well. Specific information regarding the frequency of fracturing events and the total hp-hours required per event were not generalizable to the inventory as a whole, however.

Further investigation regarding fracturing was made by contacting service companies that provide fracturing services, as well as interviewing personnel at the TRC and researching the availability of fracturing data on-line through the TRC website.

Two of the three service companies contacted provided some data for the fracturing activities they performed in 2008, which varied from the use of five 1,250 hp pump engines for a total duration of 1 hour, to the use of seven 2,500 hp pump engines for a total duration of 12 hours. The third service company contacted did not provide any data as of the time of this draft report.

Unlike the drilling permit records obtained through the "Drilling Permit Master and Trailer" database, fracturing data is not compiled by the TRC or otherwise made readily available in any summarized format through any on-line queries or electronic datasets. However, images of individual well completion records (referred to as G-1 forms for gas well completions and W-2 forms for oil well completions) are available on-line through the TRC website. Using American Petroleum Institute (API) numbers from the TRC data, a random on-line search was performed to review the G-1 and W-2 records for approximately 1,200 wells. The G-1 and W-2 forms were only found for approximately one-third of these wells. These forms are frequently completed by hand, with inconsistent data being reported by individual well operators, with much of the data being incomplete. However, based on a review of the records we were able to identify, it appears that approximately 80% of the wells in the sample had some kind of fracturing activity occurring prior to well completion.

While data is not currently available under this project to provide emission estimates for fracturing activities, due to the large engine sizes used by the pump trucks, this is a source category that may be considered for inclusion in future emission inventory development projects.

6.0 Emissions Inventory Development and Results

The 2008 activity data from the TRC and the model rig emissions profiles developed using the survey results for each model rig well type category were utilized to develop emissions estimates for selected target years as described below.

6.1 Activity Data

6.1.1 2008 Base Year Activity

Activity data for the 2008 base year was obtained from the TRC through acquisition of the "Drilling Permit Master and Trailer" database, which contains information on well drilling activities, including American Petroleum Institute (API) number, date approved, location (county), well profile (vertical, horizontal, directional), well depth, spud-in date, and well completion date. The TRC data was combined with data from the RigData® dataset used to identify survey respondents as discussed previously. This combined database was used to compile an initial list of all oil and gas wells that were either completed in 2008 (based on completion date), or that were started in 2008 (based on spud-in date).

As many of the wells completed in 2008 were started in 2007, and many of the wells started in 2008 were not completed until 2009, an adjustment was needed to the initial list of wells to determine a representative dataset for 2008. This adjustment was accomplished by including only those wells with spud dates of December 1, 2007 or later (and that were completed in 2008), and only those wells with completion dates of January 31, 2009 or earlier (and that had spud-in dates in 2008). In all, 16,964 oil and gas wells are included in the final 2008 dataset which compares favorably with the 16,569 oil and gas well completions reported by the TRC in 2008 (TRC, 2009c). The slight discrepancy with the total wells included in the 2008 dataset compared to the completion figure from the TRC is due to the fact that the TRC data only includes 2008 completions and does not account for wells started in 2008 that were not completed until 2009.

The final 2008 activity dataset contains drilling activity data for 210 of the 254 counties in Texas.

6.1.2 2002 and 2005 Prior Years Activity

Once the final 2008 activity dataset was established, activity data scaling factors for 2002 and 2005 were developed based on the ratio of the oil and gas well completions for those years relative to the number of oil and gas well completions in 2008 as reported by the TRC (TRC

2009a, TRC 2009b, TRC 2009c). This analysis was performed at the TRC district level, which allowed geographic variation in drilling trends across the state from 2002 through 2008 to be reflected in the 2002 and 2005 prior year datasets. Figure 6-1 provides a county-level map of Texas showing the location and coverage of each of the TRC districts.

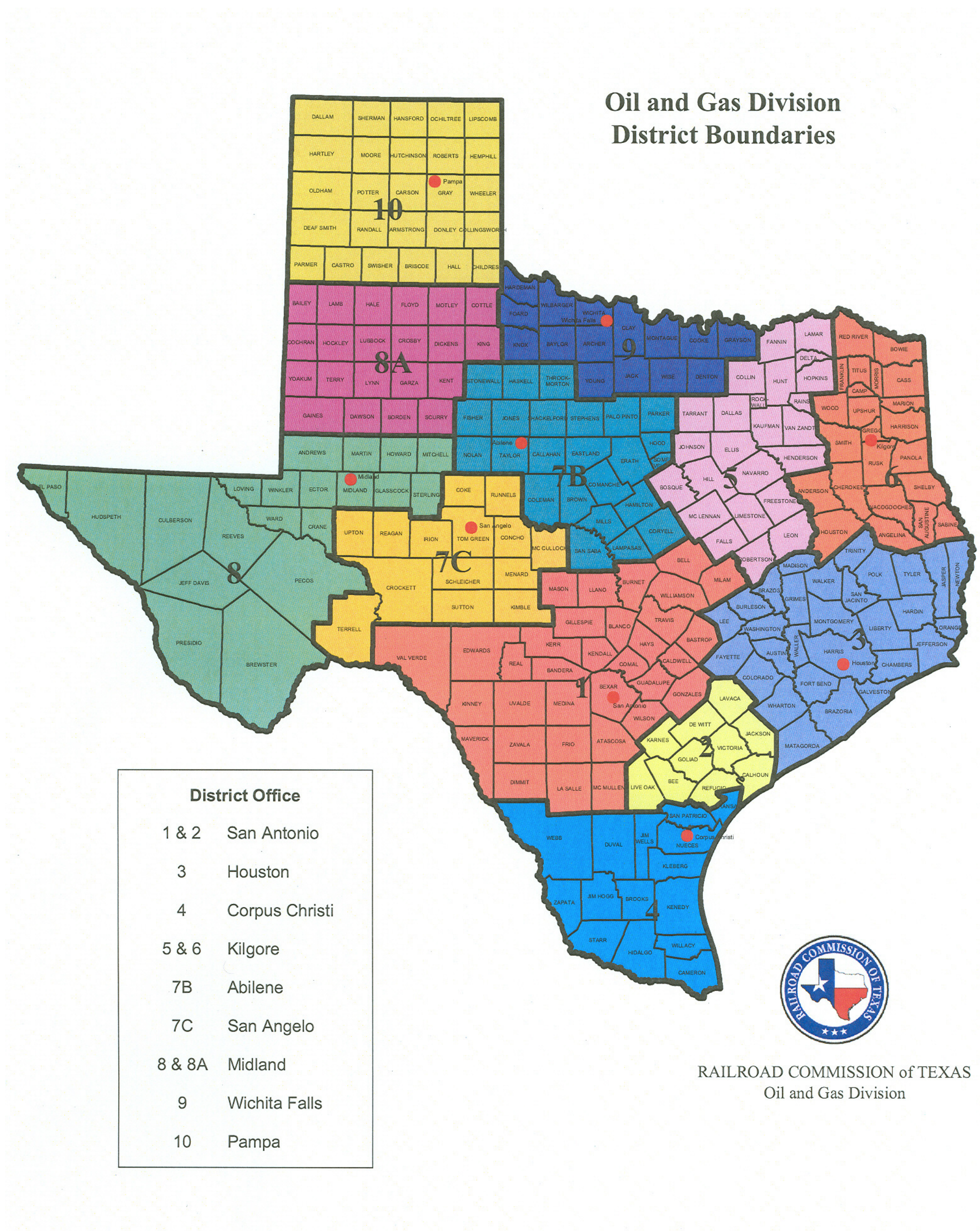

Figure 6.1 TRC District Map

For example, in 2008 there were 512 total oil/gas well completions in TRC District 1, and in 2002 there were 165 total oil/gas well completions in District 1. Therefore, the scaling factor from 2002 to 2008 is:

2002 to 2008 scaling factor = 165 wells / 512 wells = 0.32

Table 6-1 shows the 2002, 2005, and 2008 oil and gas well completion records and the resultant 2002 and 2005 scaling factors that were developed for each district for this analysis.

Table 6.1 2002 and 2005 Prior Year Activity Scaling Factors

TRC District	2008 Total Oil/Gas Completions	2002 Total Oil/Gas Completions	2002 Scaling Factor	2005 Total Oil/Gas Completions	2005 Scaling Factor
1	512	165	0.32	389	0.76
2	687	513	0.75	672	0.98
3	699	724	1.04	712	1.02
4	1,351	1,266	0.94	1,123	0.83
5	738	618	0.84	714	0.97
6	1,973	717	0.36	1,556	0.79
7B	746	298	0.40	501	0.67
7C	2,082	887	0.43	1,389	0.67
8	2,641	1,281	0.49	927	0.35
8A	559	756	1.35	626	1.12
9	3,484	1,096	0.31	1,185	0.34
10	1,095	419	0.38	856	0.78

As can be seen in Table 6-1, certain areas of the state experienced significant growth in drilling activity in 2008 relative to 2002, while other areas remained relatively stable. The most dramatic example of this change in activity can be seen in TRC District 9, which contains the Barnett Shale, an area that has experienced significant growth in drilling activity over the last 6 years. For this District, drilling activity approximately tripled between 2002 and 2008.

The scaling factors presented in Table 6-1 were applied to the 2008 base year well depth totals by county for each of the three model rig well types to determine county-level well depth for each model rig type for 2002 and 2005.

6.1.3 2009 through 2021 Projected Activity

2009 through 2021 projected activity data were developed using the 2008 base year activity data from the TRC and forecasting future activity based on US DOE Energy Information Administration (EIA) projections of oil and gas production for the Southwest and Gulf Coast regions from the *Annual Energy Outlook 2009, Updated Reference Case with ARRA* (EIA, 2009). The EIA data tables (specifically Tables 113 and 114) present estimated crude oil and natural gas production estimates for the years 2006-2030. The geographic level of the projected data is by EIA Region.

Portions of Texas fall into three EIA Regions: Gulf Coast (Region 2); Southwest (Region 4); and Midcontinent (Region 3). The majority of the State is in the Gulf Coast and Southwest EIA Regions. Only a small portion (area to the west of Oklahoma) is in the Midcontinent Region. In addition, because the Midcontinent EIA Region contains six other states, any projections data for the Midcontinent EIA Region may not be reflective of Texas operations. Thus, it was assumed that the Southwest and Gulf Coast EIA Regions are representative of Texas and each region was weighted equally to determine the statewide projections. Figure 6-2 shows the EIA regions and their coverage in Texas.

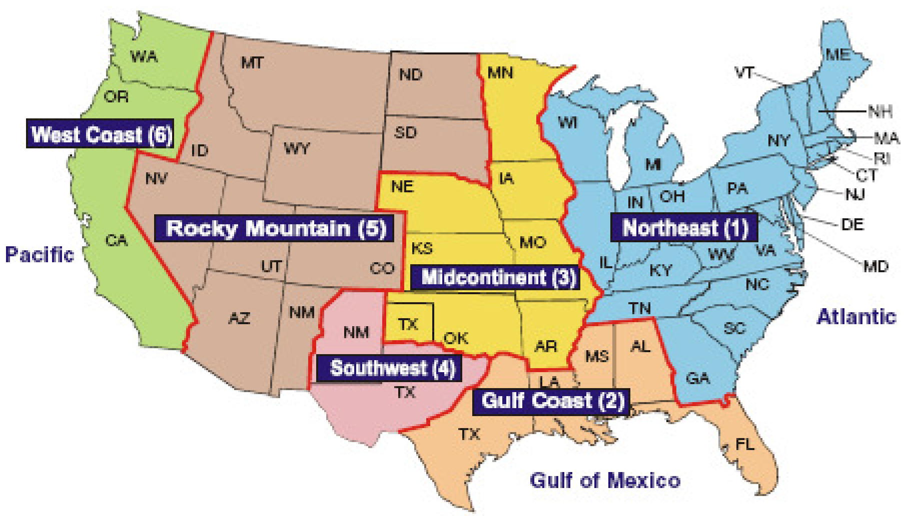

Figure 6.2 EIA Regions

Tables 6-2 and 6-3 show projected crude oil and natural gas production for the Gulf Coast and Southwest EIA Regions, as well as the combined total for both regions, from 2008 through 2021. The total percentage change for each year from 2009 through 2021 is presented relative to the base year of 2008.

This data was then used to calculate a projected growth factor (%) for each year from 2009 through 2021 by weighing the oil and gas percentage growth figures relative to the number of oil and gas wells completed in Texas 2008. For example, the projected growth factor for 2009 is calculated as follows:

Table 6.2 Projected Crude Oil Production 2008-2021

EIA Region	Crude Oil Production (MMBBL/day)													
	2008	**2009**	**2010**	**2011**	**2012**	**2103**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Gulf Coast	0.503	0.505	0.503	0.483	0.465	0.450	0.438	0.401	0.374	0.347	0.320	0.294	0.271	0.251
Southwest	0.919	0.920	0.904	0.892	0.890	0.915	0.956	1.000	1.043	1.082	1.117	1.147	1.167	1.183
Total	1.422	1.425	1.407	1.375	1.355	1.365	1.393	1.402	1.416	1.429	1.436	1.442	1.438	1.434
% change from 2008		0.21%	-1.05%	-3.29%	-4.71%	-4.01%	-2.02%	-1.42%	-0.39%	0.50%	1.02%	1.38%	1.14%	0.86%

Table 6.3 Projected Natural Gas Production 2008-2021

EIA Region	Natural Gas Production (trillion cubic feet)													
	2008	**2009**	**2010**	**2011**	**2012**	**2103**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Gulf Coast	5.412	5.165	4.792	4.606	4.415	4.326	4.233	4.162	4.086	4.020	3.959	3.921	3.903	3.825
Southwest	2.170	2.474	2.623	2.716	2.713	2.679	2.659	2.645	2.627	2.609	2.603	2.591	2.591	2.564
Total	7.582	7.639	7.415	7.321	7.128	7.005	6.892	6.807	6.713	6.629	6.563	6.512	6.495	6.388
% change from 2008		0.76%	-2.20%	-3.44%	-5.99%	-7.61%	-9.09%	-10.2%	-11.5%	-12.6%	-13.4%	-14.1%	-14.3%	-15.7%

2009 growth factor = ((% change from 2008 to 2009 in Crude Oil Production x number of oil well completions in 2008) + (% change from 2008 to 2009 in Natural Gas Production x number of gas well completions in 2008)) / (total number of oil and gas well completions in 2008)

Using the data in Tables 6-2 through 6-4, the projected growth factor for 2009 is:

2009 growth factor = ((0.21% x 6,208) + (0.76% x 10,361)) / (6,208 + 10,361) = 0.55%

Table 6-4 shows the growth factors that were developed for each projected year as a result of this analysis. These factors were then applied to the 2008 base year well depth totals by county for each of the three model rig profile well types to determine activity data for 2009 through 2021. It is worth noting that through the first five months of 2009, the number of well completions in Texas has exceeded the number of well completions for the same period in 2008. However, during the second half of 2008, there was a dramatic increase in drilling activity in Texas which dropped off significantly by the end of the year due to commodity prices and the effects of the economic recession. Therefore, while Table 6-4 presents projected production data based on the current DOE EIA data, the volatility in drilling activity during 2008, coupled with the rapidly changing economic climate over the last year, results in a high level of uncertainty regarding these (or any) projections for drilling activity in 2009 and beyond. These projections are based on the best data currently available, but should be revisited once the economic climate and oil and gas prices stabilize in order to more accurately assess future year projected emissions.

6.1.4 2002, 2005, and 2008 through 2021 Activity Summary

Once the final activity dataset for 2008 was determined, total county-level well depth for each of the three model rig well type categories was calculated by summing the individual well depths in each county by model rig well type category. The total county-level well depth for 2002, 2005, and 2009 through 2021 for each model rig well type category was then calculated based on the 2008 summary data using the methodology described above. Table 6-5 shows the total depth by model rig well type category for 2008 (blank cells indicate there was no activity in that county for that well type).

Table 6-4 Projected Growth Factors 2009-2021

2008 Well Completions		Production % change from 2008												
		2009	**2010**	**2011**	**2012**	**2103**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Oil	6,208	0.21%	-1.05%	-3.29%	-4.71%	-4.01%	-2.02%	-1.42%	-0.39%	0.50%	1.02%	1.38%	1.14%	0.86%
Natural Gas	10,361	0.76%	-2.20%	-3.44%	-5.99%	-7.61%	-9.09%	-10.2%	-11.5%	-12.6%	-13.4%	-14.1%	-14.3%	-15.7%
Projected Growth Factor		0.55%	-1.77%	-3.38%	-5.51%	-6.26%	-6.44%	-6.92%	-7.31%	-7.67%	-8.02%	-8.31%	-8.54%	-9.52%

Table 6.5 2008 Total Depth by Model Rig Well Type Category (1,000 feet)

County	Vertical <= 7,000 feet	Vertical > 7,000 feet	Directional/Horizontal
Anderson	52.20	113.70	20.33
Andrews	1,969.19	1,115.41	46.30
Angelina	1.32	394.74	101.70
Aransas	6.00	45.45	23.30
Archer	221.32	15.50	
Atascosa	39.80	38.50	
Austin	67.19	28.70	15.02
Bastrop	6.40	74.60	71.70
Baylor	45.54		5.50
Bee	239.20	204.49	240.25
Bell	4.50		
Bexar	0.80		
Borden	11.45	166.10	42.85
Bosque		10.00	15.80
Bowie		9.00	
Brazoria	15.90	252.90	103.39
Brazos		33.14	214.89
Briscoe	6.50	8.50	
Brooks	17.16	582.32	103.96
Brown	41.00		
Burleson		208.41	172.77
Caldwell	29.86		8.15
Calhoun	15.60	112.60	82.83
Callahan	81.68		
Cameron		9.50	
Carson	6.50		10.10
Cass	7.00		
Chambers		78.60	153.46
Cherokee	9.40	886.08	243.05
Childress	9.30		
Clay	116.15	23.00	52.50
Cochran	229.30	25.00	
Coke	121.70	15.70	
Coleman	97.69		
Colorado	122.71	149.88	25.42
Comanche	3.00		
Concho	167.15		
Cooke	161.00	228.84	17.90
Coryell	4.00		
Cottle	39.20	106.70	8.00
Crane	602.54	175.75	43.26
Crockett	881.48	1,822.74	131.17
Crosby	91.69		
Culberson		216.89	44.00
Dallas			99.50

Table 6.5 2008 Total Depth by Model Rig Well Type Category (1,000 feet) (Cont.)

County	Vertical <= 7,000 feet	Vertical > 7,000 feet	Directional/Horizontal
Dawson	42.70	359.69	17.50
Denton	11.10	79.50	2,491.72
DeWitt	57.40	392.08	568.84
Dickens	174.02	123.70	
Dimmit	270.51	178.14	125.64
Duval	68.80	479.83	71.95
Eastland	48.09		
Ector	501.36	1,619.73	73.30
Edwards	119.55	206.10	67.50
Ellis	1.50		269.00
Erath	29.95		97.10
Falls	1.80		
Fannin		19.00	
Fayette	15.08	22.10	93.80
Fisher	162.58	68.30	
Foard	25.10		
Fort Bend	159.90	74.65	125.04
Franklin	10.90	94.55	
Freestone	11.40	2,650.39	484.37
Frio	153.73	62.80	61.74
Gaines	407.24	633.81	56.99
Galveston	4.40	51.15	53.37
Garza	189.30	52.00	3.20
Glasscock		900.20	19.20
Goliad	231.61	377.49	76.04
Gonzales	15.53	21.26	21.50
Gray	12.15	13.00	
Grayson	12.99	49.00	37.60
Gregg		503.10	263.25
Grimes	3.90		169.64
Guadalupe	9.20		7.79
Hale	65.00		15.00
Hansford	62.41	263.33	50.20
Hardeman	12.59	96.23	28.60
Hardin	81.95	284.12	180.35
Harris	19.20	34.20	85.40
Harrison	60.61	2,900.41	1,836.28
Hartley	17.95		
Haskell	63.70		
Hemphill	6.50	3,936.45	685.47
Henderson		233.25	53.60
Hidalgo	37.54	1,324.96	347.92
Hill	7.00		1,161.12
Hockley	208.43	123.40	87.44
Hood			1,011.19

Table 6.5 2008 Total Depth by Model Rig Well Type Category (1,000 feet) (Cont.)

County	Vertical <= 7,000 feet	Vertical > 7,000 feet	Directional/Horizontal
Hopkins	4.50	21.80	
Houston	8.30	161.85	56.50
Howard	81.64	779.85	
Hudspeth	26.00	22.00	
Hutchinson	313.77	17.10	39.00
Irion	196.70	1,513.07	
Jack	197.69		137.50
Jackson	205.63	319.66	32.99
Jasper	8.10	44.50	194.33
Jefferson	24.80	166.30	300.61
Jim Hogg	9.40	194.13	14.38
Jim Wells	84.07	52.75	6.11
Johnson		52.00	8,421.16
Jones	221.93		
Karnes	21.40	100.90	179.60
Kenedy	7.00	382.44	92.50
Kent	120.99	109.80	36.00
King	203.90	7.40	
Kleberg		54.50	150.10
Knox	54.20	7.20	
La Salle	52.36	691.44	24.00
Lamb	32.80		7.50
Lavaca	107.69	552.74	216.53
Lee	35.30	24.48	83.01
Leon	68.91	524.00	310.50
Liberty	34.00	330.85	145.10
Limestone	6.30	1,876.14	451.40
Lipscomb		214.88	1,447.13
Live Oak	132.03	342.83	129.60
Loving	149.10	620.83	33.00
Lubbock	60.30		
Lynn		46.25	
Madison		36.31	66.20
Marion		104.73	66.50
Martin		3,643.04	
Matagorda	25.97	590.09	100.27
Maverick	333.88	27.00	241.35
McCulloch	1.00		
McLennan	1.23	9.50	9.50
McMullen	128.79	749.60	49.50
Medina	30.11		
Menard	70.50		
Midland	8.60	2,637.28	75.30
Milam	19.29	10.00	
Mitchell	640.83		

Table 6.5 2008 Total Depth by Model Rig Well Type Category (1,000 feet) (Cont.)

County	Vertical <= 7,000 feet	Vertical > 7,000 feet	Directional/Horizontal
Montague	107.08	475.44	365.20
Montgomery	6.00	51.95	24.52
Moore	126.48		6.30
Motley	5.00	9.00	
Nacogdoches	1.00	2,210.41	761.92
Navarro	36.15	102.10	6.60
Newton		30.55	68.50
Nolan	332.89	37.70	
Nueces	66.84	339.36	64.62
Ochiltree	16.50	309.88	427.67
Oldham		45.90	
Orange	7.00	17.00	101.32
Palo Pinto	212.17		135.05
Panola	92.08	2,693.70	1,652.45
Parker	6.45		880.85
Pecos	224.68	2,667.60	840.55
Polk	60.63	90.83	218.65
Potter	21.20		
Reagan	34.05	2,509.42	
Real	3.00		
Red River	5.80	8.20	5.80
Reeves	88.15	310.70	374.12
Refugio	588.28	335.65	
Roberts	17.80	1,337.30	361.71
Robertson		2,317.69	438.50
Runnels	375.57		4.80
Rusk	27.00	3,697.44	508.05
Sabine		8.00	
San Augustine		52.50	286.91
San Jacinto	3.70	127.95	24.00
San Patricio	29.80	94.07	89.11
Schleicher	117.95	416.02	
Scurry	155.28	224.80	96.96
Shackelford	206.38		
Shelby		546.60	881.58
Sherman	274.40	80.60	
Smith	6.50	108.75	185.85
Somervell			144.00
Starr	69.53	1,406.17	178.30
Stephens	469.77		14.40
Sterling	40.42	294.86	9.25
Stonewall	221.08		
Sutton	740.80	1,866.84	7.20
Tarrant	37.45	18.00	7,630.70
Taylor	69.30		4.00

Table 6.5 2008 Total Depth by Model Rig Well Type Category (1,000 feet) (Cont.)

County	Vertical <= 7,000 feet	Vertical > 7,000 feet	Directional/Horizontal
Terrell	79.85	295.70	92.95
Terry	26.89	86.20	55.20
Throckmorton	90.84		
Titus	4.60		
Tom Green	123.60	16.00	
Trinity	4.10		
Tyler	23.11	70.20	329.95
Upshur	11.77	260.21	96.80
Upton	78.50	4,699.94	288.60
Val Verde	3.10	73.30	
Van Zandt	8.20	35.20	
Victoria	296.15	207.20	33.03
Walker	4.90		
Waller	82.71	61.80	10.00
Ward	460.51	161.91	482.33
Washington	6.00		42.00
Webb	262.53	1,689.96	305.77
Wharton	239.83	586.42	114.77
Wheeler		3,839.70	482.40
Wichita	366.76	9.00	
Wilbarger	126.99		
Willacy		301.75	25.50
Wilson			4.45
Winkler	20.50	294.95	148.92
Wise	93.50	121.00	2,032.78
Wood	17.70	37.86	32.00
Yoakum	462.25	195.22	171.10
Young	259.30		
Zapata	6.00	2,031.18	500.35
Zavala	16.05		60.20
Statewide Total	20,746	82,337	48,121

Appendix E contains a summary of the total well depth by county and year for each model rig well type category.

6.2 Model Rig Emission Profiles

6.2.1 Model Rig Engine Profiles

As described in Section 5.2, the survey data was disaggregated into three model rig categories for the following well types and depths based on the results of the data collection survey:

- Vertical wells less than or equal to 7,000 feet;

- Vertical wells greater than 7,000 feet; and
- Horizontal/Directional wells.

For each of these rig categories, a model rig engine profile was developed. In order for the model rig engine profile data to be applied consistently to the TRC activity data, the survey results were normalized to a 1,000 foot drilling depth. This was accomplished by dividing the total drilling hours for each engine included in each survey by the well depth for that survey to obtain the hours of operation per engine per 1,000 feet of drilling depth.

As the engine profiles and functions for engines used on mechanical rigs and electrical rigs are distinctly different as described in Section 3.3, separate engine profiles for mechanical and electrical rigs were developed for each model rig well type category.

The following average engine parameters were calculated for each model rig well type category using a weighted average for each parameter based on the number of wells associated with each survey:

- Number of engines by rig type (i.e., mechanical draw works, mud pumps, and generators; electrical rig engines; and completion engines).
- Engine age
- Engine size (hp)
- Engine on-time (hours/1,000 feet drilled)
- Overall average load (%)

Surveys with missing data parameters were excluded from the weighted average calculation. The weighted averaged engine parameters developed for each model rig category by rig type are summarized in Table 6-6.

Table 6.6 Model Rig Engine Parameters

Model Rig Category	Rig Type	Engine Type	# of Engines	Average Age (yrs)	Engine Size (hp)	Hours/1,000 ft drilled	Average Load (%)
Vertical <= 7,000 ft[1]	Mechanical	Draw Works	1.60	7	442	30.8	51.8
		Mud Pumps	1.69	6	428	29.4	45.9
		Generator	0.97	4	330	28.3	70.4
Vertical > 7,000 ft	Mechanical	Draw Works	2.01	25	455	35.9	47.4
		Mud Pumps	1.62	18	761	33.2	46.0
		Generator	2.00	10	407	19.3	78.7
	Electrical		2.15	2	1,381	62.6	48.5
Horizontal/ Directional	Mechanical	Draw Works	2.00	15	483	50.1	41.1
		Mud Pumps	2.00	6	1,075	36.4	42.6
		Generator	2.00	10	390	26.8	69.0
	Electrical		2.03	2	1,346	47.3	52.5
All	All	Completion	1.00	Default	350	10.0	43.0

[1] The one electrical rig surveyed for vertical wells <= 7,000 feet represents less than 0.5% of the total wells in this model rig well type category and was considered to have a negligible contribution to the emissions profile.

As can be seen in Table 6-6, the expected trend toward larger engine sizes and more hours required per 1,000 feet for the deeper vertical wells and the horizontal/directional wells is verified. The older engine ages for the mechanical rigs used on the deeper vertical wells and the horizontal/directional wells are based on several surveys received for these well types that covered a large number of wells drilled by rigs with older engines. However, as noted in Section 3.3, the future trend for these types of wells is towards the use of electrical rigs, and the average age of the engines used on the electrical rigs for these well types is only two years.

6.2.2 Model Rig Emission Factors

Once the final mechanical and electrical rig engine profiles were established for each model rig well type category, US EPA's NONROAD model was used to develop criteria pollutant emission factors for each rig type for each year of the inventory (2002, 2005, and 2008 – 2021). Use of the NONROAD model allowed for expected reductions in emissions over time due to the phasing in of EPA's emissions standards for nonroad diesel engines.

Using the engine parameters summarized in Table 6-6, NONROAD model input files were developed (U.S. EPA, 2005). In particular, the NONROAD Activity file was modified using the hours per 1,000 feet drilled and average load, while the Population files were modified using the engine size. In addition, the population for a particular engine type was adjusted to a unit value of 1 for ease in calculation. The modified NONROAD files used in the emission factor calculation have been provided to the TCEQ in electronic format.

A total of 16 years were modeled – the base year of 2008, the prior years of 2002 and 2005, and 13 projected years from 2009 to 2021. For each year modeled, the engine model age was kept constant. For instance, the 7 year old mechanical draw works engine for vertical wells < 7,000 feet was modeled as a 2001 model year engine for the 2008 base year, as a 1995 model year engine for 2002, and as a 2014 model year engine for the future year of 2021.

The model year-specific emissions output from the NONROAD model (i.e., based on the model year fraction of the unit engine population specified by the NONROAD population file) was then ratioed up to the number of engines in each rig type.[2] For mechanical rigs, the draw works, mud pump, and generator engine emissions were aggregated together. For both mechanical and electrical rig types, a single completion engine of 350 hp running 10 hours per 1,000 feet drilled was also included to model completion activities. A composite model rig emissions profile was developed by aggregating the mechanical and electrical rig types together based upon the percentage of wells associated with each rig type. For example, for the horizontal/directional model rig well type, approximately two-thirds of the wells were represented by electrical rigs, so the resultant emission factors are weighted two-thirds by the NONROAD electrical rig emission factors, and one-third by the mechanical rig emission factors.

SO_2 emissions are based on fuel sulfur content profiles for Texas obtained from historical fuel sampling data performed for the TCEQ. The average diesel sulfur content (% weight) for a particular analysis year was developed using the county-level fuel parameter data contained in TCEQ's TexN model, weighted by the number of wells in each county. The statewide average diesel sulfur content values calculated were 0.2995% for 2002 and 2005, 0.0316% for 2008 and 2009, and 0.0015% for 2010 through 2021, reflecting the reduced sulfur requirements over time.

Total hydrocarbon (THC) exhaust emissions from the NONROAD model were converted to VOC and TOG using ratios of 1.053 and 1.070, respectively (U.S. EPA, 2005a). Crankcase THC emissions were assumed to be equivalent to both VOC and TOG (U.S. EPA, 2005b). For diesel nonroad engines, PM_{10} is assumed to be equivalent to PM, while the $PM_{2.5}$ fraction of PM_{10} is estimated to be 0.97 (U.S. EPA, 2005a).

Hazardous air pollutant (HAP) emission factors were then developed by applying speciated HAP emissions profiles for PM_{10} and TOG from the California Air Resources Board's

[2] The NONROAD model allocates the total equipment population across a distribution of model years and estimates the emissions associated with each model year. For a given calendar year this analysis is interested in just one engine age/model year representing the average age for each model profile. Therefore the emissions for the model year of interest were scaled back up as if the entire engine population specified in NONROAD were allocated to just this one model year.

(CARB) *Speciation Profile Database* for diesel combustion to the PM and TOG emissions factors obtained from the NONROAD model (ARB, 2001). ARB profile #425 was used to speciate PM_{10}, and ARB profile #818 was used to speciate TOG. Tables 6-7 and 6-8 present the speciation profiles for PM_{10} and TOG, respectively.

Table 6.7 PM_{10} Speciation Factors

HAP	HAP CAS #	Weight Fraction of PM10
Antimony	7440360	0.000036
Arsenic	7440382	0.000005
Cadmium	7440439	0.000040
Cobalt	7440484	0.000011
Chlorine	7782505	0.000344
Lead	7439921	0.000042
Manganese	7439965	0.000040
Nickel	7440020	0.000019
Mercury	7439976	0.000030
Phosphorous	7723140	0.000127
Selenium	7782492	0.000010

Table 6.8 TOG Speciation Factors

HAP	HAP CAS #	Weight Fraction of TOG
1,3-butadiene	106990	0.002
2,2,4-trimethylpentane	540841	0.003
Acetaldehyde	75070	0.074
Benzene	71432	0.02
Cumene	98828	2E-04
Ethylbenzene	100414	0.003
Formaldehyde	50000	0.147
Methanol	67561	3E-04
m-xylene	108383	0.006
Naphthalene	91203	9E-04
n-hexane	110543	0.002
o-xylene	95476	0.003
Propionaldehyde	123386	0.01
p-xylene	106423	0.001
Styrene	100425	6E-04
Toluene	108883	0.015

The final emissions profile for each of the three model rig well type categories was developed by weighing the emission profiles for each rig type (mechanical and electrical) by the percentage of wells of each rig type in each model rig well type category. Appendix F presents the emission factors developed for each of the model rig well type categories for 2002, 2005, and 2008 through 2021.

6.3 Emission Estimation Methodology

Using the model rig well type category emission profiles, county-level emission estimates were calculated using the activity data from the TRC dataset. County-level well activity data in terms of total depth (1,000 feet) drilled was obtained by summing the depth of each individual well drilled for each of the three model rig well type categories for each county as described in Section 6.1. Once the total depth drilled by model rig well type category was known and the emission factor profile for each model rig well type category was developed, annual county level emissions for each model rig well type category were estimated by multiplying the total depth drilled (in terms of 1,000 feet) by the emission factors obtained through use of the survey data and the NONROAD model as follows:

$$E_{poll\text{-}type} = (\text{Depth (1,000 feet/yr)}) \times (EF_{poll} \text{ (tons/1,000 feet)})$$

Where:

$E_{poll\text{-}type}$	=	Emissions of pollutant for county by model rig well type category (tons/yr)
Depth	=	Total depth drilled in model rig well type category by county (1,000 feet/yr)
EF_{poll}	=	Emission factor of pollutant (tons/1,000 feet)

For 2008 through 2021, NO_x emission estimates for the 110 counties subject to the Texas Low Emission Diesel (TxLED) program were adjusted downward by 6.2% to account for the effect of the rule.[3] Table 6-9 identifies the counties where this adjustment was made.

Table 6.9 TxLED Counties

Anderson	Denton	Johnson	Robertson
Angelina	Ellis	Karnes	Rockwall
Aransas	Falls	Kaufman	Rusk
Atascosa	Fannin	Lamar	Sabine
Austin	Fayette	Lavaca	San Jacinto
Bastrop	Franklin	Lee	San Patricio
Bee	Freestone	Leon	San Augustine

[3] The TxLED program requirements initiated in February 2006, so these adjustments were not applied to the 2002 and 2005 modeling scenarios.

Table 6.9 TxLED Counties (Cont.)

Bell	Fort Bend	Liberty	Shelby
Bexar	Galveston	Limestone	Smith
Bosque	Goliad	Live Oak	Somervell
Bowie	Gonzales	Madison	Tarrant
Brazoria	Grayson	Marion	Titus
Brazos	Gregg	Matagorda	Travis
Burleson	Grimes	McLennan	Trinity
Caldwell	Guadalupe	Milam	Tyler
Calhoun	Hardin	Montgomery	Upshur
Camp	Harris	Morris	Van Zandt
Cass	Harrison	Nacogdoches	Victoria
Chambers	Hays	Navarro	Walker
Cherokee	Henderson	Newton	Waller
Collin	Hill	Nueces	Washington
Colorado	Hood	Orange	Wharton
Comal	Hopkins	Panola	Williamson
Cooke	Houston	Parker	Wilson
Coryell	Hunt	Polk	Wise
Dallas	Jackson	Rains	
De Witt	Jasper	Red River	
Delta	Jefferson	Refugio	

For counties subject to TxLED requirements, NO_x emissions were estimated as follows:

$$E_{NOx\text{-}type} = (\text{Depth } (1{,}000 \text{ feet/yr})) \times (EF_{NOx} \text{ (tons/1,000 feet)}) \times (0.938)$$

Where:

$E_{NOx\text{-}type}$	=	Emissions of NO_x for each county by model rig well type category (tons/yr)
Depth	=	Total depth drilled in model rig well type category by county (1,000 feet/yr)
EF_{NOx}	=	NO_x emission factor (tons/1,000 feet)
(0.938)	=	Adjustment Factor to account for 6.2% TxLED reduction

Total county level annual emissions were then obtained by summing the total emissions for each of the three model rig well type categories for each county. Ozone season daily (OSD) emissions were calculated by dividing the annual emissions by 365 (days/year).

6.4 Results

6.4.1 Emission Summary

Table 6-10 summarizes the statewide annual criteria pollutant emission estimates for 2002, 2005, and 2008 through 2021. Table 6-11 summarizes both annual and OSD criteria pollutant emissions by county for the 2008 base year. Appendix G contains detailed tables showing statewide annual emission estimates for each year for all criteria pollutants and HAPs (Appendix G, Table 1), as well as county-level annual and OSD emission estimates for each year for all criteria pollutants and HAPs (Appendix G, Tables 2 and 3, respectively). The decreasing emissions after 2009 reflecting the falling oil and gas production projections from the EIA dataset for the areas including Texas.

As compared to the previous oil and gas study prepared by TCEQ in 2007 (for a 2005 base year), the emission estimates presented in this study reflect a significant decrease in the statewide NO_x emission estimate from drilling rig engines for 2005 (42,854 tons per year in this study compared to 119,647 tons per year in the 2007 study). While not as pronounced, there were also significant decreases in the SO_2 and CO emission estimates based on this study. For VOC, PM_{10}, and $PM_{2.5}$, the estimates contained in this study show slightly higher estimates than in the previous study. These differences in the estimates between the two studies can be attributed to the emissions estimation methodologies used in each study. While the previous study was done using a top-down approach, conservative emission estimation assumptions, and the use of AP-42 emission factors, the current study used 2008 survey data on the actual engine parameters (engine size, hours of operation, and engine load) used in drilling oil and gas wells in 2008, as well as utilizing the NONROAD model to develop emission factors.

6.4.2 NIF 3.0 Files

Once the emissions inventory was completed, NIF 3.0 area source text-formatted input files were prepared for base years 2002, 2005, and 2008. The NIF 3.0 files were created using information provided by TCEQ regarding the correct format and valid code listings for submittal to TexAER (TCEQ 2009a). Prior to submittal to TCEQ, the NIF 3.0 files were pre-processed using EPA's NIF Basic Format and Content Checker to check for errors and inconsistencies. Additionally, ERG performed a test upload to TexAER to ensure the files were complete and accurate and in a format consistent with the TexAER area source file data requirements.

Table 6.10 Texas Drilling Rig Estimates (tons/year)

Year	CO	NOx	PM_{10}	$PM_{2.5}$	SO_2	VOC
2002	13,305	35,828	2,552	2,475	4,776	3,631
2005	15,878	42,854	3,036	2,945	5,977	4,337
2008	16,721	55,238	2,543	2,467	956	4,326
2009	16,769	55,457	2,550	2,474	961	4,340
2010	16,336	53,123	2,417	2,344	45	4,182
2011	15,117	48,462	2,319	2,249	44	3,806
2012	14,748	46,253	2,263	2,196	43	3,665
2013	12,008	39,793	1,378	1,337	38	3,413
2014	11,945	39,461	1,372	1,331	38	3,392
2015	11,755	38,837	1,350	1,310	37	3,349
2016	11,558	36,440	1,320	1,280	37	3,320
2017	8,915	34,771	1,118	1,085	36	2,800
2018	6,114	31,282	811	787	35	2,227
2019	6,073	31,127	805	781	35	2,215
2020	6,035	30,771	800	776	35	2,205
2021	3,299	26,063	448	435	33	1,504

Table 6.11 2008 Annual and OSD County-Level Criteria Pollutant Emission Estimates

County	CO-ANN tons/yr	CO-OSD tons/day	NO_X-ANN tons/yr	NO_X-OSD tons/day	PM_{10}-ANN tons/yr	PM_{10}-OSD tons/day	$PM_{2.5}$-ANN tons/yr	$PM_{2.5}$-OSD tons/day	SO_2-ANN tons/yr	SO_2-OSD tons/day	VOC-ANN tons/yr	VOC-OSD tons/day
Anderson	2.03E+01	5.53E-02	5.94E+01	1.62E-01	3.10E+00	8.47E-03	3.01E+00	8.21E-03	1.04E+00	2.83E-03	5.11E+00	1.40E-02
Andrews	2.33E+02	6.36E-01	7.75E+02	2.12E+00	3.52E+01	9.61E-02	3.41E+01	9.33E-02	1.37E+01	3.74E-02	5.64E+01	1.54E-01
Angelina	6.70E+01	1.83E-01	1.93E+02	5.27E-01	1.03E+01	2.82E-02	1.00E+01	2.73E-02	3.26E+00	8.91E-03	1.72E+01	4.71E-02
Aransas	8.80E+00	2.41E-02	2.75E+01	7.51E-02	1.34E+00	3.67E-03	1.30E+00	3.56E-03	4.85E-01	1.32E-03	2.28E+00	6.23E-03
Archer	9.32E+00	2.55E-02	3.94E+01	1.08E-01	1.35E+00	3.68E-03	1.31E+00	3.57E-03	8.11E-01	2.22E-03	2.05E+00	5.61E-03
Atascosa	7.02E+00	1.92E-02	2.05E+01	5.61E-02	1.07E+00	2.93E-03	1.04E+00	2.84E-03	3.69E-01	1.01E-03	1.72E+00	4.71E-03
Austin	7.59E+00	2.07E-02	2.63E+01	7.20E-02	1.13E+00	3.10E-03	1.10E+00	3.01E-03	5.13E-01	1.40E-03	1.87E+00	5.10E-03
Bastrop	1.69E+01	4.63E-02	5.76E+01	1.57E-01	2.56E+00	7.01E-03	2.49E+00	6.80E-03	1.04E+00	2.85E-03	4.46E+00	1.22E-02
Baylor	1.87E+00	5.10E-03	9.04E+00	2.47E-02	2.65E-01	7.24E-04	2.57E-01	7.02E-04	1.90E-01	5.19E-04	4.23E-01	1.16E-03
Bee	5.68E+01	1.55E-01	2.06E+02	5.62E-01	8.51E+00	2.32E-02	8.25E+00	2.25E-02	3.92E+00	1.07E-02	1.47E+01	4.01E-02
Bell	1.42E-01	3.89E-04	6.28E-01	1.72E-03	2.01E-02	5.49E-05	1.95E-02	5.32E-05	1.45E-02	3.97E-05	2.98E-02	8.14E-05
Bexar	2.53E-02	6.92E-05	1.12E-01	3.05E-04	3.57E-03	9.76E-06	3.46E-03	9.47E-06	2.58E-03	7.06E-06	5.30E-03	1.45E-05
Borden	2.86E+01	7.80E-02	8.82E+01	2.41E-01	4.39E+00	1.20E-02	4.25E+00	1.16E-02	1.41E+00	3.85E-03	7.32E+00	2.00E-02
Bosque	2.72E+00	7.44E-03	9.98E+00	2.73E-02	4.09E-01	1.12E-03	3.97E-01	1.08E-03	1.85E-01	5.06E-04	7.29E-01	1.99E-03
Bowie	1.35E+00	3.68E-03	3.50E+00	9.57E-03	2.09E-01	5.70E-04	2.03E-01	5.53E-04	5.63E-02	1.54E-04	3.41E-01	9.32E-04
Brazoria	4.64E+01	1.27E-01	1.40E+02	3.84E-01	7.10E+00	1.94E-02	6.89E+00	1.88E-02	2.44E+00	6.65E-03	1.20E+01	3.27E-02
Brazos	2.17E+01	5.92E-02	9.57E+01	2.62E-01	3.18E+00	8.69E-03	3.09E+00	8.43E-03	1.88E+00	5.13E-03	6.02E+00	1.64E-02
Briscoe	1.48E+00	4.04E-03	4.49E+00	1.23E-02	2.26E-01	6.18E-04	2.19E-01	6.00E-04	7.41E-02	2.02E-04	3.65E-01	9.98E-04
Brooks	9.58E+01	2.62E-01	2.87E+02	7.84E-01	1.48E+01	4.03E-02	1.43E+01	3.91E-02	4.50E+00	1.23E-02	2.45E+01	6.69E-02
Brown	1.30E+00	3.54E-03	6.10E+00	1.67E-02	1.83E-01	5.00E-04	1.78E-01	4.85E-04	1.32E-01	3.62E-04	2.71E-01	7.42E-04
Burleson	4.46E+01	1.22E-01	1.48E+02	4.04E-01	6.77E+00	1.85E-02	6.57E+00	1.80E-02	2.65E+00	7.23E-03	1.17E+01	3.21E-02
Caldwell	1.58E+00	4.31E-03	7.31E+00	2.00E-02	2.25E-01	6.14E-04	2.18E-01	5.96E-04	1.60E-01	4.36E-04	3.78E-01	1.03E-03
Calhoun	2.38E+01	6.50E-02	7.79E+01	2.13E-01	3.61E+00	9.87E-03	3.50E+00	9.57E-03	1.40E+00	3.82E-03	6.21E+00	1.70E-02
Callahan	2.58E+00	7.06E-03	1.22E+01	3.32E-02	3.65E-01	9.96E-04	3.54E-01	9.67E-04	2.64E-01	7.21E-04	5.41E-01	1.48E-03
Cameron	1.42E+00	3.89E-03	3.94E+00	1.08E-02	2.20E-01	6.02E-04	2.14E-01	5.84E-04	5.94E-02	1.62E-04	3.60E-01	9.84E-04
Carson	9.90E-01	2.71E-03	5.12E+00	1.40E-02	1.42E-01	3.89E-04	1.38E-01	3.77E-04	9.95E-02	2.72E-04	2.67E-01	7.29E-04
Cass	2.22E-01	6.05E-04	9.77E-01	2.67E-03	3.13E-02	8.54E-05	3.03E-02	8.28E-05	2.26E-02	6.17E-05	4.63E-02	1.27E-04
Chambers	2.37E+01	6.47E-02	8.97E+01	2.45E-01	3.55E+00	9.69E-03	3.44E+00	9.40E-03	1.68E+00	4.60E-03	6.38E+00	1.74E-02
Cherokee	1.52E+02	4.15E-01	4.40E+02	1.20E+00	2.33E+01	6.37E-02	2.26E+01	6.18E-02	7.46E+00	2.04E-02	3.90E+01	1.07E-01
Childress	2.94E-01	8.04E-04	1.38E+00	3.78E-03	4.15E-02	1.13E-04	4.03E-02	1.10E-04	3.00E-02	8.20E-05	6.16E-02	1.68E-04

Table 6.11 2008 Annual and OSD County-Level Criteria Pollutant Emission Estimates (Cont.)

County	CO-ANN tons/yr	CO-OSD tons/day	NO_X-ANN tons/yr	NO_X-OSD tons/day	PM_{10}-ANN tons/yr	PM_{10}-OSD tons/day	$PM_{2.5}$-ANN tons/yr	$PM_{2.5}$-OSD tons/day	SO_2-ANN tons/yr	SO_2-OSD tons/day	VOC-ANN tons/yr	VOC-OSD tons/day
Clay	1.12E+01	3.06E-02	4.84E+01	1.32E-01	1.64E+00	4.48E-03	1.59E+00	4.35E-03	9.27E-01	2.53E-03	2.80E+00	7.66E-03
Cochran	1.10E+01	3.01E-02	4.45E+01	1.22E-01	1.60E+00	4.38E-03	1.56E+00	4.25E-03	8.97E-01	2.45E-03	2.47E+00	6.74E-03
Coke	6.20E+00	1.69E-02	2.46E+01	6.73E-02	9.08E-01	2.48E-03	8.80E-01	2.41E-03	4.91E-01	1.34E-03	1.40E+00	3.83E-03
Coleman	3.09E+00	8.45E-03	1.45E+01	3.97E-02	4.36E-01	1.19E-03	4.23E-01	1.16E-03	3.15E-01	8.62E-04	6.47E-01	1.77E-03
Colorado	2.83E+01	7.73E-02	8.52E+01	2.33E-01	4.31E+00	1.18E-02	4.18E+00	1.14E-02	1.53E+00	4.18E-03	7.06E+00	1.93E-02
Comanche	9.49E-02	2.59E-04	4.46E-01	1.22E-03	1.34E-02	3.66E-05	1.30E-02	3.55E-05	9.69E-03	2.65E-05	1.99E-02	5.43E-05
Concho	5.29E+00	1.45E-02	2.49E+01	6.80E-02	7.46E-01	2.04E-03	7.24E-01	1.98E-03	5.40E-01	1.47E-03	1.11E+00	3.02E-03
Cooke	4.07E+01	1.11E-01	1.18E+02	3.24E-01	6.23E+00	1.70E-02	6.04E+00	1.65E-02	2.09E+00	5.71E-03	1.01E+01	2.77E-02
Coryell	1.27E-01	3.46E-04	5.58E-01	1.53E-03	1.79E-02	4.88E-05	1.73E-02	4.73E-05	1.29E-02	3.53E-05	2.65E-02	7.23E-05
Cottle	1.78E+01	4.87E-02	5.34E+01	1.46E-01	2.74E+00	7.49E-03	2.66E+00	7.26E-03	8.56E-01	2.34E-03	4.48E+00	1.22E-02
Crane	4.87E+01	1.33E-01	1.80E+02	4.93E-01	7.25E+00	1.98E-02	7.04E+00	1.92E-02	3.38E+00	9.24E-03	1.16E+01	3.17E-02
Crockett	3.11E+02	8.50E-01	9.41E+02	2.57E+00	4.77E+01	1.30E-01	4.63E+01	1.26E-01	1.53E+01	4.17E-02	7.79E+01	2.13E-01
Crosby	2.90E+00	7.93E-03	1.36E+01	3.73E-02	4.09E-01	1.12E-03	3.97E-01	1.08E-03	2.96E-01	8.09E-04	6.07E-01	1.66E-03
Culberson	3.59E+01	9.80E-02	1.08E+02	2.95E-01	5.53E+00	1.51E-02	5.36E+00	1.46E-02	1.70E+00	4.64E-03	9.20E+00	2.51E-02
Dallas	7.73E+00	2.11E-02	3.84E+01	1.05E-01	1.12E+00	3.05E-03	1.08E+00	2.96E-03	7.73E-01	2.11E-03	2.21E+00	6.03E-03
Dawson	5.66E+01	1.55E-01	1.63E+02	4.45E-01	8.73E+00	2.39E-02	8.47E+00	2.31E-02	2.52E+00	6.89E-03	1.43E+01	3.91E-02
Denton	2.06E+02	5.62E-01	9.93E+02	2.71E+00	2.99E+01	8.16E-02	2.90E+01	7.91E-02	1.99E+01	5.44E-02	5.83E+01	1.59E-01
DeWitt	1.05E+02	2.86E-01	3.80E+02	1.04E+00	1.57E+01	4.30E-02	1.53E+01	4.17E-02	7.06E+00	1.93E-02	2.79E+01	7.61E-02
Dickens	2.40E+01	6.56E-02	7.72E+01	2.11E-01	3.65E+00	9.96E-03	3.54E+00	9.66E-03	1.34E+00	3.65E-03	5.84E+00	1.60E-02
Dimmit	4.50E+01	1.23E-01	1.66E+02	4.53E-01	6.75E+00	1.84E-02	6.55E+00	1.79E-02	2.96E+00	8.10E-03	1.13E+01	3.10E-02
Duval	7.96E+01	2.17E-01	2.39E+02	6.53E-01	1.22E+01	3.35E-02	1.19E+01	3.25E-02	3.78E+00	1.03E-02	2.02E+01	5.53E-02
Eastland	1.52E+00	4.16E-03	7.16E+00	1.96E-02	2.15E-01	5.87E-04	2.08E-01	5.69E-04	1.55E-01	4.24E-04	3.18E-01	8.70E-04
Ector	2.64E+02	7.21E-01	7.77E+02	2.12E+00	4.06E+01	1.11E-01	3.94E+01	1.08E-01	1.23E+01	3.36E-02	6.64E+01	1.81E-01
Edwards	3.99E+01	1.09E-01	1.31E+02	3.58E-01	6.07E+00	1.66E-02	5.89E+00	1.61E-02	2.20E+00	6.01E-03	1.01E+01	2.76E-02
Ellis	2.09E+01	5.72E-02	1.04E+02	2.84E-01	3.03E+00	8.27E-03	2.94E+00	8.02E-03	2.10E+00	5.73E-03	5.97E+00	1.63E-02
Erath	8.49E+00	2.32E-02	4.44E+01	1.21E-01	1.22E+00	3.34E-03	1.19E+00	3.24E-03	8.51E-01	2.33E-03	2.35E+00	6.42E-03
Falls	5.70E-02	1.56E-04	2.51E-01	6.87E-04	8.04E-03	2.20E-05	7.80E-03	2.13E-05	5.81E-03	1.59E-05	1.19E-02	3.26E-05
Fannin	2.84E+00	7.77E-03	7.39E+00	2.02E-02	4.41E-01	1.20E-03	4.28E-01	1.17E-03	1.19E-01	3.24E-04	7.20E-01	1.97E-03
Fayette	1.11E+01	3.03E-02	4.69E+01	1.28E-01	1.63E+00	4.46E-03	1.58E+00	4.33E-03	9.16E-01	2.50E-03	3.02E+00	8.24E-03
Fisher	1.54E+01	4.20E-02	5.25E+01	1.44E-01	2.31E+00	6.31E-03	2.24E+00	6.12E-03	9.52E-01	2.60E-03	3.67E+00	1.00E-02

Table 6.11 2008 Annual and OSD County-Level Criteria Pollutant Emission Estimates (Cont.)

County	CO-ANN tons/yr	CO-OSD tons/day	NO_X-ANN tons/yr	NO_X-OSD tons/day	PM_{10}-ANN tons/yr	PM_{10}-OSD tons/day	$PM_{2.5}$-ANN tons/yr	$PM_{2.5}$-OSD tons/day	SO_2-ANN tons/yr	SO_2-OSD tons/day	VOC-ANN tons/yr	VOC-OSD tons/day
Foard	7.94E-01	2.17E-03	3.74E+00	1.02E-02	1.12E-01	3.06E-04	1.09E-01	2.97E-04	8.10E-02	2.21E-04	1.66E-01	4.54E-04
Fort Bend	2.60E+01	7.09E-02	9.96E+01	2.72E-01	3.85E+00	1.05E-02	3.73E+00	1.02E-02	1.95E+00	5.34E-03	6.66E+00	1.82E-02
Franklin	1.45E+01	3.96E-02	3.83E+01	1.05E-01	2.24E+00	6.13E-03	2.17E+00	5.94E-03	6.26E-01	1.71E-03	3.66E+00	9.99E-03
Freestone	4.35E+02	1.19E+00	1.22E+03	3.33E+00	6.70E+01	1.83E-01	6.50E+01	1.77E-01	2.04E+01	5.56E-02	1.11E+02	3.04E-01
Frio	1.91E+01	5.21E-02	7.43E+01	2.03E-01	2.84E+00	7.75E-03	2.75E+00	7.52E-03	1.37E+00	3.74E-03	4.77E+00	1.30E-02
Gaines	1.12E+02	3.07E-01	3.47E+02	9.48E-01	1.72E+01	4.69E-02	1.66E+01	4.55E-02	5.72E+00	1.56E-02	2.80E+01	7.65E-02
Galveston	1.19E+01	3.26E-02	4.11E+01	1.12E-01	1.81E+00	4.93E-03	1.75E+00	4.78E-03	7.49E-01	2.05E-03	3.15E+00	8.61E-03
Garza	1.40E+01	3.83E-02	5.11E+01	1.39E-01	2.09E+00	5.70E-03	2.02E+00	5.53E-03	9.61E-01	2.63E-03	3.30E+00	9.00E-03
Glasscock	1.36E+02	3.72E-01	3.81E+02	1.04E+00	2.11E+01	5.76E-02	2.05E+01	5.59E-02	5.78E+00	1.58E-02	3.46E+01	9.44E-02
Goliad	6.97E+01	1.91E-01	2.09E+02	5.70E-01	1.06E+01	2.91E-02	1.03E+01	2.82E-02	3.70E+00	1.01E-02	1.75E+01	4.79E-02
Gonzales	5.35E+00	1.46E-02	1.87E+01	5.12E-02	8.04E-01	2.20E-03	7.80E-01	2.13E-03	3.50E-01	9.57E-04	1.39E+00	3.79E-03
Gray	2.33E+00	6.37E-03	7.20E+00	1.97E-02	3.56E-01	9.72E-04	3.45E-01	9.43E-04	1.20E-01	3.29E-04	5.73E-01	1.57E-03
Grayson	1.07E+01	2.91E-02	3.54E+01	9.66E-02	1.62E+00	4.42E-03	1.57E+00	4.28E-03	6.40E-01	1.75E-03	2.78E+00	7.59E-03
Gregg	9.58E+01	2.62E-01	2.97E+02	8.12E-01	1.46E+01	4.00E-02	1.42E+01	3.88E-02	5.19E+00	1.42E-02	2.49E+01	6.81E-02
Grimes	1.33E+01	3.64E-02	6.59E+01	1.80E-01	1.92E+00	5.25E-03	1.86E+00	5.09E-03	1.33E+00	3.64E-03	3.79E+00	1.03E-02
Guadalupe	8.96E-01	2.45E-03	4.29E+00	1.17E-02	1.29E-01	3.51E-04	1.25E-01	3.41E-04	9.02E-02	2.47E-04	2.34E-01	6.38E-04
Hale	3.22E+00	8.80E-03	1.58E+01	4.33E-02	4.59E-01	1.25E-03	4.45E-01	1.22E-03	3.26E-01	8.92E-04	7.63E-01	2.08E-03
Hansford	4.53E+01	1.24E-01	1.39E+02	3.80E-01	6.95E+00	1.90E-02	6.74E+00	1.84E-02	2.24E+00	6.11E-03	1.15E+01	3.14E-02
Hardeman	1.70E+01	4.65E-02	5.35E+01	1.46E-01	2.61E+00	7.13E-03	2.53E+00	6.92E-03	8.64E-01	2.36E-03	4.37E+00	1.19E-02
Hardin	5.91E+01	1.62E-01	1.92E+02	5.23E-01	8.98E+00	2.45E-02	8.71E+00	2.38E-02	3.44E+00	9.40E-03	1.53E+01	4.18E-02
Harris	1.24E+01	3.38E-02	4.89E+01	1.34E-01	1.84E+00	5.02E-03	1.78E+00	4.87E-03	9.40E-01	2.57E-03	3.32E+00	9.06E-03
Harrison	5.79E+02	1.58E+00	1.84E+03	5.04E+00	8.82E+01	2.41E-01	8.55E+01	2.34E-01	3.26E+01	8.91E-02	1.51E+02	4.13E-01
Hartley	5.68E-01	1.55E-03	2.67E+00	7.30E-03	8.01E-02	2.19E-04	7.77E-02	2.12E-04	5.80E-02	1.58E-04	1.19E-01	3.25E-04
Haskell	2.02E+00	5.51E-03	9.48E+00	2.59E-02	2.84E-01	7.77E-04	2.76E-01	7.54E-04	2.06E-01	5.62E-04	4.22E-01	1.15E-03
Hemphill	6.43E+02	1.76E+00	1.92E+03	5.23E+00	9.90E+01	2.71E-01	9.61E+01	2.62E-01	3.00E+01	8.18E-02	1.64E+02	4.49E-01
Henderson	3.91E+01	1.07E-01	1.11E+02	3.04E-01	6.01E+00	1.64E-02	5.83E+00	1.59E-02	1.87E+00	5.12E-03	1.00E+01	2.74E-02
Hidalgo	2.27E+02	6.19E-01	6.98E+02	1.91E+00	3.48E+01	9.51E-02	3.38E+01	9.23E-02	1.11E+01	3.03E-02	5.82E+01	1.59E-01
Hill	9.04E+01	2.47E-01	4.49E+02	1.23E+00	1.31E+01	3.57E-02	1.27E+01	3.46E-02	9.05E+00	2.47E-02	2.58E+01	7.04E-02
Hockley	3.19E+01	8.71E-02	1.18E+02	3.23E-01	4.77E+00	1.30E-02	4.63E+00	1.27E-02	2.12E+00	5.80E-03	8.00E+00	2.18E-02
Hood	7.86E+01	2.15E-01	3.90E+02	1.07E+00	1.13E+01	3.10E-02	1.10E+01	3.01E-02	7.86E+00	2.15E-02	2.24E+01	6.12E-02

Table 6.11 2008 Annual and OSD County-Level Criteria Pollutant Emission Estimates (Cont.)

County	CO-ANN tons/yr	CO-OSD tons/day	NO_X-ANN tons/yr	NO_X-OSD tons/day	PM_{10}-ANN tons/yr	PM_{10}-OSD tons/day	$PM_{2.5}$-ANN tons/yr	$PM_{2.5}$-OSD tons/day	SO_2-ANN tons/yr	SO_2-OSD tons/day	VOC-ANN tons/yr	VOC-OSD tons/day
Hopkins	3.41E+00	9.31E-03	9.11E+00	2.49E-02	5.26E-01	1.44E-03	5.10E-01	1.39E-03	1.51E-01	4.12E-04	8.56E-01	2.34E-03
Houston	2.89E+01	7.89E-02	8.59E+01	2.35E-01	4.43E+00	1.21E-02	4.29E+00	1.17E-02	1.48E+00	4.04E-03	7.44E+00	2.03E-02
Howard	1.19E+02	3.26E-01	3.36E+02	9.17E-01	1.85E+01	5.04E-02	1.79E+01	4.89E-02	5.14E+00	1.40E-02	3.01E+01	8.23E-02
Hudspeth	4.12E+00	1.12E-02	1.30E+01	3.55E-02	6.26E-01	1.71E-03	6.08E-01	1.66E-03	2.21E-01	6.05E-04	1.01E+00	2.75E-03
Hutchinson	1.55E+01	4.24E-02	6.98E+01	1.91E-01	2.24E+00	6.11E-03	2.17E+00	5.92E-03	1.42E+00	3.89E-03	3.59E+00	9.81E-03
Irion	2.33E+02	6.36E-01	6.57E+02	1.79E+00	3.60E+01	9.83E-02	3.49E+01	9.54E-02	1.01E+01	2.76E-02	5.87E+01	1.60E-01
Jack	1.69E+01	4.63E-02	8.59E+01	2.35E-01	2.43E+00	6.63E-03	2.35E+00	6.43E-03	1.71E+00	4.66E-03	4.36E+00	1.19E-02
Jackson	5.69E+01	1.56E-01	1.66E+02	4.53E-01	8.70E+00	2.38E-02	8.44E+00	2.31E-02	2.92E+00	7.97E-03	1.42E+01	3.88E-02
Jasper	2.20E+01	6.02E-02	9.34E+01	2.55E-01	3.25E+00	8.88E-03	3.15E+00	8.61E-03	1.81E+00	4.96E-03	6.05E+00	1.65E-02
Jefferson	4.90E+01	1.34E-01	1.84E+02	5.03E-01	7.34E+00	2.01E-02	7.12E+00	1.95E-02	3.46E+00	9.44E-03	1.31E+01	3.59E-02
Jim Hogg	3.05E+01	8.33E-02	8.78E+01	2.40E-01	4.71E+00	1.29E-02	4.57E+00	1.25E-02	1.36E+00	3.70E-03	7.74E+00	2.12E-02
Jim Wells	1.10E+01	3.01E-02	3.69E+01	1.01E-01	1.67E+00	4.56E-03	1.62E+00	4.42E-03	6.49E-01	1.77E-03	2.69E+00	7.36E-03
Johnson	6.62E+02	1.81E+00	3.27E+03	8.93E+00	9.57E+01	2.62E-01	9.28E+01	2.54E-01	6.58E+01	1.80E-01	1.89E+02	5.15E-01
Jones	7.02E+00	1.92E-02	3.30E+01	9.02E-02	9.91E-01	2.71E-03	9.61E-01	2.63E-03	7.17E-01	1.96E-03	1.47E+00	4.01E-03
Karnes	2.97E+01	8.12E-02	1.11E+02	3.05E-01	4.45E+00	1.22E-02	4.32E+00	1.18E-02	2.10E+00	5.73E-03	7.95E+00	2.17E-02
Kenedy	6.47E+01	1.77E-01	1.98E+02	5.40E-01	9.94E+00	2.72E-02	9.64E+00	2.63E-02	3.13E+00	8.56E-03	1.66E+01	4.53E-02
Kent	2.31E+01	6.30E-02	7.83E+01	2.14E-01	3.49E+00	9.54E-03	3.39E+00	9.25E-03	1.36E+00	3.71E-03	5.76E+00	1.57E-02
King	7.56E+00	2.07E-02	3.34E+01	9.13E-02	1.08E+00	2.96E-03	1.05E+00	2.87E-03	7.05E-01	1.93E-03	1.63E+00	4.45E-03
Kleberg	1.98E+01	5.42E-02	8.43E+01	2.30E-01	2.95E+00	8.06E-03	2.86E+00	7.82E-03	1.51E+00	4.12E-03	5.39E+00	1.47E-02
Knox	2.79E+00	7.63E-03	1.11E+01	3.02E-02	4.09E-01	1.12E-03	3.97E-01	1.08E-03	2.20E-01	6.01E-04	6.32E-01	1.73E-03
La Salle	1.07E+02	2.92E-01	3.04E+02	8.32E-01	1.65E+01	4.52E-02	1.60E+01	4.38E-02	4.68E+00	1.28E-02	2.71E+01	7.40E-02
Lamb	1.62E+00	4.43E-03	7.96E+00	2.18E-02	2.31E-01	6.30E-04	2.24E-01	6.11E-04	1.64E-01	4.49E-04	3.83E-01	1.05E-03
Lavaca	1.03E+02	2.81E-01	3.14E+02	8.57E-01	1.57E+01	4.30E-02	1.53E+01	4.17E-02	5.49E+00	1.50E-02	2.65E+01	7.23E-02
Lee	1.12E+01	3.07E-02	4.65E+01	1.27E-01	1.66E+00	4.53E-03	1.61E+00	4.39E-03	9.12E-01	2.49E-03	3.00E+00	8.20E-03
Leon	1.05E+02	2.86E-01	3.33E+02	9.10E-01	1.59E+01	4.36E-02	1.55E+01	4.23E-02	5.91E+00	1.61E-02	2.72E+01	7.43E-02
Liberty	6.19E+01	1.69E-01	1.89E+02	5.18E-01	9.46E+00	2.58E-02	9.17E+00	2.51E-02	3.31E+00	9.03E-03	1.60E+01	4.37E-02
Limestone	3.16E+02	8.64E-01	9.05E+02	2.47E+00	4.86E+01	1.33E-01	4.72E+01	1.29E-01	1.53E+01	4.17E-02	8.12E+01	2.22E-01
Lipscomb	1.45E+02	3.95E-01	6.84E+02	1.87E+00	2.12E+01	5.80E-02	2.06E+01	5.63E-02	1.26E+01	3.44E-02	4.02E+01	1.10E-01
Live Oak	6.56E+01	1.79E-01	2.02E+02	5.51E-01	1.00E+01	2.73E-02	9.70E+00	2.65E-02	3.58E+00	9.77E-03	1.67E+01	4.58E-02
Loving	1.00E+02	2.74E-01	2.93E+02	8.01E-01	1.54E+01	4.22E-02	1.50E+01	4.09E-02	4.62E+00	1.26E-02	2.53E+01	6.90E-02

Table 6.11 2008 Annual and OSD County-Level Criteria Pollutant Emission Estimates (Cont.)

County	CO-ANN tons/yr	CO-OSD tons/day	NO_X-ANN tons/yr	NO_X-OSD tons/day	PM_{10}-ANN tons/yr	PM_{10}-OSD tons/day	$PM_{2.5}$-ANN tons/yr	$PM_{2.5}$-OSD tons/day	SO_2-ANN tons/yr	SO_2-OSD tons/day	VOC-ANN tons/yr	VOC-OSD tons/day
Lubbock	1.91E+00	5.21E-03	8.97E+00	2.45E-02	2.69E-01	7.36E-04	2.61E-01	7.14E-04	1.95E-01	5.32E-04	3.99E-01	1.09E-03
Lynn	6.92E+00	1.89E-02	1.92E+01	5.24E-02	1.07E+00	2.93E-03	1.04E+00	2.84E-03	2.89E-01	7.90E-04	1.75E+00	4.79E-03
Madison	1.06E+01	2.89E-02	3.96E+01	1.08E-01	1.59E+00	4.33E-03	1.54E+00	4.20E-03	7.41E-01	2.03E-03	2.84E+00	7.77E-03
Marion	2.08E+01	5.70E-02	6.64E+01	1.81E-01	3.18E+00	8.68E-03	3.08E+00	8.42E-03	1.17E+00	3.20E-03	5.44E+00	1.49E-02
Martin	5.45E+02	1.49E+00	1.51E+03	4.13E+00	8.45E+01	2.31E-01	8.20E+01	2.24E-01	2.28E+01	6.22E-02	1.38E+02	3.77E-01
Matagorda	9.69E+01	2.65E-01	2.72E+02	7.43E-01	1.49E+01	4.08E-02	1.45E+01	3.96E-02	4.55E+00	1.24E-02	2.48E+01	6.77E-02
Maverick	3.34E+01	9.11E-02	1.60E+02	4.37E-01	4.83E+00	1.32E-02	4.68E+00	1.28E-02	3.12E+00	8.53E-03	8.58E+00	2.35E-02
McCulloch	3.16E-02	8.65E-05	1.49E-01	4.07E-04	4.46E-03	1.22E-05	4.33E-03	1.18E-05	3.23E-03	8.82E-06	6.62E-03	1.81E-05
McLennan	2.20E+00	6.01E-03	7.53E+00	2.06E-02	3.33E-01	9.08E-04	3.23E-01	8.81E-04	1.37E-01	3.75E-04	5.79E-01	1.58E-03
McMullen	1.20E+02	3.28E-01	3.50E+02	9.58E-01	1.85E+01	5.06E-02	1.80E+01	4.91E-02	5.49E+00	1.50E-02	3.04E+01	8.30E-02
Medina	9.53E-01	2.60E-03	4.48E+00	1.22E-02	1.34E-01	3.67E-04	1.30E-01	3.56E-04	9.72E-02	2.66E-04	1.99E-01	5.45E-04
Menard	2.23E+00	6.10E-03	1.05E+01	2.87E-02	3.15E-01	8.60E-04	3.05E-01	8.34E-04	2.28E-01	6.22E-04	4.67E-01	1.28E-03
Midland	4.01E+02	1.10E+00	1.13E+03	3.08E+00	6.21E+01	1.70E-01	6.02E+01	1.64E-01	1.71E+01	4.67E-02	1.02E+02	2.78E-01
Milam	2.11E+00	5.76E-03	6.58E+00	1.80E-02	3.18E-01	8.69E-04	3.09E-01	8.43E-04	1.25E-01	3.41E-04	5.07E-01	1.38E-03
Mitchell	2.03E+01	5.54E-02	9.54E+01	2.61E-01	2.86E+00	7.82E-03	2.78E+00	7.58E-03	2.07E+00	5.65E-03	4.24E+00	1.16E-02
Montague	1.03E+02	2.81E-01	3.63E+02	9.92E-01	1.56E+01	4.26E-02	1.51E+01	4.14E-02	6.16E+00	1.68E-02	2.68E+01	7.33E-02
Montgomery	9.87E+00	2.70E-02	3.05E+01	8.33E-02	1.51E+00	4.12E-03	1.46E+00	3.99E-03	5.35E-01	1.46E-03	2.55E+00	6.98E-03
Moore	4.49E+00	1.23E-02	2.14E+01	5.85E-02	6.35E-01	1.74E-03	6.16E-01	1.68E-03	4.57E-01	1.25E-03	9.77E-01	2.67E-03
Motley	1.51E+00	4.11E-03	4.48E+00	1.22E-02	2.31E-01	6.31E-04	2.24E-01	6.13E-04	7.24E-02	1.98E-04	3.74E-01	1.02E-03
Nacogdoches	3.90E+02	1.07E+00	1.15E+03	3.15E+00	5.98E+01	1.63E-01	5.80E+01	1.59E-01	1.97E+01	5.39E-02	1.01E+02	2.75E-01
Navarro	1.69E+01	4.63E-02	4.73E+01	1.29E-01	2.60E+00	7.11E-03	2.53E+00	6.90E-03	8.06E-01	2.20E-03	4.26E+00	1.16E-02
Newton	9.90E+00	2.70E-02	3.83E+01	1.05E-01	1.48E+00	4.04E-03	1.43E+00	3.92E-03	7.23E-01	1.98E-03	2.68E+00	7.31E-03
Nolan	1.62E+01	4.42E-02	6.52E+01	1.78E-01	2.36E+00	6.45E-03	2.29E+00	6.26E-03	1.31E+00	3.58E-03	3.63E+00	9.93E-03
Nueces	5.79E+01	1.58E-01	1.66E+02	4.54E-01	8.90E+00	2.43E-02	8.63E+00	2.36E-02	2.84E+00	7.76E-03	1.47E+01	4.03E-02
Ochiltree	8.01E+01	2.19E-01	3.07E+02	8.38E-01	1.21E+01	3.30E-02	1.17E+01	3.20E-02	5.31E+00	1.45E-02	2.13E+01	5.83E-02
Oldham	6.87E+00	1.88E-02	1.90E+01	5.20E-02	1.06E+00	2.91E-03	1.03E+00	2.82E-03	2.87E-01	7.84E-04	1.74E+00	4.76E-03
Orange	1.06E+01	2.91E-02	4.67E+01	1.27E-01	1.56E+00	4.27E-03	1.52E+00	4.14E-03	9.16E-01	2.50E-03	2.94E+00	8.02E-03
Palo Pinto	1.72E+01	4.70E-02	8.71E+01	2.38E-01	2.46E+00	6.73E-03	2.39E+00	6.53E-03	1.73E+00	4.74E-03	4.40E+00	1.20E-02
Panola	5.35E+02	1.46E+00	1.70E+03	4.64E+00	8.14E+01	2.23E-01	7.90E+01	2.16E-01	3.00E+01	8.19E-02	1.39E+02	3.81E-01
Parker	6.86E+01	1.88E-01	3.40E+02	9.30E-01	9.91E+00	2.71E-02	9.62E+00	2.63E-02	6.87E+00	1.88E-02	1.96E+01	5.35E-02

Table 6.11 2008 Annual and OSD County-Level Criteria Pollutant Emission Estimates (Cont.)

County	CO-ANN tons/yr	CO-OSD tons/day	NO_X-ANN tons/yr	NO_X-OSD tons/day	PM_{10}-ANN tons/yr	PM_{10}-OSD tons/day	$PM_{2.5}$-ANN tons/yr	$PM_{2.5}$-OSD tons/day	SO_2-ANN tons/yr	SO_2-OSD tons/day	VOC-ANN tons/yr	VOC-OSD tons/day
Pecos	4.72E+02	1.29E+00	1.49E+03	4.06E+00	7.23E+01	1.98E-01	7.02E+01	1.92E-01	2.39E+01	6.54E-02	1.21E+02	3.31E-01
Polk	3.25E+01	8.88E-02	1.28E+02	3.50E-01	4.83E+00	1.32E-02	4.69E+00	1.28E-02	2.46E+00	6.73E-03	8.69E+00	2.37E-02
Potter	6.71E-01	1.83E-03	3.16E+00	8.62E-03	9.47E-02	2.59E-04	9.18E-02	2.51E-04	6.84E-02	1.87E-04	1.40E-01	3.83E-04
Reagan	3.77E+02	1.03E+00	1.05E+03	2.86E+00	5.84E+01	1.59E-01	5.66E+01	1.55E-01	1.58E+01	4.32E-02	9.54E+01	2.61E-01
Real	9.49E-02	2.59E-04	4.46E-01	1.22E-03	1.34E-02	3.66E-05	1.30E-02	3.55E-05	9.69E-03	2.65E-05	1.99E-02	5.43E-05
Red River	1.86E+00	5.09E-03	6.24E+00	1.70E-02	2.81E-01	7.68E-04	2.73E-01	7.45E-04	1.15E-01	3.14E-04	4.78E-01	1.31E-03
Reeves	7.84E+01	2.14E-01	2.96E+02	8.08E-01	1.18E+01	3.22E-02	1.14E+01	3.13E-02	5.13E+00	1.40E-02	2.07E+01	5.64E-02
Refugio	6.89E+01	1.88E-01	2.13E+02	5.81E-01	1.04E+01	2.85E-02	1.01E+01	2.76E-02	4.00E+00	1.09E-02	1.66E+01	4.54E-02
Roberts	2.29E+02	6.25E-01	7.06E+02	1.93E+00	3.52E+01	9.61E-02	3.41E+01	9.32E-02	1.12E+01	3.07E-02	5.88E+01	1.61E-01
Robertson	3.81E+02	1.04E+00	1.07E+03	2.93E+00	5.87E+01	1.60E-01	5.69E+01	1.56E-01	1.79E+01	4.89E-02	9.76E+01	2.67E-01
Runnels	1.23E+01	3.35E-02	5.79E+01	1.58E-01	1.73E+00	4.73E-03	1.68E+00	4.59E-03	1.25E+00	3.41E-03	2.59E+00	7.08E-03
Rusk	5.94E+02	1.62E+00	1.64E+03	4.48E+00	9.16E+01	2.50E-01	8.88E+01	2.43E-01	2.71E+01	7.42E-02	1.52E+02	4.14E-01
Sabine	1.20E+00	3.27E-03	3.11E+00	8.50E-03	1.86E-01	5.07E-04	1.80E-01	4.92E-04	5.00E-02	1.37E-04	3.03E-01	8.29E-04
San Augustine	3.02E+01	8.24E-02	1.31E+02	3.58E-01	4.44E+00	1.21E-02	4.30E+00	1.18E-02	2.56E+00	6.99E-03	8.35E+00	2.28E-02
San Jacinto	2.11E+01	5.77E-02	5.96E+01	1.63E-01	3.25E+00	8.89E-03	3.16E+00	8.62E-03	9.98E-01	2.73E-03	5.41E+00	1.48E-02
San Patricio	2.19E+01	6.00E-02	7.51E+01	2.05E-01	3.32E+00	9.06E-03	3.22E+00	8.79E-03	1.38E+00	3.76E-03	5.74E+00	1.57E-02
Schleicher	6.60E+01	1.80E-01	1.90E+02	5.19E-01	1.02E+01	2.78E-02	9.87E+00	2.70E-02	2.98E+00	8.15E-03	1.66E+01	4.52E-02
Scurry	4.61E+01	1.26E-01	1.56E+02	4.27E-01	7.00E+00	1.91E-02	6.79E+00	1.85E-02	2.66E+00	7.27E-03	1.17E+01	3.20E-02
Shackelford	6.53E+00	1.78E-02	3.07E+01	8.39E-02	9.21E-01	2.52E-03	8.94E-01	2.44E-03	6.66E-01	1.82E-03	1.37E+00	3.73E-03
Shelby	1.50E+02	4.11E-01	5.53E+02	1.51E+00	2.26E+01	6.17E-02	2.19E+01	5.98E-02	1.03E+01	2.81E-02	4.03E+01	1.10E-01
Sherman	2.07E+01	5.67E-02	7.43E+01	2.03E-01	3.09E+00	8.46E-03	3.00E+00	8.20E-03	1.39E+00	3.80E-03	4.87E+00	1.33E-02
Smith	3.09E+01	8.45E-02	1.15E+02	3.14E-01	4.64E+00	1.27E-02	4.50E+00	1.23E-02	2.15E+00	5.86E-03	8.29E+00	2.26E-02
Somervell	1.12E+01	3.06E-02	5.55E+01	1.52E-01	1.62E+00	4.42E-03	1.57E+00	4.28E-03	1.12E+00	3.06E-03	3.19E+00	8.72E-03
Starr	2.27E+02	6.19E-01	6.67E+02	1.82E+00	3.49E+01	9.54E-02	3.39E+01	9.26E-02	1.04E+01	2.84E-02	5.77E+01	1.58E-01
Stephens	1.60E+01	4.37E-02	7.58E+01	2.07E-01	2.26E+00	6.17E-03	2.19E+00	5.99E-03	1.63E+00	4.45E-03	3.43E+00	9.37E-03
Sterling	4.61E+01	1.26E-01	1.32E+02	3.61E-01	7.12E+00	1.95E-02	6.91E+00	1.89E-02	2.05E+00	5.59E-03	1.17E+01	3.18E-02
Stonewall	7.00E+00	1.91E-02	3.29E+01	8.99E-02	9.87E-01	2.70E-03	9.57E-01	2.62E-03	7.14E-01	1.95E-03	1.46E+00	4.00E-03
Sutton	3.03E+02	8.29E-01	8.88E+02	2.43E+00	4.67E+01	1.28E-01	4.53E+01	1.24E-01	1.41E+01	3.86E-02	7.58E+01	2.07E-01
Tarrant	5.97E+02	1.63E+00	2.95E+03	8.07E+00	8.62E+01	2.36E-01	8.36E+01	2.29E-01	5.95E+01	1.63E-01	1.70E+02	4.65E-01
Taylor	2.50E+00	6.84E-03	1.20E+01	3.27E-02	3.54E-01	9.68E-04	3.44E-01	9.39E-04	2.55E-01	6.96E-04	5.47E-01	1.50E-03

Table 6.11 2008 Annual and OSD County-Level Criteria Pollutant Emission Estimates (Cont.)

County	CO-ANN tons/yr	CO-OSD tons/day	NO_X-ANN tons/yr	NO_X-OSD tons/day	PM_{10}-ANN tons/yr	PM_{10}-OSD tons/day	$PM_{2.5}$-ANN tons/yr	$PM_{2.5}$-OSD tons/day	SO_2-ANN tons/yr	SO_2-OSD tons/day	VOC-ANN tons/yr	VOC-OSD tons/day
Terrell	5.40E+01	1.48E-01	1.73E+02	4.72E-01	8.26E+00	2.26E-02	8.01E+00	2.19E-02	2.83E+00	7.73E-03	1.38E+01	3.77E-02
Terry	1.80E+01	4.93E-02	6.24E+01	1.71E-01	2.74E+00	7.48E-03	2.66E+00	7.26E-03	1.05E+00	2.88E-03	4.67E+00	1.28E-02
Throckmorton	2.87E+00	7.85E-03	1.35E+01	3.69E-02	4.06E-01	1.11E-03	3.93E-01	1.07E-03	2.93E-01	8.01E-04	6.01E-01	1.64E-03
Titus	1.46E-01	3.98E-04	6.42E-01	1.75E-03	2.05E-02	5.61E-05	1.99E-02	5.44E-05	1.49E-02	4.06E-05	3.05E-02	8.32E-05
Tom Green	6.31E+00	1.72E-02	2.50E+01	6.84E-02	9.23E-01	2.52E-03	8.95E-01	2.45E-03	4.99E-01	1.36E-03	1.42E+00	3.89E-03
Trinity	1.30E-01	3.54E-04	5.72E-01	1.56E-03	1.83E-02	5.00E-05	1.78E-02	4.85E-05	1.32E-02	3.62E-05	2.71E-02	7.42E-05
Tyler	3.69E+01	1.01E-01	1.58E+02	4.31E-01	5.43E+00	1.48E-02	5.27E+00	1.44E-02	3.08E+00	8.41E-03	1.01E+01	2.77E-02
Upshur	4.68E+01	1.28E-01	1.40E+02	3.83E-01	7.18E+00	1.96E-02	6.96E+00	1.90E-02	2.42E+00	6.60E-03	1.21E+01	3.30E-02
Upton	7.28E+02	1.99E+00	2.08E+03	5.68E+00	1.13E+02	3.08E-01	1.09E+02	2.98E-01	3.19E+01	8.71E-02	1.85E+02	5.06E-01
Val Verde	1.11E+01	3.02E-02	3.09E+01	8.43E-02	1.71E+00	4.68E-03	1.66E+00	4.54E-03	4.68E-01	1.28E-03	2.80E+00	7.65E-03
Van Zandt	5.53E+00	1.51E-02	1.48E+01	4.05E-02	8.53E-01	2.33E-03	8.28E-01	2.26E-03	2.46E-01	6.73E-04	1.39E+00	3.79E-03
Victoria	4.30E+01	1.17E-01	1.35E+02	3.68E-01	6.50E+00	1.78E-02	6.30E+00	1.72E-02	2.51E+00	6.85E-03	1.05E+01	2.88E-02
Walker	1.55E-01	4.24E-04	6.84E-01	1.87E-03	2.19E-02	5.98E-05	2.12E-02	5.80E-05	1.58E-02	4.32E-05	3.24E-02	8.86E-05
Waller	1.26E+01	3.46E-02	3.94E+01	1.08E-01	1.92E+00	5.23E-03	1.86E+00	5.08E-03	7.31E-01	2.00E-03	3.11E+00	8.50E-03
Ward	7.63E+01	2.08E-01	3.34E+02	9.12E-01	1.12E+01	3.07E-02	1.09E+01	2.98E-02	6.25E+00	1.71E-02	1.99E+01	5.43E-02
Washington	3.45E+00	9.43E-03	1.70E+01	4.65E-02	4.98E-01	1.36E-03	4.83E-01	1.32E-03	3.46E-01	9.45E-04	9.71E-01	2.65E-03
Webb	2.85E+02	7.79E-01	8.66E+02	2.37E+00	4.38E+01	1.20E-01	4.25E+01	1.16E-01	1.38E+01	3.77E-02	7.26E+01	1.98E-01
Wharton	1.04E+02	2.85E-01	3.06E+02	8.36E-01	1.60E+01	4.36E-02	1.55E+01	4.23E-02	5.33E+00	1.46E-02	2.64E+01	7.20E-02
Wheeler	6.12E+02	1.67E+00	1.79E+03	4.89E+00	9.45E+01	2.58E-01	9.17E+01	2.50E-01	2.77E+01	7.58E-02	1.56E+02	4.27E-01
Wichita	1.30E+01	3.54E-02	5.83E+01	1.59E-01	1.85E+00	5.04E-03	1.79E+00	4.89E-03	1.24E+00	3.39E-03	2.77E+00	7.57E-03
Wilbarger	4.02E+00	1.10E-02	1.89E+01	5.16E-02	5.67E-01	1.55E-03	5.50E-01	1.50E-03	4.10E-01	1.12E-03	8.41E-01	2.30E-03
Willacy	4.72E+01	1.29E-01	1.36E+02	3.71E-01	7.29E+00	1.99E-02	7.07E+00	1.93E-02	2.08E+00	5.69E-03	1.20E+01	3.28E-02
Wilson	3.46E-01	9.45E-04	1.72E+00	4.69E-03	4.99E-02	1.36E-04	4.84E-02	1.32E-04	3.46E-02	9.45E-05	9.86E-02	2.69E-04
Winkler	5.64E+01	1.54E-01	1.87E+02	5.10E-01	8.61E+00	2.35E-02	8.35E+00	2.28E-02	3.07E+00	8.38E-03	1.46E+01	3.99E-02
Wise	1.79E+02	4.89E-01	8.44E+02	2.31E+00	2.60E+01	7.11E-02	2.53E+01	6.90E-02	1.69E+01	4.61E-02	5.03E+01	1.37E-01
Wood	8.71E+00	2.38E-02	2.95E+01	8.07E-02	1.32E+00	3.60E-03	1.28E+00	3.49E-03	5.42E-01	1.48E-03	2.26E+00	6.18E-03
Yoakum	5.71E+01	1.56E-01	2.20E+02	6.01E-01	8.51E+00	2.33E-02	8.26E+00	2.26E-02	4.04E+00	1.10E-02	1.43E+01	3.89E-02
Young	8.21E+00	2.24E-02	3.86E+01	1.05E-01	1.16E+00	3.16E-03	1.12E+00	3.07E-03	8.37E-01	2.29E-03	1.72E+00	4.69E-03
Zapata	3.43E+02	9.38E-01	1.05E+03	2.87E+00	5.28E+01	1.44E-01	5.12E+01	1.40E-01	1.66E+01	4.54E-02	8.81E+01	2.41E-01
Zavala	5.19E+00	1.42E-02	2.71E+01	7.41E-02	7.47E-01	2.04E-03	7.25E-01	1.98E-03	5.20E-01	1.42E-03	1.44E+00	3.94E-03

7.0 Conclusions and Recommendations

This study presents a comprehensive, statewide 2008 emissions inventory for Texas for drilling rig engines. This inventory was prepared using well drilling activity data obtained through permit records from the TRC, combined with emissions data derived through detailed drilling rig engine data collected through a bottom-up survey effort.

Survey data was collected through a phone and email survey which resulted in the collection of 45 completed surveys obtained from 39 different drilling rig contractors and/or oil and gas well operators. These surveys were representative of over 1,500 wells drilled in Texas in 2008, or about 10% of all wells drilled in that year, and covered all of the major oil and gas basins in the state (Andarko, East Texas, Ft. Worth/Bend Arch, Permian, and Western Gulf). The data collected included drilling rig engine sizes (hp), ages, hours of operation, and model year.

The 2008 inventory was used as the basis for developing 2002 and 2005 year inventories, as well as projected inventories for 2009 through 2021. As compared to the previous oil and gas study prepared by TCEQ in 2007 (for a 2005 base year), the emission estimates presented in this study reflect a significant decrease in the statewide NO_x emission estimate for 2005 (42,854 tons per year in this study compared to 119,647 tons per year in the 2007 study). While not as pronounced, there were also significant decreases in the SO_2 and CO emission estimates based on this study. For VOC, PM_{10}, and $PM_{2.5}$, the estimates contained in this study show slightly higher estimates than in the previous study.

Further improvements to this inventory could be made through the addition of emission estimates for fracturing operations, as well as additional refinement of the activity data used for projected years 2009 through 2021.

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Appendix A – Approved Data Collection Plan

5608 Parkcrest Drive, Suite 100
Austin, TX 78731

MEMORANDUM

TO: Greg Lauderdale (TCEQ)

FROM: Rick Baker, Mike Pring (ERG)

DATE: April 3, 2009

SUBJECT: Work Order # 582-7-83985-FY09-01, Deliverable 2b- Final Data Collection Plan

This document serves as the final deliverable for Task 2 of the Work Order, and includes the results of ERG's review of existing activity and emissions data, and presents a Data Collection Plan which identifies the proposed approach for collecting the information needed to develop a comprehensive emissions inventory for land-based drilling rig engines in the state of Texas in 2008. In addition, as described in the Work Plan, we have included our recommendations on how to proceed with the Texas oil and gas drilling activity emissions estimation project.

The methodology used to develop the 2008 emissions inventory will be based on the 2005 emissions inventory ERG completed for TCEQ in 2007, but will expand on that effort by improving the analysis and data collection of both activity data and emissions data. ERG will conduct the data collection survey as per the proposed Data Collection Plan and as approved by TCEQ.

1.0 Review of Existing Studies, Data, and Industry Websites

Under Task 2, ERG has conducted a literature review and evaluated existing information and studies pertinent to the development of a comprehensive oil and gas drilling activity emissions inventory for the state of Texas for the year 2008. The results of this research is discussed below in two parts, the first being a review of existing studies that address estimating emissions from oil and gas drill rig operations, and the second being the results of our review of existing Texas data available from government and industry websites and publications.

1.1 Review of Existing Studies

As mentioned above, the goal of this project is to improve upon the 2005 emissions inventory ERG completed for TCEQ in 2007 for drill rig engines by obtaining more highly resolved activity data, as well as more accurate emissions information. Over the last several years, numerous studies have been conducted in the western states to develop area source emission estimates for oil and gas sources, with subsequent studies improving upon the data collection methodology and emission estimation approaches in prior studies. The relevant studies ERG has identified are provided in Table 1.

Table 1. Existing Drill Rig Engine Studies

Report	Geographic Coverage	Publication Date
Oil and Gas Emission Inventories for the Western States (WRAP Phase I)	WRAP States	December, 2005
Ozone Precursors Emission Inventory for San Juan and Rio Arriba Counties, New Mexico	San Juan and Rio Arriba Counties, New Mexico	August, 2006
Emissions from Oil and Gas Production Facilities	Texas	August, 2007
WRAP Area Source Emissions Inventory Projections and Control Strategy Evaluation Phase II	WRAP States	September, 2007
Development of Baseline 2006 Emissions from Oil and Gas Activity in the Denver-Julesburg Basin	Denver-Julesburg Basin, Colorado	April, 2008
Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories	CENRAP States	November, 2008
Development of Baseline 2006 Emissions from Oil and Gas Activity in the Piceance Basin	Piceance Basin, Colorado	January, 2009

As a result of a review of the existing literature, ERG has been able to develop a firm understanding of the types of equipment currently used by industry for different drilling activities, as well as basic approaches to surveying and compiling emissions estimates. Based on this review, ERG anticipates organizing our survey based on rig type (drilling rigs vs. completion/workover rigs), rig engine application (draw works engines, mud pump engines, and engines for general rig power), whether the rig is mechanical or electrical, well depth, and wellbore type (vertical, horizontal). Engine size (hp) will also be critical in our analysis, but the parameters listed above will dictate the various engine sizes we anticipate seeing. For example, many workover and completion rigs may be powered by a single engine at less than 600 hp, while rigs used on deep (over 15,000 feet) horizontal wells may require four or five engines, ranging in size from 500 to 1,000 hp each.

In addition to process information, example surveys and survey questions were included in several studies, and ERG anticipates formulating the survey used for this project utilizing examples provided in these reports.

It should be noted that these existing studies were comprehensive in nature, inclusive of all emission sources found at oil and gas exploration and production locations. While well drilling was included as an emission source, this source category was not a major focus of these efforts. As such, many of the surveys used in these studies were sent to the oil and gas producers themselves, and not directly to the owners and operators of the drill rigs, who are typically contracted by the producers to drill the well. Once a given well is completed, the drilling contractor will move on to the next well. Therefore, ERG anticipates focusing our survey efforts on the drilling contractors themselves, with less emphasis on the production companies as has been done previously.

Of the reports listed in Table 1, the CENRAP report appears to be the most relevant for this study as Texas is one of the CENRAP states covered under the report, and the report also provides "default" activity data and emission factors for the five major oil and gas basins in Texas (Andarko, East Texas, Fort Worth, Permian, and Western Gulf). While ERG anticipates developing specific activity data and emissions data from our survey efforts as part of this project, the CENRAP report may be useful for gap-filling and/or validation depending upon the results of our survey activities.

1.2 Review of Existing Activity Data

The primary source of activity data to be used to compile the 2008 drill rig emissions inventory will come from the Texas Railroad Commission (RRC). ERG has contacted the RRC and obtained a copy of the "Drilling Permit Master and Trailer" database, which contains information on every application to drill for an oil or gas well in Texas since 1976, including American Petroleum Institute (API) number, date approved, location (county), wellbore profile, well depth, spud-in date, and well completion date. ERG is currently in the process of translating this database into Access for ease of use in estimating emissions. This data will allow us to allocate emissions spatially (aggregated at the county level), as well as temporally (based on spud-in date and well completion date for each individual well). Use of this database will result in a more highly refined dataset than was used in development of the 2005 emissions inventory, which was based on total depth drilled by county by wellbore type, with drilling times estimated from the "worst case" well for each county/wellbore-type combination.

In addition, by obtaining the complete dataset, ERG will be able to analyze activity data for multiple years. As described in the work plan, ERG has concerns regarding the representativeness of activity data for 2008 given the extreme volatility in the market that year. Once the data has been properly compiled, ERG will consult with TCEQ and make a final recommendation as to the base year for this inventory effort. Regardless of which base year is chosen, the RRC data will be used to backcast the base year inventory to develop the 2002 and 2005 prior year inventories based on drilling permit records for those years. ERG anticipates developing 2009 through 2021 projected inventories using the base year inventory and forecasting future activity based on US DOE Energy Information Administration projections of oil and gas production for the Southwest and Gulf Coast regions from the *Annual Energy Outlook 2009.*

1.3 Review of Industry Websites

Using information available on the International Association of Drilling Contractors (IADC) website, we were able to identify many of the larger drilling contractors in Texas (while there may be non-IADC members with significant drilling activities in Texas, we did not identify any during our review). A review of the websites for these larger contractors provided useful information regarding the drilling rig fleets in use in Texas, and we were able to easily assimilate a dataset with specific equipment information on over 225 drill rigs. A few examples of this type of information can be found at the following drill rig operator websites:

a) http://www.gwdrilling.com/services/riglist.htm
b) http://www.pioneerdrlg.com/HTML/RigFleet.html
c) http://www.rowancompanies.com/fw/main/Land-Rig-Fleet-61.html

This effort was not exhaustive, and if additional information is needed to gap-fill or supplement our survey findings, there is additional information that can be obtained online. For example, Appendix A contains an example “spec sheet” for a specific rig used by Pioneer Drilling, including specific makes and models of both the draw works engines and mud pump engines. ERG will compile this information to the extent possible prior to conducting the survey in order to familiarize ourselves with the engine makes and models we are likely to encounter through the survey.

2.0 Data Collection Plan

By obtaining and translating the RRC “Drilling Permit Master and Trailer” database, we will have highly resolved data on all drilling activity that occurred in Texas during the base year. In addition to wells that were started and finished during the base year, we will also have data on drilling activities that commenced during the year preceding the base year (but finalized during the base year), as well as data on wells that were started during the base year but were not completed until the following year. Therefore, we feel we have obtained the best activity data available to use as the basis for the base year inventory.

As we will have obtained the activity data needed to estimate emissions from the RRC database, the primary focus of our data collection and survey activities will be on obtaining real data from rig operators who were actively drilling in Texas in 2008. The goal of this survey will be to develop a series of "model rig profiles" for different rig types, well depths, and geographic locations (basin-specific profiles are preferred).

Our proposed survey methodology for obtaining this information is provided below.

2.1 Participant Recruitment

In order to encourage survey response, stakeholder support for the study will be sought. At the current time, ERG has consulted with contacts at the University of Texas, Southern Methodist University, the Texas Railroad Commission, and the IADC in an effort to obtain an understanding of well drilling practices, and to assist us in encouraging stakeholder participation. The IADC provided helpful information on industry practices, but their organization does not endorse or participate in any survey activities, so further contribution from them may be limited to feedback on our draft survey materials and/or survey approach.

In addition to those sources we have already contacted, ERG anticipates encouraging additional stakeholder participation by contacting the following trade associations and local organizations:

a) Texas Oil and Gas Association (TxOGA)
b) Texas Independent Producers and Royalty Owners Association (TIPRO)
c) Independent Petroleum Association of America (IPAA)
d) Petroleum Equipment Suppliers Association (PESA)
e) The Barnett Shale Energy Education Council (BSEEC)

If possible, ERG will attempt to provide information regarding the study and survey to trade associations before administering the survey to promote cooperation with the study and to identify potential survey participants. We will prepare a draft survey for peer review by members of the Petroleum Engineering Department at the University of Texas to obtain feedback prior to implementation. ERG will also request trade associations and stakeholders help distribute a letter of introduction about the project on TCEQ letterhead to the owners and operators of drill rigs.

2.2 Mail and Phone Surveys

At this point we do not have a specific list of target respondents, but in general, will seek to find willing participants through our planned communication with the trade groups as described above, as well as searches through business listings and directories obtained from such sources as USA Data. Once we have identified a comprehensive listing of likely drilling rig operators, ERG will obtain the services of a survey contractor to execute this portion of the Data Collection Plan. ERG will train the survey contractor staff in conducting phone surveys of drill rig operators, providing background in the purpose of the study and familiarizing staff with industry terminology they may encounter. Once trained, the survey contractor will initiate the survey, first by phone calls to targeted respondents, then potentially by follow-up with phone, mail or fax surveys (as needed). Respondents will be asked to specify their preferred survey response mode, although phone surveys will be encouraged in order to reduce incomplete responses and errors.

Upon completion of the first week of phone surveys (and at regular intervals thereafter), ERG will review and audit the results of the phone surveys to confirm that we are contacting participants willing to provide us the needed information over the phone (or willing to continue with the mail survey), and determine if adjustments need to be made to the survey or survey method in order to ensure sufficient response for proper stratification of our model rig profiles.

The survey itself will focus on collecting the following information for representative, or average (based on a particular basin or drilling depth), drilling operations:

a) The number of engines on a rig
b) Engine make, model, model year, and size (hp)
c) Average load for each engine
d) Engine function (draw works, mud pumps, power)

e) Actual engine hour data for well completion (total hours)
f) Actual engine fuel use data for well completion (total fuel use)
g) Engine fuel type (and sulfur content for diesel fuel)
h) Engine-specific emission factors (based on manufacturers' or vendor data) or actual test data if available
i) Well location (county, API #)
j) Total well drilling time (actual number of drilling days)
k) Total well completion time (number of days needed for well completion activities)
l) Well depth

Depending on how responsive the survey participant are to the phone survey, and what level of aggregation they have data available, we may request "average" data for their rigs, or specific examples based on actual data for specific wells drilled in the base year. ERG will first attempt to obtain all the required information via the phone survey, but it is expected that specific information may more readily be obtained by following up with a mail survey.

Appendix B presents an example cover letter that will be included with the mail survey, and Appendix C provides an example of the types of information that will be requested. ERG will periodically review the mail survey responses to see if adjustments are needed in order to obtain a sufficient response rate by checking that all fields/basins are being covered, ensure all wellbore types are included, and check that the survey adequately covers the range of well depths included in the RRC drilling permit dataset.

2.3 Field Observations

Once ERG has obtained initial responses to our phone and/or mail surveys and with approval from the TCEQ project manager, ERG will attempt to obtain permission for site visits to active drilling sites through survey participation and stakeholder contacts. ERG's protocol for conducting on-site visits includes a standardized data collection form, such as that presented in Appendix D. This form essentially requests the same information as requested during the phone/mail survey, but adds additional contact information and site visit date. On-site observations of drill rig engine operation and specifications will be used to verify the data collected in the mail and phone surveys, and to attempt to establish equipment load factors and any other adjustment factors deemed necessary.

Site visits will be coordinated in advance, obtaining the site location, name of contact, and date/time for each visit. Site contacts will be called one business day in advance to confirm the time and location for the visit, as well as to determine any site-specific safety or operation requirements. For example, it is expected that active drilling sites will require steel-toed boots, hard hat, and safety glasses before entry. ERG representatives will adhere to all company requirements while on site. If necessary, the TCEQ Project Representative shall obtain an official letter on TCEQ letterhead explaining the purpose of the study to be presented to site foremen or other company representatives as requested.

Once on site, each engine will be assigned a unique identifier, and data collection will involve an inspection of each engine located on site to collect the following information:

a) Make and model, model year, and size
b) A description of how each unit is used (obtained from the site foreman)
c) Typical Fuel usage information (gallons per day over the course of the drilling activity)
d) Typical operating schedule (hours per day over the course of the drilling activity)
e) Typical operating load if available

The on-site data collected will be recorded using the standard reporting form such as that provided in Appendix D.

ERG will attempt to arrange for visits to multiple locations/fleets for field observations, and will seek to arrange visits to different types and sizes of rigs, with a preference for a geographical distribution reflective of the well drilling data obtained from the RRC (as feasible given the project resources). Preference will be given to companies operating multiple drill rigs in order to improve data collection efficiency.

2.4 Confidentiality

Confidentiality will be stressed to participants participating in the study, and will be addressed in the survey cover letters and/or phone questionnaire scripts. ERG is particularly sensitive to the privacy of individuals and businesses. Therefore all interviews and data collection efforts will begin with a guarantee of privacy, anonymity, and confidentiality. To ensure survey respondent's rights to privacy, respondents will be informed of the research purpose, the kinds of questions that will be asked, and how TCEQ may use the results of the study. Confidentiality will be maintained by eliminating names from interview records, stripping all respondent-identifying characteristics from study datasets. In addition, all project staff will be given explicit training regarding confidentiality protocols and commitments.

3.0 Emissions Calculation Methodology

Once the Data Collection survey is complete, ERG will develop emission estimates for model rig fleets which we will then apply to the population of wells from the RRC dataset. It is anticipated that model rig fleets will be stratified according to:

a) Well location (basin, as identified by County)
b) Well depth (based on RRC data)
c) Well type (vertical, horizontal)

While these parameters are provided in the RRC dataset, and based on our review of available literature and operator interviews appear to be the most critical parameters in terms of differentiating wells for emission estimation purposes, we may encounter other variables that provide additional distinction between our model rig fleets based on our survey results. For example, we anticipate the total hp of each rig profile to vary by well depth, and although rig power information is not provided in the RRC data, it will be critical in estimating emissions. Once we have compiled the survey data into model rig fleets, an average emissions profile will be developed for an average well in that fleet. The emissions profile will be developed for each model rig fleet using a combination of emission and deterioration factors obtained through our survey, EPA's NONROAD model, and/or AP-42 emission factors. For HAPs, emission factors will be obtained from the SPECIATE database, and/or AP-42.

Each well in the RRC dataset will then be assigned to a specific model fleet, and emissions will be calculated for each well base on scaling emissions from the model fleet to each individual well based on the ratio of the actual well depth for that well to the model fleet average well depth. For calculating daily emission estimates (for purposes of ozone-season daily estimates), the total emissions for each wellbore will be evenly divided by the total number of days between spud date and completion date, as obtained by the RRC dataset. The end result will be an estimate of the actual emissions for each well for each day of the drilling period.

4.0 Recommendations

ERG recommends that TCEQ proceed with the drill rig engine emission estimation project as described above. By obtaining the RRC well permit database in electronic format, the activity data we now have available provides us with a much greater level of geographical and spatial resolution for emission estimates than was available when ERG compiled the 2005 oil and gas emissions inventory. In addition, our literature review has indicated that the "state of the art" emissions estimation approaches and methodology have continued to be refined over the last few years as regional, state, and local agencies have become increasingly aware of the magnitude of emissions from the sources associated with oil and gas exploration and production. Subsequent studies of emissions from these sources make use of previous studies, and build upon those with further refinement of the activity and emission factor data used in the estimates. ERG anticipates being able to continue this evolution for estimating emissions from drill rig engines in Texas.

The next challenge in this process will be to continue to solicit support from stakeholders, namely, the trade associations representing oil and gas drill rig operators, as well as the operators themselves. Through data available on the IADC website, we have obtained contact information for many of the major drill rig owners and operators in Texas. While we could proceed to contact them directly at this point, we feel it will be beneficial to the ultimate success of this project to obtain the endorsement and support from the industry as a whole through the trade associations if possible.

APPENDIX A

EXAMPLE OF DRILLING RIG INFORMATION AVAILABLE ONLINE

APPENDIX B
ADVANCED LETTER TO DRILL RIG OWNERS/OPERATORS --- on TCEQ letter head (distributed via fax &/or trade associations)

Dear Drill Rig Manager OR <Mr./Ms. LAST NAME>:

The Texas Commission on Environmental Quality (TCEQ) requests your help. We are asking for your voluntary participation in a study about engines used in the drilling of new and/or recompleted oil and gas wells in Texas during 2008. The study will involve rig owners sharing information regarding the operating practices (such as hours of operation) and rig configuration (such as the number and size of engines) in their fleet. This information will provide a better understanding of how drilling rig operations are conducted under real-world practices.

TCEQ contracted with Eastern Research Group (ERG), an independent research organization, to administer this study. We urge you to participate – **the results will improve the accuracy of TCEQ's emissions estimates for drilling rigs across the state.**

Prominent trade associations are supporting this study, encouraging their members to participate, including the [TxOGA, IPAA, etc…] These organizations represent the interests of oil and gas exploration and production companies at the local, state, and national levels and recognize the value of the study to industry as well as to government.

Your participation is both voluntary and completely confidential. ERG guarantees the confidentiality of all participants in this study. This means the information your company provides will be used for statistical purposes only. Responses will be kept confidential and will not be disclosed in identifiable form to anyone other than ERG employees or agents without your consent. Every ERG employee with access to identifying information will sign a confidentiality agreement. This agreement guarantees that we will not disclose any information that may identify you, such as your address, contact information or worksite locations, unless required by law.

The study involves 3 easy steps.

1. First, the person most knowledgeable about your business' drilling rig operations will be asked to participate in a short phone survey about the typical rig configurations and engine numbers and types used to drill wells in Texas in 2008. In most cases, this survey will take ten to fifteen minutes.
2. Second, after completion of the phone survey, ERG may send you a written survey requesting more detailed information about operating practices you employed in drilling wells in Texas during 2008. In order to minimize the amount of data we are requesting from any one participant, we would request data for a select number of drilling operations, most likely requesting information on 2-3 examples for a particular well-depth, oil field or basin, and well type. However, we would be willing to accept as much data as made available to us, and can also accept existing data and query it to meet our

needs if you have existing data that would be helpful, but is not currently in a format consistent with our survey.

3. Third, after completion of the surveys, ERG may ask for permission to visit one of your active drilling sites. Pending your approval, an ERG representative will travel to an active well site and collect information on each engine found on-site. This data includes make, model, year, load, and engine clock hour readings and fuel usage. Only a small percentage of companies will be asked to participate in on-site field data collection.

Again, we appreciate your assistance in this important study. If you have any questions, please call Greg Lauderdale in the Air Quality Division of TCEQ at 512-239-1433. To contact the independent research firm conducting the study, call the survey project manager, Rick Baker at 512-407-1823, or email him at rick.baker@erg.com.

Thank you in advance,

{TCEQ Signature authority}

APPENDIX C
DRILL RIG SURVEY QUESTIONS

Part 1. General Site Information

1. Name of Company:	
2. Well API #:	
3. Contact Name:	
4. Number of engines on site:	
5. Well Type (Vertical, Horizontal):	
6. Well Depth:	
7. Total Well Drilling Duration (days):	
8. Fuel Type (and sulfur content for diesel fuel)	

Part 2. Engine-Specific Information (for each engine)

Engine ID	Engine Use (Drawworks, Mud Pump, Power)	Make/ Model	Model Year	Engine HP	Average Fuel Use (gallons)	Average Operating Schedule (hours)	Average Engine Load (%)

APPENDIX D
FIELD DATA COLLECTION FORM

Part 1. General Site Information

1. Name of Company:	
2. Company ID:	
3. Well API #:	
4. Site Personnel Contact Name:	
5. Site Personnel Title:	
6. Site Personnel Phone #:	
7. Number of engines on site:	
8. Well Type (Vertical, Horizontal)	
9. Well Depth:	
10. Total Well Drilling Duration (days):	
11. Fuel Type (and sulfur content for diesel fuel)	
12. Date of site visit:	

Part 2. Engine-Specific Information (for each engine)

Engine ID	Engine Use (Draw works, Mud Pump, Power)	Make/ Model	Model Year	Engine HP	Average Fuel Use (gallons)	Average Operating Schedule (hours)	Average Engine Load (%)

Appendix B – Survey Letter

EASTERN RESEARCH GROUP, INC.

Dear Owner/Operator:

Eastern Research Group (ERG), an independent research organization, is conducting a study on drilling rig engine emissions for the State of Texas for calendar year 2008. ERG is conducting this study with the support of the Texas Independent Producers and Royalty Owners Association (TIPRO) and the Texas Oil & Gas Association (TXOGA). These organizations represent the interests of oil and gas exploration and production companies in Texas and recognize the value of the study to industry as well as to government.

We are asking for your voluntary participation in this study of oil and gas wells that were drilled in Texas during 2008. The study will involve sharing information regarding the operating practices (such as the hours of operation) and rig configuration (such as the number and size of engines) used during well drilling.

Your participation is voluntary and completely confidential, individual wells do not need to be identified. The information your company provides will be used for statistical purposes only in order to develop county-level estimates and will not be republished or disseminated for other purposes. Responses will not be disclosed in identifiable form to anyone other than ERG employees or agents.

The attached Excel workbook contains our study questions. We are seeking basin specific rig profiles to complete a typical well in the Andarko, Bend Arch-Fort Worth, East Texas, Permian, and Western Gulf basins. For each basin, we would like one profile for a vertical well, and a second profile for a horizontal/directional well. If you operate in multiple basins in Texas, please complete one worksheet for each basin and well type that you are familiar with. For your convenience, the county/basin assignments are included in the workbook in the "Counties by Basin" worksheet. An example of a completed worksheet is also provided. Your expertise is valued; please include comments or clarifications!

Your response is requested by June 5, 2009. Completed forms may be submitted via email to Len Boatman at llboatman@gmail.com, or via fax to **512-579-0315**. For further information or assistance in completing this form, please call Len Boatman at 512-579-0315.

We appreciate your assistance in this important study. If you have any questions on the study, please feel free to contact me at (919) 468-7840, or via email at mike.pring@erg.com.

Sincerely,

Mike Pring
Senior Environmental Engineer
Eastern Research Group, Inc.

Appendix C – Drill Rig Survey Form

DRILL RIG SURVEY QUESTIONS

Part 1. General Site Information

Owner/Operator:	
Owner/Operator Contact Name:	
Owner/Operator Contact Phone:	

Please use county or basin averages for each question.

1. Well Locations (county or basin)	
2. Well Type (vertical, horizontal, directional)	
3. Typical Well Measurement Depth (feet)	
4. Typical Well Drilling Duration (days)	
5. Typical Number of engines on site	
6. Typical Rig Fuel Use (gal/day)	
7. Typical Workover/Completion (hours)	
8. Typical Workover/Completion Engine Size (HP)	
9. Fracing; Yes/No; Duration (days)	

Part 2. Drill Rig Engine-Specific Information (for each engine on a typical rig).

Engine Function (Draw works, Mud Pump, Power)	Typical Make and Model	Typical Model Year	Typical Engine Size (HP)	Typical Engine On-time (hr/day)	Typical Engine time under load (hr/day)	Typical Engine Load (%)

Appendix D – Survey Data

Table D.1 Survey Data – Horizontal and Directional Wells

Survey ID	# of wells covered by survey	Well Type	Well Depth	Engine ID	Engine Function	Make and Model	Model Year	Engine Size (HP)	Total Well Drilling Days	Total Engine On-time (hours)	Engine On-time (hours/ 1,000 feet)	Average Load %
D200a	5	Directional	10,150	1	(All) Electric Rig	Cat 3512	2006	1192.5	40	960	94.58	65
D200a	5	Directional	10,150	2	(All) Electric Rig	Cat 3512	2006	1192.5	40	960	94.58	65
D200a	5	Directional	10,150	3	(All) Electric Rig	Cat 3512	2006	1192.5	40	960	94.58	65
D180	5	Horizontal	8,000	1	Drawworks	Cat 3406	1985	400	22.5	540	67.50	62.5
D180	5	Horizontal	8,000	2	Drawworks	Cat 3406	1985	400	22.5	540	67.50	62.5
D180	5	Horizontal	8,000	3	Mud Pump	Cat 399	1985	1260	22.5	540	67.50	75
D180	5	Horizontal	8,000	4	Mud Pump	Cat 399	1985	1260	22.5	540	67.50	75
D180	5	Horizontal	8,000	5	Generator	Cat 3406		400	22.5	540	67.50	80
D180	5	Horizontal	8,000	6	Generator	Cat 3406		400	22.5	540	67.50	80
D81	33	Horizontal	9,500	1	Drawworks	Cat 3412B	1985	475	13.5	324	34.11	25.5
D81	33	Horizontal	9,500	2	Drawworks	Cat 3412B	1985	475	13.5	162	17.05	25.5
D81	33	Horizontal	9,500	3	Mud Pump	Cat 3508B	2005	950	13.5	162	17.05	25.8
D81	33	Horizontal	9,500	4	Mud Pump	Cat 3508B	2005	950	13.5	162	17.05	25.8
D81	33	Horizontal	9,500	5	Generator	Cat 3306	1985	270	13.5	162	17.05	60

Table D.1 Survey Data – Horizontal and Directional Wells (Cont.)

Survey ID	# of wells covered by survey	Well Type	Well Depth	Engine ID	Engine Function	Make and Model	Model Year	Engine Size (HP)	Total Well Drilling Days	Total Engine On-time (hours)	Engine On-time (hours/ 1,000 feet)	Average Load %
D81	33	Horizontal	9,500	6	Generator	Cat 3306	1985	270	13.5	162	17.05	60
D50a	34	Horizontal	10,109	1	(All) Electric Rig	Cat 3508	2006	950	16	384	37.99	60
D50a	34	Horizontal	10,109	2	(All) Electric Rig	Cat 3508	2006	950	16	384	37.99	60
D119	20	Horizontal	11,500	1	(All) Electric Rig	Cat 3512	2006	1192.5	19	456	39.65	60
D119	20	Horizontal	11,500	2	(All) Electric Rig	Cat 3512	2006	1192.5	19	456	39.65	60
D97	9	Horizontal	13,000	1	Drawworks	Cat 379	1984	550	45	1080	83.08	40.5
D97	9	Horizontal	13,000	2	Drawworks	Cat 379	1984	550	45	1080	83.08	40.5
D97	9	Horizontal	13,000	3	Mud Pump	Cat 3508	1995	900	45	1080	83.08	55.8
D97	9	Horizontal	13,000	4	Mud Pump	Cat 399	1989	1250	45	324	24.92	55.8
D97	9	Horizontal	13,000	5	Generator	Detroit Series 60	2002	400	45	540	41.54	60
D97	9	Horizontal	13,000	6	Generator	Detroit Series 60	2002	400	45	540	41.54	60
D50c	3	Horizontal	14,900	1	(All) Electric Rig	Cat 3512C	2006	1478	67	1608	107.92	40
D50c	3	Horizontal	14,900	2	(All) Electric Rig	Cat 3512C	2006	1478	67	1608	107.92	40
D50f	11	Horizontal	17,668	1	(All) Electric Rig	Cat 3512C	2006	1478	72	1728	97.80	40

Table D.1 Survey Data – Horizontal and Directional Wells (Cont.)

Survey ID	# of wells covered by survey	Well Type	Well Depth	Engine ID	Engine Function	Make and Model	Model Year	Engine Size (HP)	Total Well Drilling Days	Total Engine On-time (hours)	Engine On-time (hours/ 1,000 feet)	Average Load %
D50f	11	Horizontal	17,668	2	(All) Electric Rig	Cat 3512C	2006	1478	72	1728	97.80	40
D1a	14	Horizontal/ Directional	10,000	1	Drawworks	Detroit Series 60	2008	470	21	504	50.40	49.4
D1a	14	Horizontal/ Directional	10,000	2	Mud Pump # 1	Detroit 16V2000	2008	1,205	21	504	50.40	35.5
D1a	14	Horizontal/ Directional	10,000	3	Mud Pump # 2	Detroit 16V2000	2008	1,205	21	504	50.40	35.5
D1a	14	Horizontal/ Directional	10,000	4	Drawworks/ Swivel Motor	Detroit Series 60	2008	470	21	504	50.40	49.4
D1a	14	Horizontal/ Directional	10,000	5	Generator # 1	Detroit Series 60	2008	470	21	252	25.20	90
D1a	14	Horizontal/ Directional	10,000	6	Generator # 2	Detroit Series 60	2008	470	21	252	25.20	90
D1b	18	Horizontal/ Directional	10,000	1	Drawworks	Detroit Series 60	2008	470	21	504	50.40	49.4
D1b	18	Horizontal/ Directional	10,000	2	Mud Pump # 1	Detroit 16V2000	2008	1,205	21	504	50.40	35.5
D1b	18	Horizontal/ Directional	10,000	3	Mud Pump # 2	Detroit 16V2000	2008	1,205	21	504	50.40	35.5
D1b	18	Horizontal/ Directional	10,000	4	Drawworks/ Swivel Motor	Detroit Series 60	2008	470	21	504	50.40	49.4
D1b	18	Horizontal/ Directional	10,000	5	Generator # 1	Detroit Series 60	2008	470	21	252	25.20	90
D1b	18	Horizontal/ Directional	10,000	6	Generator # 2	Detroit Series 60	2008	470	21	252	25.20	90
D162a	7	Horizontal/ Directional	11,335	1	Drawworks	Cat C-18	2005	600	34	816	71.99	60

Table D.1 Survey Data – Horizontal and Directional Wells (Cont.)

Survey ID	# of wells covered by survey	Well Type	Well Depth	Engine ID	Engine Function	Make and Model	Model Year	Engine Size (HP)	Total Well Drilling Days	Total Engine On-time (hours)	Engine On-time (hours/ 1,000 feet)	Average Load %
D162a	7	Horizontal/ Directional	11,335	2	Drawworks	Cat C-18	2005	600	34	816	71.99	60
D162a	7	Horizontal/ Directional	11,335	3	Mud Pump	Cat 3508	2005	1300	34	408	35.99	80
D162a	7	Horizontal/ Directional	11,335	4	Mud Pump	Cat 3508	2005	1300	34	408	35.99	80
D162a	7	Horizontal/ Directional	11,335	5	Generator	Cat C-15	2005	485	34	408	35.99	60
D162a	7	Horizontal/ Directional	11,335	6	Generator	Cat C-15	2005	485	34	408	35.99	60
S51	10	Horizontal	8,692	1	Drawworks	Cat D-353	1975	450	17.5	420	48.32	43
S51	10	Horizontal	8,692	2	Drawworks	Cat D-353	1975	450	17.5	420	48.32	43
S51	10	Horizontal	8,692	3	Mud Pump	Cat D 398	1984	825	17.5	210	24.16	66.2
S51	10	Horizontal	8,692	4	Mud Pump	Cat D 398	1984	825	17.5	210	24.16	66.2
S51	10	Horizontal	8,692	5	Generator	Cat D 3412	1998	450	17.5	210	24.16	40
S51	10	Horizontal	8,692	6	Generator	Cat D 3412	1998	450	17.5	210	24.16	40
D11	119	Horizontal	10,570	1	(All) Electric Rig	Cat 3512	2006	1476	19	456	43.14	50
D11	119	Horizontal	10,570	2	(All) Electric Rig	Cat 3512	2006	1476	19	456	43.14	50

Table D.2 Survey Data – Vertical Wells <= 7,000 feet

Survey ID	# of wells covered by survey	Well Type	Well Depth	Engine ID	Engine Function	Make and Model	Model Year	Engine Size (HP)	Total Well Drilling Days	Total Engine On-time (hrs/day)	Engine On-time (hours/ 1,000 feet)	Average Load %
D80	37	Vertical	1,000	1	Drawworks	Cummins	1990	450	3	10	30.00	59
D80	37	Vertical	1,000	2	Mud Pump	Cat 343	1985	400	3	10	30.00	49.4
D150	10	Vertical	1,850	1	Drawworks and Mud Pump	Cummins KT450	1980	500	2.5	10	13.51	50
D150	10	Vertical	1,850	2	Generator	Deutz	1980	50	2.5	10	13.51	20
D74	48	Vertical	2,200	1	Draw	Cat 3406	1990	470	2	24	21.82	60
D74	48	Vertical	2,200	2	Mud pump	Cat 3408	1990	470	2	15	13.64	80
D74	48	Vertical	2,200	3	Generator			25	2	24	21.82	25
D51	72	Vertical	2,500	1	Draw	Cat 3406	1992	425	2	24	19.20	80
D51	72	Vertical	2,500	2	Mud pump	Cat 3406	1992	425	2	24	19.20	50
D51	72	Vertical	2,500	3	Generator	John Deere	2000	80	2	12	9.60	20
D172	6	Vertical	3,300	1	Drawworks	Cummins 400	1985	400	6.5	24	47.27	75
D172	6	Vertical	3,300	2	Mud Pump	Cummins 400	1985	400	6.5	24	47.27	75
D172	6	Vertical	3,300	3	Generator	Perkins 4 Cylinder	1995	48	6.5	24	47.27	77.5
D72	41	Vertical	3,700	1	Draw	Detroit 60	2006	470	10	24	64.86	65

Table D.2 Survey Data – Vertical Wells <= 7,000 feet (Cont.)

Survey ID	# of wells covered by survey	Well Type	Well Depth	Engine ID	Engine Function	Make and Model	Model Year	Engine Size (HP)	Total Well Drilling Days	Total Engine On-time (hrs/day)	Engine On-time (hours/ 1,000 feet)	Average Load %
D72	41	Vertical	3,700	2	Mud Pump	Cummins 350	2002	350	10	24	64.86	70
D72	41	Vertical	3,700	3	Mud pump	Cummins 350	2002	350	10	24	64.86	11
D72	41	Vertical	3,700	4	Generator	Cat 3404	2006	280	10	24	64.86	50
D113	23	Vertical	4,200	1	Drawworks	Cat 3408	1982	489	6	24	34.29	52.65
D113	23	Vertical	4,200	2	Mud Pump	JD 600	2008	600	6	24	34.29	73.9
D113	23	Vertical	4,200	3	Generator	Cat 3304	1985	97	6	24	34.29	65
S23	13	Vertical	4,500	1	Mud Pump 1	Cat 353		350	11	24	58.67	77
S23	13	Vertical	4,500	2	Drawworks	Detroit Series 60		400	11	24	58.67	
S23	13	Vertical	4,500	3	Mud Pump 2	Detroit Series 60		330	11		-	
S23	13	Vertical	4,500	4	Generator	John Deere		80	11	24	58.67	
S3	16	Vertical	4,900	1	Generator	Cat 3406	2002	475	11		40.82	37.5
S3	16	Vertical	4,900	2	Drawworks	Cat 3406	2002	475	11		40.82	37.5
S3	16	Vertical	4,900	3	Mud Pump	Detroit Series 60	2000	500	11		20.41	75
S3	16	Vertical	4,900	4	Mud Pump	Detroit Series 60	2000	500	11		20.41	75

Table D.2 Survey Data – Vertical Wells <= 7,000 feet (Cont.)

Survey ID	# of wells covered by survey	Well Type	Well Depth	Engine ID	Engine Function	Make and Model	Model Year	Engine Size (HP)	Total Well Drilling Days	Total Engine On-time (hrs/day)	Engine On-time (hours/ 1,000 feet)	Average Load %
D141	14	Vertical	5,000	1	Drawworks	Cat 3406	1988	425	10	24	48.00	65
D141	14	Vertical	5,000	2	Mud Pump	Cat 3503	1988	375	10	5	10.00	67.5
D141	14	Vertical	5,000	3	Mud Pump	Cat 3406	1992	425	10	24	48.00	67.5
D141	14	Vertical	5,000	4	Generator	Detroit Diesel	1990	250	10	12	24.00	75
D1	519	Vertical	5,000	1	Drawworks	Cat C-15	2007	425	5		24.00	49.4
D1	519	Vertical	5,000	2	Mud Pump # 1	Cat C-15	2007	425	5		24.00	35.5
D1	519	Vertical	5,000	3	Mud Pump # 2	Cat C-15	2007	425	5		24.00	35.5
D1	519	Vertical	5,000	4	Drawworks/ Swivel Motor	Cat C-15	2007	425	5		24.00	49.4
D1	519	Vertical	5,000	5	Generator	Detroit Series 60	2007	470	5		24.00	90
D118	25	Vertical	5,000	1	Drawworks	Cat 3408	2005	550	12	24	57.60	27
D118	25	Vertical	5,000	2	Mud Pump	Detroit Series 60	2007	550	12	24	57.60	90
D118	25	Vertical	5,000	3	Generator	Detroit Series 60	2007	350	12	24	57.60	75
D139	14	Vertical	5,200	1	Drawworks	Cat 3406B	1993	400	8	24	36.92	32
D139	14	Vertical	5,200	2	Drawworks	Cat 3406B	1993	400	8	24	36.92	32

Table D.2 Survey Data – Vertical Wells <= 7,000 feet (Cont.)

Survey ID	# of wells covered by survey	Well Type	Well Depth	Engine ID	Engine Function	Make and Model	Model Year	Engine Size (HP)	Total Well Drilling Days	Total Engine On-time (hrs/day)	Engine On-time (hours/ 1,000 feet)	Average Load %
D139	14	Vertical	5,200	3	Mud Pump	Cat 353E	1985	435	8	3	4.62	85
D139	14	Vertical	5,200	4	Mud Pump	Cat 353E	1985	435	8	24	36.92	85
D139	14	Vertical	5,200	5	Generator	Cat 3306B	1993	400	8	12	18.46	85
D139	14	Vertical	5,200	6	Generator	Cat 3306B	1993	400	8	12	18.46	85
D163	8	Vertical	6,000	1	Drawworks	Cat V71	1965	700	10	24	40.00	50
D163	8	Vertical	6,000	2	Drawworks	Cat V71	1965	700	10	24	40.00	50
D163	8	Vertical	6,000	3	Mud Pump	Cat V379	1975	600	10	24	40.00	75
D163	8	Vertical	6,000	4	Mud Pump	Cat V379	1975	600	10	24	40.00	75
D163	8	Vertical	6,000	5	Generator	Cat 3306	1975	175	10	24	40.00	75
D152	4	Vertical	6,500	1	(All) Electric Rig	Detroit Series 60	2008	425	14	24	51.69	70
D152	4	Vertical	6,500	2	(All) Electric Rig	Detroit Series 60	2008	425	14	24	51.69	70
D70	50	Vertical	3,000	1	Drawworks	Detroit 8V-92	1989	475	8.5	24	68.00	40.4
D70	50	Vertical	3,000	2	Mud Pump	Cat 3406	1989	425	8.5	24	68.00	48.8
D70	50	Vertical	3,000	3	Generator	John Deer 4 cylinder	1989	50	8.5	24	68.00	80

Table D.3 Survey Data – Vertical Wells > 7,000 Feet

Survey ID	# of wells covered by survey	Well Type	Well Depth	Engine ID	Engine Function	Make and Model	Model Year	Engine Size (HP)	Total Well Drilling Days	Total Engine On-time (hours)	Engine On-time (hours/ 1,000 feet)	Average Load %
D142	19	Vertical	7,500	1	Drawworks	Cat 3406	2005	400	20	480	64.00	34.6
D142	19	Vertical	7,500	2	Drawworks	Cat 3406	2005	400	20	480	64.00	34.6
D142	19	Vertical	7,500	3	Mud Pump	Cat 3412	2006	650	20	240	32.00	73.1
D142	19	Vertical	7,500	4	Mud Pump	Cat C-18	2006	600	20	240	32.00	73.1
D142	19	Vertical	7,500	5	Generator	Cat 3406	2000	400	20	240	32.00	45.5
D142	19	Vertical	7,500	6	Generator	Cat 3406	2000	400	20	240	32.00	45.5
D35	114	Vertical	8,300	1	Drawworks	Cat 353	1970	450	12	288	34.70	52.4
D35	114	Vertical	8,300	2	Drawworks	Cat 353	1970	450	12	288	34.70	52.4
D35	114	Vertical	8,300	3	Mud Pump	Cat 398	1997	800	12	288	34.70	45.3
D35	114	Vertical	8,300	4	Generator	Cat 3408	2000	350	12	144	17.35	80
D35	114	Vertical	8,300	5	Generator	Cat 3408	2000	350	12	144	17.35	80
D200	9	Vertical	9,550	1	(All) Electric Rig	Cat 3512	2006	1192.5	30.5	732	76.65	65
D200	9	Vertical	9,550	2	(All) Electric Rig	Cat 3512	2006	1192.5	30.5	732	76.65	65

Table D.3 Survey Data – Vertical Wells > 7,000 Feet (Cont.)

Survey ID	# of wells covered by survey	Well Type	Well Depth	Engine ID	Engine Function	Make and Model	Model Year	Engine Size (HP)	Total Well Drilling Days	Total Engine On-time (hours)	Engine On-time (hours/ 1,000 feet)	Average Load %
D200	9	Vertical	9,550	3	(All) Electric Rig	Cat 3512	2006	1192.5	30.5	732	76.65	65
D83	36	Vertical	9,750	1	Drawworks	Cat C-15	2004	475	15.5	186	19.08	45.3
D83	36	Vertical	9,750	2	Drawworks	Cat C-15	2004	475	15.5	186	19.08	45.3
D83	36	Vertical	9,750	3	Mud Pump	Cat 398	1975	970	15.5	186	19.08	52.4
D83	36	Vertical	9,750	4	Mud Pump	Cat 398	1975	970	15.5	186	19.08	52.4
D83	36	Vertical	9,750	5	Generator	Cat 3406	1995	435	15.5	186	19.08	80
D83	36	Vertical	9,750	6	Generator	Cat 3406	1995	435	15.5	186	19.08	80
S12	12	Vertical	10,000	1	(All) Electric Rig	Cat 3512		1192.5	17	408	40.80	65
S12	12	Vertical	10,000	2	(All) Electric Rig	Cat 3512		1192.5	17	408	40.80	65
D206	2	Vertical	10,000	1	Drawworks	Cat 3408 DITA		475	17.5	420	42.00	24.25
D206	2	Vertical	10,000	2	Drawworks	Cat 3408 DITA		475	17.5	420	42.00	24.25
D206	2	Vertical	10,000	3	Mud Pump	Cat D399PC		1200	17.5	420	42.00	24.25
D206	2	Vertical	10,000	4	Mud Pump	Cat D399PC		1200	17.5	420	42.00	24.25

Table D.3 Survey Data – Vertical Wells > 7,000 Feet (Cont.)

Survey ID	# of wells covered by survey	Well Type	Well Depth	Engine ID	Engine Function	Make and Model	Model Year	Engine Size (HP)	Total Well Drilling Days	Total Engine On-time (hours)	Engine On-time (hours/ 1,000 feet)	Average Load %
D206	2	Vertical	10,000	5	Generator	Cat 3406		425	17.5	210	21.00	100
D206	2	Vertical	10,000	6	Generator	Cat 3406		425	17.5	210	21.00	100
D191	3	Vertical	10,000	1	Drawworks	Cat C-13	2006	410	15	360	36.00	67.5
D191	3	Vertical	10,000	2	Drawworks	Cat C-13	2006	410	15	360	36.00	67.5
D191	3	Vertical	10,000	3	Mud Pump	Cat C-15	2006	500	15	360	36.00	67.5
D191	3	Vertical	10,000	4	Mud Pump	Cat C-15	2006	500	15	360	36.00	67.5
D191	3	Vertical	10,000	5	Generator	Cat C-15	2006	500	15	360	36.00	80
D191	3	Vertical	10,000	6	Generator	Cat C-15	2006	500	15	360	36.00	80
D37	101	Vertical	10,300	1	Drawworks	Cat 353	1981	450	13.5	324	31.46	45.5
D37	101	Vertical	10,300	2	Drawworks	Cat 353	1981	450	13.5	324	31.46	45.5
D37	101	Vertical	10,300	3	Mud Pump	Cat 379	1981	550	13.5	324	31.46	36.9
D37	101	Vertical	10,300	4	Mud Pump	Cat 379	1981	550	13.5	324	31.46	36.9
D37	101	Vertical	10,300	5	Generator	Cat 3406	1995	425	13.5	162	15.73	90
D37	101	Vertical	10,300	6	Generator	Cat 3406	1995	425	13.5	162	15.73	90

Table D.3 Survey Data – Vertical Wells > 7,000 Feet (Cont.)

Survey ID	# of wells covered by survey	Well Type	Well Depth	Engine ID	Engine Function	Make and Model	Model Year	Engine Size (HP)	Total Well Drilling Days	Total Engine On-time (hours)	Engine On-time (hours/ 1,000 feet)	Average Load %
D190	3	Vertical	10,500	1	Drawworks	Cat C-15	2005	475	30	720	68.57	67.5
D190	3	Vertical	10,500	2	Drawworks	Cat C-15	2005	475	30	720	68.57	67.5
D190	3	Vertical	10,500	3	Drawworks	Cat C-15	2005	475	30	720	68.57	67.5
D190	3	Vertical	10,500	4	Mud Pump	Cat 399		1200	30	720	68.57	67.5
D190	3	Vertical	10,500	5	Mud Pump	Cat 399		1200	30	720	68.57	67.5
D190	3	Vertical	10,500	6	Generator	Cat 3412		1000	30	360	34.29	62.5
D190	3	Vertical	10,500	7	Generator	Cat 3412		1000	30	360	34.29	62.5
D121	12	Vertical	10,800	1	Drawworks	Cat C-15	2004	485	32.5	780	72.22	27.2
D121	12	Vertical	10,800	2	Drawworks	Cat C-15	2004	485	32.5	780	72.22	27.2
D121	12	Vertical	10,800	3	Mud Pump	Cat D399TA	2004	1200	32.5	780	72.22	35.5
D121	12	Vertical	10,800	4	Mud Pump	Cat D399TA	2004	1200	32.5	780	72.22	35.5
D121	12	Vertical	10,800	5	Generator	Cat C-15	2004	485	32.5	390	36.11	35
D121	12	Vertical	10,800	6	Generator	Cat C-15	2004	485	32.5	390	36.11	35
D162	8	Vertical	11,500	1	Drawworks	Cat C-18	2005	600	25	600	52.17	60

Table D.3 Survey Data – Vertical Wells > 7,000 Feet (Cont.)

Survey ID	# of wells covered by survey	Well Type	Well Depth	Engine ID	Engine Function	Make and Model	Model Year	Engine Size (HP)	Total Well Drilling Days	Total Engine On-time (hours)	Engine On-time (hours/ 1,000 feet)	Average Load %
D162	8	Vertical	11,500	2	Drawworks	Cat C-18	2005	600	25	600	52.17	60
D162	8	Vertical	11,500	3	Mud Pump	Cat 3508	2005	1300	25	300	26.09	80
D162	8	Vertical	11,500	4	Mud Pump	Cat 3508	2005	1300	25	300	26.09	80
D162	8	Vertical	11,500	5	Generator	Cat C-15	2005	485	25	300	26.09	60
D162	8	Vertical	11,500	6	Generator	Cat C-15	2005	485	25	300	26.09	60
D215	1	Vertical	12,200	1	Mud Pump	Detroit 2000	2008	1205	16	384	31.48	60
D215	1	Vertical	12,200	2	Mud Pump	Detroit 2000	2008	1205	16	384	31.48	60
D215	1	Vertical	12,200	3	Drawworks	Detroit Series 60	2008	470	16	384	31.48	50
D215	1	Vertical	12,200	4	Drawworks	Detroit Series 60	2008	470	16	384	31.48	50
D215	1	Vertical	12,200	5	Generator	Detroit Series 60	2008	470	16	192	15.74	50
D215	1	Vertical	12,200	6	Generator	Detroit Series 60	2008	470	16	192	15.74	50
D50b	16	Vertical	12,211	1	(All) Electric Rig	Cat 3512C	2006	1478	21	504	41.27	40
D50b	16	Vertical	12,211	2	(All) Electric Rig	Cat 3512C	2006	1478	21	504	41.27	40

Table D.3 Survey Data – Vertical Wells > 7,000 Feet (Cont.)

Survey ID	# of wells covered by survey	Well Type	Well Depth	Engine ID	Engine Function	Make and Model	Model Year	Engine Size (HP)	Total Well Drilling Days	Total Engine On-time (hours)	Engine On-time (hours/ 1,000 feet)	Average Load %
D50d	6	Vertical	12,483	1	(All) Electric Rig	Cat 3512C	2006	1478	22	528	42.30	40
D50d	6	Vertical	12,483	2	(All) Electric Rig	Cat 3512C	2006	1478	22	528	42.30	40
D50g	9	Vertical	17,778	1	(All) Electric Rig	Cat 3512C	2006	1478	55	1320	74.25	40
D50g	9	Vertical	17,778	2	(All) Electric Rig	Cat 3512C	2006	1478	55	1320	74.25	40
D50e	10	Vertical	17,970	1	(All) Electric Rig	Cat 3512C	2006	1478	84	2016	112.19	40
D50e	10	Vertical	17,970	2	(All) Electric Rig	Cat 3512C	2006	1478	84	2016	112.19	40

Appendix E – Total Drilling Depth by County by Model Rig Well Type Category

(see file "TCEQ Drilling Rig Engine Report_Appendices.xls")

Appendix F – Emission Factors

Table F.1 Emission Factors for Vertical Wells > 7,000 Feet

Pollutant	Emission Factor (ton/1,000 feet)															
	2002	2005	2008	2009	2010	2011	2012	2103	2014	2015	2016	2017	2018	2019	2020	2021
CO	2.07E-01	2.06E-01	1.50E-01	1.49E-01	1.49E-01	1.45E-01	1.45E-01	1.11E-01	1.11E-01	1.11E-01	1.10E-01	9.82E-02	6.44E-02	6.42E-02	6.41E-02	3.55E-02
NOx	4.61E-01	4.60E-01	4.15E-01	4.14E-01	4.11E-01	3.88E-01	3.88E-01	3.62E-01	3.62E-01	3.61E-01	3.42E-01	3.38E-01	2.99E-01	2.98E-01	2.98E-01	2.52E-01
PM10	4.03E-02	4.02E-02	2.32E-02	2.32E-02	2.27E-02	2.27E-02	2.27E-02	1.31E-02	1.30E-02	1.30E-02	1.27E-02	1.20E-02	8.29E-03	8.27E-03	8.25E-03	4.31E-03
PM2.5	3.91E-02	3.90E-02	2.25E-02	2.25E-02	2.20E-02	2.20E-02	2.20E-02	1.27E-02	1.26E-02	1.26E-02	1.24E-02	1.16E-02	8.04E-03	8.02E-03	8.00E-03	4.18E-03
SO2	5.92E-02	5.92E-02	6.25E-03	6.25E-03	2.97E-04	2.97E-04	2.97E-04	2.73E-04	2.73E-04	2.73E-04	2.73E-04	2.73E-04	2.73E-04	2.73E-04	2.73E-04	2.58E-04
TOG	5.61E-02	5.59E-02	3.85E-02	3.85E-02	3.82E-02	3.74E-02	3.73E-02	3.11E-02	3.11E-02	3.11E-02	3.10E-02	2.82E-02	2.09E-02	2.08E-02	2.08E-02	1.29E-02
VOC	5.52E-02	5.50E-02	3.79E-02	3.79E-02	3.76E-02	3.68E-02	3.67E-02	3.07E-02	3.06E-02	3.06E-02	3.05E-02	2.78E-02	2.05E-02	2.05E-02	2.05E-02	1.27E-02
Formaldehyde	8.25E-03	8.22E-03	5.67E-03	5.66E-03	5.62E-03	5.50E-03	5.49E-03	4.58E-03	4.58E-03	4.57E-03	4.56E-03	4.15E-03	3.07E-03	3.07E-03	3.06E-03	1.89E-03
Methanol	1.68E-05	1.68E-05	1.16E-05	1.15E-05	1.15E-05	1.12E-05	1.12E-05	9.34E-06	9.33E-06	9.32E-06	9.31E-06	8.47E-06	6.26E-06	6.25E-06	6.24E-06	3.86E-06
Benzene	1.12E-03	1.12E-03	7.70E-04	7.69E-04	7.63E-04	7.48E-04	7.46E-04	6.23E-04	6.22E-04	6.21E-04	6.20E-04	5.65E-04	4.17E-04	4.17E-04	4.16E-04	2.57E-04
Acetaldehyde	4.12E-03	4.11E-03	2.83E-03	2.83E-03	2.81E-03	2.75E-03	2.74E-03	2.29E-03	2.29E-03	2.28E-03	2.28E-03	2.08E-03	1.53E-03	1.53E-03	1.53E-03	9.45E-04
Naphthalene	5.05E-05	5.03E-05	3.47E-05	3.46E-05	3.44E-05	3.36E-05	3.36E-05	2.80E-05	2.80E-05	2.80E-05	2.79E-05	2.54E-05	1.88E-05	1.88E-05	1.87E-05	1.16E-05
o-xylene	1.91E-04	1.90E-04	1.31E-04	1.31E-04	1.30E-04	1.27E-04	1.27E-04	1.06E-04	1.06E-04	1.06E-04	1.05E-04	9.60E-05	7.10E-05	7.08E-05	7.07E-05	4.37E-05
Cumene	1.12E-05	1.12E-05	7.70E-06	7.69E-06	7.63E-06	7.48E-06	7.46E-06	6.23E-06	6.22E-06	6.21E-06	6.20E-06	5.65E-06	4.17E-06	4.17E-06	4.16E-06	2.57E-06
Ethylbenzene	1.74E-04	1.73E-04	1.19E-04	1.19E-04	1.18E-04	1.16E-04	1.16E-04	9.66E-05	9.64E-05	9.63E-05	9.62E-05	8.75E-05	6.47E-05	6.46E-05	6.45E-05	3.99E-05
Styrene	3.36E-05	3.35E-05	2.31E-05	2.31E-05	2.29E-05	2.24E-05	2.24E-05	1.87E-05	1.87E-05	1.86E-05	1.86E-05	1.69E-05	1.25E-05	1.25E-05	1.25E-05	7.72E-06
p-xylene	5.61E-05	5.59E-05	3.85E-05	3.85E-05	3.82E-05	3.74E-05	3.73E-05	3.11E-05	3.11E-05	3.11E-05	3.10E-05	2.82E-05	2.09E-05	2.08E-05	2.08E-05	1.29E-05
1,3-butadiene	1.07E-04	1.06E-04	7.32E-05	7.31E-05	7.25E-05	7.10E-05	7.09E-05	5.92E-05	5.91E-05	5.90E-05	5.89E-05	5.36E-05	3.97E-05	3.96E-05	3.95E-05	2.44E-05
m-xylene	3.42E-04	3.41E-04	2.35E-04	2.35E-04	2.33E-04	2.28E-04	2.28E-04	1.90E-04	1.90E-04	1.89E-04	1.89E-04	1.72E-04	1.27E-04	1.27E-04	1.27E-04	7.85E-05
Toluene	8.24E-04	8.21E-04	5.66E-04	5.65E-04	5.61E-04	5.49E-04	5.49E-04	4.58E-04	4.57E-04	4.57E-04	4.56E-04	4.15E-04	3.07E-04	3.06E-04	3.06E-04	1.89E-04
n-hexane	8.97E-05	8.94E-05	6.16E-05	6.15E-05	6.11E-05	5.98E-05	5.97E-05	4.98E-05	4.98E-05	4.97E-05	4.96E-05	4.52E-05	3.34E-05	3.33E-05	3.33E-05	2.06E-05
Propionaldehyde	5.44E-04	5.42E-04	3.74E-04	3.73E-04	3.70E-04	3.63E-04	3.62E-04	3.02E-04	3.02E-04	3.01E-04	3.01E-04	2.74E-04	2.02E-04	2.02E-04	2.02E-04	1.25E-04
2,2,4-trimethylpentane	1.68E-04	1.68E-04	1.16E-04	1.15E-04	1.15E-04	1.12E-04	1.12E-04	9.34E-05	9.33E-05	9.32E-05	9.31E-05	8.47E-05	6.26E-05	6.25E-05	6.24E-05	3.86E-05
Lead	1.69E-06	1.69E-06	9.74E-07	9.73E-07	9.52E-07	9.55E-07	9.53E-07	5.49E-07	5.47E-07	5.46E-07	5.35E-07	5.04E-07	3.48E-07	3.47E-07	3.46E-07	1.81E-07
Manganese	1.61E-06	1.61E-06	9.28E-07	9.26E-07	9.06E-07	9.09E-07	9.07E-07	5.22E-07	5.21E-07	5.20E-07	5.10E-07	4.80E-07	3.32E-07	3.31E-07	3.30E-07	1.73E-07
Mercury	1.21E-06	1.21E-06	6.96E-07	6.95E-07	6.80E-07	6.82E-07	6.81E-07	3.92E-07	3.91E-07	3.90E-07	3.82E-07	3.60E-07	2.49E-07	2.48E-07	2.47E-07	1.29E-07
Nickel	7.66E-07	7.64E-07	4.41E-07	4.40E-07	4.31E-07	4.32E-07	4.31E-07	2.48E-07	2.48E-07	2.47E-07	2.42E-07	2.28E-07	1.58E-07	1.57E-07	1.57E-07	8.19E-08
Antimony	1.45E-06	1.45E-06	8.35E-07	8.34E-07	8.16E-07	8.18E-07	8.17E-07	4.70E-07	4.69E-07	4.68E-07	4.59E-07	4.32E-07	2.98E-07	2.98E-07	2.97E-07	1.55E-07
Arsenic	2.02E-07	2.01E-07	1.16E-07	1.16E-07	1.13E-07	1.14E-07	1.13E-07	6.53E-08	6.52E-08	6.50E-08	6.37E-08	6.00E-08	4.15E-08	4.13E-08	4.12E-08	2.16E-08
Cadmium	1.61E-06	1.61E-06	9.28E-07	9.26E-07	9.06E-07	9.09E-07	9.07E-07	5.22E-07	5.21E-07	5.20E-07	5.10E-07	4.80E-07	3.32E-07	3.31E-07	3.30E-07	1.73E-07

Table F.1 Emission Factors for Vertical Wells > 7,000 Feet (Cont.)

Pollutant	Emission Factor (ton/1,000 feet)															
	2002	2005	2008	2009	2010	2011	2012	2103	2014	2015	2016	2017	2018	2019	2020	2021
Cobalt	4.44E-07	4.42E-07	2.55E-07	2.55E-07	2.49E-07	2.50E-07	2.50E-07	1.44E-07	1.43E-07	1.43E-07	1.40E-07	1.32E-07	9.12E-08	9.09E-08	9.07E-08	4.74E-08
Phosphorous	5.12E-06	5.10E-06	2.95E-06	2.94E-06	2.88E-06	2.89E-06	2.88E-06	1.66E-06	1.65E-06	1.65E-06	1.62E-06	1.52E-06	1.05E-06	1.05E-06	1.05E-06	5.48E-07
Selenium	4.03E-07	4.02E-07	2.32E-07	2.32E-07	2.27E-07	2.27E-07	2.27E-07	1.31E-07	1.30E-07	1.30E-07	1.27E-07	1.20E-07	8.29E-08	8.27E-08	8.25E-08	4.31E-08
Chlorine	1.39E-05	1.38E-05	7.98E-06	7.97E-06	7.80E-06	7.82E-06	7.80E-06	4.49E-06	4.48E-06	4.47E-06	4.38E-06	4.13E-06	2.85E-06	2.84E-06	2.84E-06	1.48E-06

Table F.2 Emission Factors for Vertical Wells > 7,000 Feet

Pollutant	Emission Factor (ton/1,000 feet)															
	2002	2005	2008	2009	2010	2011	2012	2103	2014	2015	2016	2017	2018	2019	2020	2021
CO	6.17E-02	4.13E-02	3.16E-02	3.09E-02	3.01E-02	2.95E-02	2.93E-02	2.86E-02	2.78E-02	2.23E-02	2.21E-02	1.39E-02	4.37E-03	4.21E-03	4.05E-03	3.91E-03
NOx	2.21E-01	1.82E-01	1.49E-01	1.47E-01	1.33E-01	1.30E-01	1.12E-01	8.76E-02	8.28E-02	7.46E-02	7.41E-02	6.20E-02	4.02E-02	3.97E-02	2.76E-02	1.36E-02
PM10	9.25E-03	6.68E-03	4.46E-03	4.43E-03	4.00E-03	3.94E-03	3.68E-03	3.37E-03	3.32E-03	2.66E-03	2.64E-03	1.67E-03	5.39E-04	5.16E-04	4.94E-04	4.75E-04
PM2.5	8.97E-03	6.48E-03	4.33E-03	4.30E-03	3.88E-03	3.83E-03	3.57E-03	3.27E-03	3.22E-03	2.58E-03	2.56E-03	1.62E-03	5.23E-04	5.00E-04	4.79E-04	4.60E-04
SO2	3.06E-02	3.06E-02	3.23E-03	3.23E-03	1.53E-04	1.53E-04	1.53E-04	1.53E-04	1.53E-04	1.43E-04	1.43E-04	1.28E-04	1.11E-04	1.11E-04	1.11E-04	1.11E-04
TOG	1.43E-02	7.54E-03	6.72E-03	6.63E-03	6.53E-03	6.44E-03	6.39E-03	6.30E-03	6.21E-03	5.85E-03	5.81E-03	5.28E-03	4.68E-03	4.64E-03	4.61E-03	4.58E-03
VOC	1.41E-02	7.42E-03	6.62E-03	6.53E-03	6.43E-03	6.34E-03	6.29E-03	6.20E-03	6.12E-03	5.76E-03	5.72E-03	5.20E-03	4.60E-03	4.57E-03	4.53E-03	4.51E-03
Formaldehyde	2.11E-03	1.11E-03	9.89E-04	9.75E-04	9.60E-04	9.48E-04	9.39E-04	9.26E-04	9.14E-04	8.60E-04	8.54E-04	7.77E-04	6.88E-04	6.83E-04	6.78E-04	6.74E-04
Methanol	4.30E-06	2.26E-06	2.02E-06	1.99E-06	1.96E-06	1.93E-06	1.92E-06	1.89E-06	1.86E-06	1.75E-06	1.74E-06	1.58E-06	1.40E-06	1.39E-06	1.38E-06	1.37E-06
Benzene	2.87E-04	1.51E-04	1.34E-04	1.33E-04	1.31E-04	1.29E-04	1.28E-04	1.26E-04	1.24E-04	1.17E-04	1.16E-04	1.06E-04	9.35E-05	9.28E-05	9.22E-05	9.16E-05
Acetaldehyde	1.05E-03	5.54E-04	4.94E-04	4.87E-04	4.80E-04	4.74E-04	4.69E-04	4.63E-04	4.57E-04	4.30E-04	4.27E-04	3.88E-04	3.44E-04	3.41E-04	3.39E-04	3.37E-04
Naphthalene	1.29E-05	6.78E-06	6.05E-06	5.97E-06	5.88E-06	5.80E-06	5.75E-06	5.67E-06	5.59E-06	5.26E-06	5.23E-06	4.75E-06	4.21E-06	4.18E-06	4.15E-06	4.12E-06
o-xylene	4.87E-05	2.56E-05	2.29E-05	2.25E-05	2.22E-05	2.19E-05	2.17E-05	2.14E-05	2.11E-05	1.99E-05	1.97E-05	1.80E-05	1.59E-05	1.58E-05	1.57E-05	1.56E-05
Cumene	2.87E-06	1.51E-06	1.34E-06	1.33E-06	1.31E-06	1.29E-06	1.28E-06	1.26E-06	1.24E-06	1.17E-06	1.16E-06	1.06E-06	9.35E-07	9.28E-07	9.22E-07	9.16E-07
Ethylbenzene	4.44E-05	2.34E-05	2.08E-05	2.05E-05	2.02E-05	2.00E-05	1.98E-05	1.95E-05	1.93E-05	1.81E-05	1.80E-05	1.64E-05	1.45E-05	1.44E-05	1.43E-05	1.42E-05
Styrene	8.60E-06	4.52E-06	4.03E-06	3.98E-06	3.92E-06	3.87E-06	3.83E-06	3.78E-06	3.73E-06	3.51E-06	3.48E-06	3.17E-06	2.81E-06	2.78E-06	2.76E-06	2.75E-06
p-xylene	1.43E-05	7.54E-06	6.72E-06	6.63E-06	6.53E-06	6.44E-06	6.39E-06	6.30E-06	6.21E-06	5.85E-06	5.81E-06	5.28E-06	4.68E-06	4.64E-06	4.61E-06	4.58E-06
1,3-butadiene	2.72E-05	1.43E-05	1.28E-05	1.26E-05	1.24E-05	1.22E-05	1.21E-05	1.20E-05	1.18E-05	1.11E-05	1.10E-05	1.00E-05	8.89E-06	8.82E-06	8.75E-06	8.70E-06
m-xylene	8.74E-05	4.60E-05	4.10E-05	4.04E-05	3.98E-05	3.93E-05	3.89E-05	3.84E-05	3.79E-05	3.57E-05	3.54E-05	3.22E-05	2.85E-05	2.83E-05	2.81E-05	2.79E-05
Toluene	2.11E-04	1.11E-04	9.89E-05	9.74E-05	9.60E-05	9.47E-05	9.39E-05	9.26E-05	9.13E-05	8.60E-05	8.54E-05	7.76E-05	6.87E-05	6.82E-05	6.77E-05	6.73E-05
n-hexane	2.29E-05	1.21E-05	1.08E-05	1.06E-05	1.04E-05	1.03E-05	1.02E-05	1.01E-05	9.94E-06	9.36E-06	9.29E-06	8.45E-06	7.48E-06	7.43E-06	7.37E-06	7.33E-06

Table F.2 Emission Factors for Vertical Wells > 7,000 Feet (Cont.)

Pollutant	Emission Factor (ton/1,000 feet)															
	2002	2005	2008	2009	2010	2011	2012	2103	2014	2015	2016	2017	2018	2019	2020	2021
Propionaldehyde	1.39E-04	7.31E-05	6.52E-05	6.43E-05	6.33E-05	6.25E-05	6.19E-05	6.11E-05	6.03E-05	5.67E-05	5.63E-05	5.12E-05	4.54E-05	4.50E-05	4.47E-05	4.44E-05
2,2,4-trimethylpentane	4.30E-05	2.26E-05	2.02E-05	1.99E-05	1.96E-05	1.93E-05	1.92E-05	1.89E-05	1.86E-05	1.75E-05	1.74E-05	1.58E-05	1.40E-05	1.39E-05	1.38E-05	1.37E-05
Lead	3.89E-07	2.81E-07	1.88E-07	1.86E-07	1.68E-07	1.66E-07	1.55E-07	1.42E-07	1.39E-07	1.12E-07	1.11E-07	7.00E-08	2.26E-08	2.17E-08	2.07E-08	1.99E-08
Manganese	3.70E-07	2.67E-07	1.79E-07	1.77E-07	1.60E-07	1.58E-07	1.47E-07	1.35E-07	1.33E-07	1.07E-07	1.06E-07	6.66E-08	2.16E-08	2.06E-08	1.97E-08	1.90E-08
Mercury	2.78E-07	2.00E-07	1.34E-07	1.33E-07	1.20E-07	1.18E-07	1.10E-07	1.01E-07	9.96E-08	7.99E-08	7.91E-08	5.00E-08	1.62E-08	1.55E-08	1.48E-08	1.42E-08
Nickel	1.76E-07	1.27E-07	8.48E-08	8.41E-08	7.60E-08	7.49E-08	6.99E-08	6.41E-08	6.31E-08	5.06E-08	5.01E-08	3.16E-08	1.02E-08	9.80E-09	9.38E-09	9.02E-09
Antimony	3.33E-07	2.40E-07	1.61E-07	1.59E-07	1.44E-07	1.42E-07	1.32E-07	1.21E-07	1.20E-07	9.59E-08	9.50E-08	6.00E-08	1.94E-08	1.86E-08	1.78E-08	1.71E-08
Arsenic	4.63E-08	3.34E-08	2.23E-08	2.21E-08	2.00E-08	1.97E-08	1.84E-08	1.69E-08	1.66E-08	1.33E-08	1.32E-08	8.33E-09	2.69E-09	2.58E-09	2.47E-09	2.37E-09
Cadmium	3.70E-07	2.67E-07	1.79E-07	1.77E-07	1.60E-07	1.58E-07	1.47E-07	1.35E-07	1.33E-07	1.07E-07	1.06E-07	6.66E-08	2.16E-08	2.06E-08	1.97E-08	1.90E-08
Cobalt	1.02E-07	7.35E-08	4.91E-08	4.87E-08	4.40E-08	4.34E-08	4.05E-08	3.71E-08	3.65E-08	2.93E-08	2.90E-08	1.83E-08	5.93E-09	5.67E-09	5.43E-09	5.22E-09
Phosphorous	1.17E-06	8.48E-07	5.67E-07	5.62E-07	5.08E-07	5.01E-07	4.67E-07	4.28E-07	4.22E-07	3.38E-07	3.35E-07	2.12E-07	6.84E-08	6.55E-08	6.27E-08	6.03E-08
Selenium	9.25E-08	6.68E-08	4.46E-08	4.43E-08	4.00E-08	3.94E-08	3.68E-08	3.37E-08	3.32E-08	2.66E-08	2.64E-08	1.67E-08	5.39E-09	5.16E-09	4.94E-09	4.75E-09
Chlorine	3.18E-06	2.30E-06	1.54E-06	1.52E-06	1.38E-06	1.36E-06	1.27E-06	1.16E-06	1.14E-06	9.17E-07	9.07E-07	5.73E-07	1.85E-07	1.77E-07	1.70E-07	1.63E-07

Table F.3 Emission Factors for Directional/Horizontal Wells

Pollutant	Emission Factor (ton/1,000 feet)															
	2002	2005	2008	2009	2010	2011	2012	2103	2014	2015	2016	2017	2018	2019	2020	2021
CO	1.27E-01	1.09E-01	7.77E-02	7.75E-02	7.72E-02	6.47E-02	6.45E-02	6.40E-02	6.38E-02	6.36E-02	6.07E-02	2.66E-02	2.61E-02	2.59E-02	2.58E-02	1.34E-02
NOx	5.20E-01	5.22E-01	4.11E-01	4.11E-01	4.00E-01	3.55E-01	3.37E-01	2.52E-01	2.49E-01	2.43E-01	2.24E-01	2.01E-01	2.00E-01	1.99E-01	1.99E-01	1.80E-01
PM10	2.43E-02	1.97E-02	1.12E-02	1.12E-02	1.06E-02	9.28E-03	9.38E-03	6.75E-03	6.74E-03	6.75E-03	6.65E-03	3.92E-03	3.90E-03	3.88E-03	3.86E-03	2.70E-03
PM2.5	2.36E-02	1.91E-02	1.09E-02	1.08E-02	1.03E-02	9.00E-03	9.10E-03	6.55E-03	6.54E-03	6.55E-03	6.45E-03	3.81E-03	3.79E-03	3.76E-03	3.74E-03	2.62E-03
SO2	7.36E-02	7.36E-02	7.77E-03	7.77E-03	3.69E-04	3.69E-04	3.69E-04	3.00E-04	3.00E-04	3.00E-04	3.00E-04	2.83E-04	2.83E-04	2.83E-04	2.83E-04	2.76E-04
TOG	3.95E-02	3.51E-02	2.25E-02	2.25E-02	2.17E-02	1.64E-02	1.53E-02	2.08E-02	2.06E-02	2.03E-02	2.00E-02	1.34E-02	1.34E-02	1.33E-02	1.33E-02	1.11E-02
VOC	3.89E-02	3.46E-02	2.22E-02	2.21E-02	2.14E-02	1.62E-02	1.50E-02	2.05E-02	2.03E-02	2.00E-02	1.97E-02	1.32E-02	1.32E-02	1.31E-02	1.31E-02	1.09E-02
Formaldehyde	5.81E-03	5.17E-03	3.31E-03	3.30E-03	3.20E-03	2.42E-03	2.25E-03	3.07E-03	3.04E-03	2.98E-03	2.95E-03	1.98E-03	1.97E-03	1.96E-03	1.96E-03	1.63E-03
Methanol	1.18E-05	1.05E-05	6.75E-06	6.74E-06	6.52E-06	4.93E-06	4.58E-06	6.25E-06	6.19E-06	6.08E-06	6.01E-06	4.03E-06	4.01E-06	4.00E-06	3.99E-06	3.33E-06
Benzene	7.90E-04	7.03E-04	4.50E-04	4.49E-04	4.35E-04	3.29E-04	3.05E-04	4.17E-04	4.13E-04	4.06E-04	4.01E-04	2.69E-04	2.68E-04	2.67E-04	2.66E-04	2.22E-04
Acetaldehyde	2.90E-03	2.58E-03	1.65E-03	1.65E-03	1.60E-03	1.21E-03	1.12E-03	1.53E-03	1.52E-03	1.49E-03	1.47E-03	9.88E-04	9.84E-04	9.81E-04	9.79E-04	8.16E-04
Naphthalene	3.55E-05	3.16E-05	2.03E-05	2.02E-05	1.96E-05	1.48E-05	1.37E-05	1.88E-05	1.86E-05	1.83E-05	1.80E-05	1.21E-05	1.20E-05	1.20E-05	1.20E-05	9.99E-06

Table F.3 Emission Factors for Directional/Horizontal Wells (Cont.)

Pollutant	Emission Factor (ton/1,000 feet)															
	2002	2005	2008	2009	2010	2011	2012	2103	2014	2015	2016	2017	2018	2019	2020	2021
o-xylene	1.34E-04	1.19E-04	7.66E-05	7.63E-05	7.39E-05	5.59E-05	5.19E-05	7.09E-05	7.02E-05	6.90E-05	6.82E-05	4.57E-05	4.55E-05	4.54E-05	4.53E-05	3.78E-05
Cumene	7.90E-06	7.03E-06	4.50E-06	4.49E-06	4.35E-06	3.29E-06	3.05E-06	4.17E-06	4.13E-06	4.06E-06	4.01E-06	2.69E-06	2.68E-06	2.67E-06	2.66E-06	2.22E-06
Ethylbenzene	1.22E-04	1.09E-04	6.98E-05	6.96E-05	6.74E-05	5.09E-05	4.73E-05	6.46E-05	6.40E-05	6.29E-05	6.22E-05	4.17E-05	4.15E-05	4.14E-05	4.13E-05	3.44E-05
Styrene	2.37E-05	2.11E-05	1.35E-05	1.35E-05	1.30E-05	9.86E-06	9.16E-06	1.25E-05	1.24E-05	1.22E-05	1.20E-05	8.07E-06	8.03E-06	8.01E-06	7.99E-06	6.66E-06
p-xylene	3.95E-05	3.51E-05	2.25E-05	2.25E-05	2.17E-05	1.64E-05	1.53E-05	2.08E-05	2.06E-05	2.03E-05	2.00E-05	1.34E-05	1.34E-05	1.33E-05	1.33E-05	1.11E-05
1,3-butadiene	7.50E-05	6.68E-05	4.28E-05	4.27E-05	4.13E-05	3.12E-05	2.90E-05	3.96E-05	3.92E-05	3.85E-05	3.81E-05	2.55E-05	2.54E-05	2.54E-05	2.53E-05	2.11E-05
m-xylene	2.41E-04	2.14E-04	1.37E-04	1.37E-04	1.33E-04	1.00E-04	9.31E-05	1.27E-04	1.26E-04	1.24E-04	1.22E-04	8.20E-05	8.16E-05	8.14E-05	8.12E-05	6.77E-05
Toluene	5.80E-04	5.17E-04	3.31E-04	3.30E-04	3.20E-04	2.42E-04	2.24E-04	3.06E-04	3.03E-04	2.98E-04	2.95E-04	1.98E-04	1.97E-04	1.96E-04	1.96E-04	1.63E-04
n-hexane	6.32E-05	5.62E-05	3.60E-05	3.59E-05	3.48E-05	2.63E-05	2.44E-05	3.33E-05	3.30E-05	3.25E-05	3.21E-05	2.15E-05	2.14E-05	2.14E-05	2.13E-05	1.78E-05
Propionaldehyde	3.83E-04	3.41E-04	2.18E-04	2.18E-04	2.11E-04	1.59E-04	1.48E-04	2.02E-04	2.00E-04	1.97E-04	1.94E-04	1.30E-04	1.30E-04	1.29E-04	1.29E-04	1.08E-04
2,2,4-trimethylpentane	1.18E-04	1.05E-04	6.75E-05	6.74E-05	6.52E-05	4.93E-05	4.58E-05	6.25E-05	6.19E-05	6.08E-05	6.01E-05	4.03E-05	4.01E-05	4.00E-05	3.99E-05	3.33E-05
Lead	1.02E-06	8.28E-07	4.71E-07	4.70E-07	4.46E-07	3.90E-07	3.94E-07	2.84E-07	2.83E-07	2.84E-07	2.79E-07	1.65E-07	1.64E-07	1.63E-07	1.62E-07	1.14E-07
Manganese	9.73E-07	7.89E-07	4.49E-07	4.47E-07	4.25E-07	3.71E-07	3.75E-07	2.70E-07	2.70E-07	2.70E-07	2.66E-07	1.57E-07	1.56E-07	1.55E-07	1.54E-07	1.08E-07
Mercury	7.30E-07	5.91E-07	3.37E-07	3.35E-07	3.19E-07	2.78E-07	2.81E-07	2.03E-07	2.02E-07	2.03E-07	1.99E-07	1.18E-07	1.17E-07	1.16E-07	1.16E-07	8.11E-08
Nickel	4.62E-07	3.75E-07	2.13E-07	2.12E-07	2.02E-07	1.76E-07	1.78E-07	1.28E-07	1.28E-07	1.28E-07	1.26E-07	7.45E-08	7.42E-08	7.37E-08	7.33E-08	5.14E-08
Antimony	8.76E-07	7.10E-07	4.04E-07	4.02E-07	3.82E-07	3.34E-07	3.38E-07	2.43E-07	2.43E-07	2.43E-07	2.39E-07	1.41E-07	1.41E-07	1.40E-07	1.39E-07	9.74E-08
Arsenic	1.22E-07	9.86E-08	5.61E-08	5.59E-08	5.31E-08	4.64E-08	4.69E-08	3.38E-08	3.37E-08	3.38E-08	3.32E-08	1.96E-08	1.95E-08	1.94E-08	1.93E-08	1.35E-08
Cadmium	9.73E-07	7.89E-07	4.49E-07	4.47E-07	4.25E-07	3.71E-07	3.75E-07	2.70E-07	2.70E-07	2.70E-07	2.66E-07	1.57E-07	1.56E-07	1.55E-07	1.54E-07	1.08E-07
Cobalt	2.68E-07	2.17E-07	1.23E-07	1.23E-07	1.17E-07	1.02E-07	1.03E-07	7.43E-08	7.41E-08	7.43E-08	7.31E-08	4.32E-08	4.29E-08	4.27E-08	4.24E-08	2.98E-08
Phosphorous	3.09E-06	2.50E-06	1.43E-06	1.42E-06	1.35E-06	1.18E-06	1.19E-06	8.57E-07	8.56E-07	8.58E-07	8.44E-07	4.98E-07	4.96E-07	4.93E-07	4.90E-07	3.44E-07
Selenium	2.43E-07	1.97E-07	1.12E-07	1.12E-07	1.06E-07	9.28E-08	9.38E-08	6.75E-08	6.74E-08	6.75E-08	6.65E-08	3.92E-08	3.90E-08	3.88E-08	3.86E-08	2.70E-08
Chlorine	8.37E-06	6.78E-06	3.86E-06	3.85E-06	3.65E-06	3.19E-06	3.23E-06	2.32E-06	2.32E-06	2.32E-06	2.29E-06	1.35E-06	1.34E-06	1.33E-06	1.33E-06	9.31E-07

Appendix G – Annual and OSD County-Level Emission Estimates (Criteria Pollutants and HAPs, 2002, 2005, 2008-2021)

(see file "TCEQ Drilling Rig Engine Report_Appendices.xls")