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Task 9

Oil and Gas Emission Inventory Improvement Plan, Eagle Ford

Technical Proposal

August 1st, 2012

Prepared by:

Alamo Area Council of Governments

Prepared in Cooperation with the
Texas Commission on Environmental Quality

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Title: Oil and Gas Hydraulic Fracturing Emission Inventory Improvement Plan, South East Texas	**Report Date:** August 1st, 2012
Authors: AACOG Natural Resources/ Transportation Department	**Type of Report:** Technical Proposal
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Abstract: San Antonio is in danger of violating the 75 ppb ozone standard if readings exceed the standard in the next few years. From 2008 to 2011, sixty nine percent of the 48-hour 100-meter back trajectories ending at CAMS58 cross the Eagle Ford shale development on days exceeding the 8-hour ozone NAAQS. To meet air quality standards, local and state air quality planners need an accurate account of emissions from increased oil and gas production in the Eagle Ford. Unlike the Haynesville and Barnett Shale formations in northern Texas that primarily produce gas, the Eagle Ford shale features high oil yields and wet gas across much of the play. Consequently, equipment types, processes, and activities in the Eagle Ford may differ from those employed dry gas shale formations. Before an emission inventory is started, an inventory improvement plan is completed describing how an emission inventory will be conducted. To produce natural gas, condensate, and oil from Eagle Ford wells, there are 5 main phases that can emit ozone precursor emissions: exploration and pad construction, drilling operation, hydraulic fracturing and completion operation, production, and mid-stream sources. Emissions sources can include drill rigs, compressors, pumps, heaters, other non-road equipment, process emissions, flares, storage tanks, and fugitive emissions. Existing oil and gas drilling inventories in Texas and data from the Railroad Commission of Texas will be used to develop an inventory of the Eagle Ford emission sources. When available, results from the TCEQ's Barnett Shale area special inventory phase two study will be used to calculate emissions. Throughout this process, local officials will continue to work with oil and gas companies, drilling contractors, engine manufactures, and industry representatives to refine data inputs after the emission inventory protocol is submitted to TCEQ. Emissions from the Eagle Ford are projected to continue to grow as development increases over the next few years. Using the latest available data from other studies, local data, and regional data, emissions will be calculated for 2011 and projected to 2015 and 2018. Projections of activity in the Eagle Ford will be based on three scenarios: low development, medium development, and aggressive development. The scenarios cover a range of potential growth in the Eagle Ford based on best available information including local data, industrial projections, and projected price of petroleum products. The Eagle Ford emission inventory will be provided in an organized electronic format that can be readily incorporated into photochemical models.

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EXECUTIVE SUMMARY

In the last 4 years, San Antonio had 26 days exceeding the 75 ppb 8-hour ozone National Ambient Air Quality Standards (NAAQS) and the ozone design value has remained at the 75 ppb ozone standard for the last two years. San Antonio is in danger of violating the 75 ppb standard if ozone readings are higher in the next few years. Sixty nine percent (19 days) of the 48-hour 100-meter back trajectories ending at CAMS58 cross the Eagle Ford shale development on days exceeding the 8-hour ozone NAAQS from 2008 to 2011. In 2011, the majority of ozone exceedance days back trajectories, 7 out of 10 days, passed over the Eagle Ford before arriving at CAMS23 and CAMS58.

To meet air quality standards, local and state air quality planners need an accurate account of emissions and their sources in the region. This assessment will provide key information on the impact of increased oil and gas hydraulic fracturing on local ozone readings. Before an emission inventory is started, an inventory improvement plan (IPP) is completed describing how an emission inventory will be conducted. The plan is a detailed description of the need for the improvement, the data sources required, a discussion of standard methods/approaches used elsewhere, how the approach will be different and why, how primary data will be collected, any adjustments to the data, the expected accuracy of the results, and timeline for the emission inventory development. The goal of this improvement protocol is to establish a foundation for a comprehensive emission inventory of oil and gas production activities in the Eagle Ford.

Hydraulic fracturing is the process of creating fissures, or fractures, in underground formations to allow natural gas and oil to flow up the wellbore to a pipeline or tank battery. In the Eagle Ford Shale, companies pumps water, sand and other additives under high pressure into the formation to create fractures to release oil and gas deposits. Unlike the Haynesville and Barnett shale formations in northern Texas that primarily produce gas, the Eagle Ford Shale features high oil yields and wet gas/condensate across much of the play. Consequently, equipment types, processes, and activities in the Eagle Ford may differ from those employed in dry gas shale formations. To produce hydrocarbons from Eagle Ford wells, there are 5 main phases that can emit ozone precursor emissions: exploration and pad construction, drilling operation, hydraulic fracturing and completion operation, production, and mid-stream sources. Emissions sources can include drill rigs, compressors, pumps, heaters, other non-road equipment, process emissions, flares, storage tanks, and fugitive emissions.

Existing oil and gas emission inventories in Texas and data from the Railroad Commission of Texas will be used to develop an emissions inventory of the Eagle Ford. These studies includes: Eastern Research Group's (ERG) "Characterization of Oil and Gas Production Equipment and Develop a Methodology to Estimate Statewide Emissions", ERG's Drilling Rig Emission Inventory for the State of Texas, and ENVIRON's "An Emission Inventory for Natural Gas Development in the Haynesville Shale and Evaluation of Ozone Impacts". TCEQ also conducted a mail survey through the Barnett Shale area special inventory phase two study on natural gas fracturing operations west of Dallas. When available, results from the Barnett Shale area special inventory will be used to calculate emissions. Throughout this process, local officials will continue to work with oil and gas companies, drilling contractors, engine manufactures, and industry representatives to refine data inputs after the emission inventory protocol is submitted. Emphases will be put on collecting data and calculating emissions for large source categories such as drill rigs and pump engines.

A partnership between the oil and gas industry and AACOG's technical air quality staff is critical for the successful development of an ozone precursors' emissions inventory. AACOG is working closely with local oil and gas industry, equipment manufactures, and Texas Center for Applied Technology (TCAT) to collect improved local data, conduct surveys, and get industry input. The Eagle Ford emission inventory will be provided in an organized electronic format that can be readily incorporated into photochemical models. Once the inventory protocol is approved, the final Eagle Ford emission inventory will be completed.

Equations, data sources, and methodology will be checked throughout the development of the emission inventory and at strategic points. Special emphases will be put on critical components, such as drill rigs and hydraulic fracturing pumps, for quality checks. Eagle Ford data developed through the emission inventory process will be compared to previous data sets from other shale oil and gas emission inventories. When errors and omissions are identified they will be corrected immediately and all documentation will be updated with the corrections. All emission inventory calculation methodology will be documented and described in detail so external officials and other interested parties can replicate results. For every emission inventory source, documentation will be consistent and will contain data sources, methodology, formulas, and results. When the emission inventory is completed, documentations and spreadsheets will be sent to local industry, TCEQ, and other interested parties for review. Categories indicating major differences between the inventories will be flagged for review.

Emissions from the Eagle Ford are projected to continue to grow as oil and gas development increases over the next few years. Using the latest available data from other studies, local data, and regional data, VOC, NO_X and CO emissions will be projected to 2018. Projections of activity in the Eagle Ford will use a methodology similar to ENVIRON's Haynesville Shale emission inventory which was based on three scenarios: low development, medium development, and aggressive development. The scenarios cover a range of potential growth in the Eagle Ford based on best available information including local data, industrial projections, and projected price of petroleum products. Projected emissions are derived by the drilling activity in the region and production estimations for each well. Since hydraulic fracturing of oil reserves on a wide scale is relatively new occurrence, activity and emission projections will have a high uncertain factor.

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1 BACKGROUND

"The Eagle Ford Shale is a hydrocarbon producing formation of significant importance due to its capability of producing both gas and more oil than other traditional shale plays. It contains a much higher carbonate shale percentage, upwards to 70% in south Texas, and becomes shallower and the shale content increases as it moves to the northwest. The high percentage of carbonate makes it more brittle and 'fracable'."[1] Hydraulic fracturing is a technological advancement which allows producers to recover natural gas and oil resources from these shale formations. "Experts have known for years that natural gas and oil deposits existed in deep shale formations, but until recently the vast quantities of natural gas and oil in these formations were not able to be technically or economically recoverable." Today, significant amounts of natural gas and oil from deep shale formations across the United States are being produced through the use of horizontal drilling and hydraulic fracturing.[2]

Hydraulic fracturing is the process of creating fissures, or fractures, in underground formations to allow natural gas and oil to flow up the wellbore to a pipeline or tank battery. In the Eagle Ford Shale, companies "pumps water, sand and other additives under high pressure into the formation to create fractures. The fluid is approximately 98% water and sand, along with a small amount of special-purpose additives. The newly created fractures are "propped" open by the sand, which allows the natural gas and oil to flow into the wellbore and be collected at the surface. Variables such as surrounding rock formations and thickness of the targeted shale formation are studied by scientists before fracking is conducted."[3]

Locations of the Eagle Ford and other Shale Plays in the lower 48 states are provided in Figure 1-1.[4] Unlike the Haynesville and Barnett Shale formations in northern Texas that primarily produce gas, the Eagle Ford Shale features high oil yields and wet gas/condensate across much of the play. Consequently, equipment types, processes, and activities in the Eagle Ford may differ from those employed in more traditional shale formations. Emission processes in the inventory include exploration and pad construction, drilling, hydraulic fracturing and completion operations, production, and midstream facilities. Emissions sources can include drill rigs, compressors, pumps, heaters, other non-road equipment, process emissions, flares, storage tanks, and fugitive emissions.

Existing oil and gas drilling inventories in Texas and data from the Railroad Commission of Texas will be used to develop an emissions inventory of the Eagle Ford. These studies includes: Eastern Research Group's (ERG) "Characterization of Oil and Gas Production Equipment and Develop a Methodology to Estimate Statewide Emissions", ERG's Drilling Rig Emission Inventory for the State of Texas, and ENVIRON's "An Emission Inventory for Natural Gas Development in the Haynesville Shale and Evaluation of Ozone Impacts".

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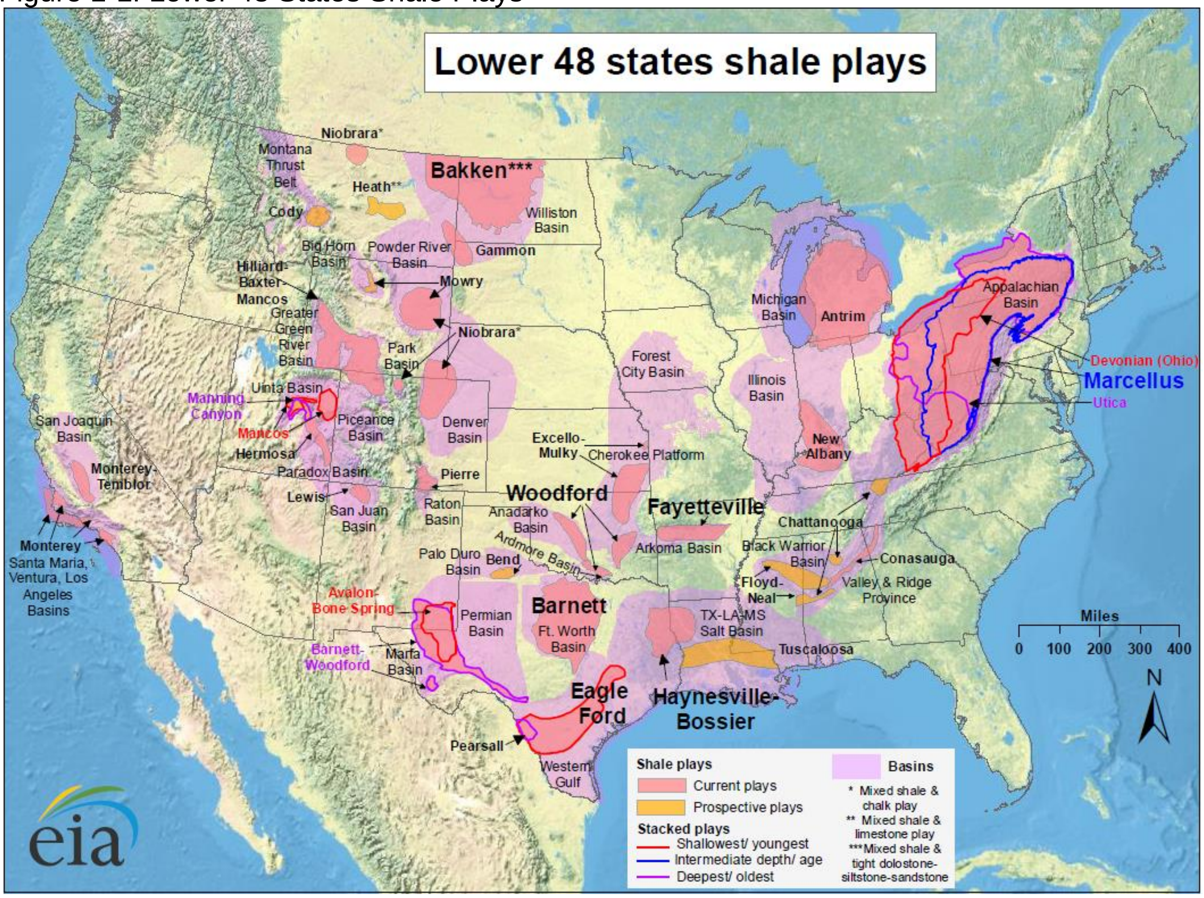
[1] Railroad Commission of Texas, May 22, 2012. "Eagle Ford Information". Austin, Texas. Available online: http://www.rrc.state.tx.us/eagleford/index.php. Accessed 05/30/2012.
[2] Chesapeake Energy, Sept. 2011. "Eagle Ford Shale Hydraulic Fracturing". Available online: http://www.chk.com/Media/Educational-Library/Fact-Sheets/EagleFord/EagleFord_Hydraulic_Fracturing_Fact_Sheet.pdf. Accessed: 04/12/2012.
[3] *Ibid*.
[4] Energy Information Administration (EIA), May 9, 2011. "Maps: Exploration, Resources, Reserves, and Production". Available online: ftp://www.eia.doe.gov/pub/oil_gas/natural_gas/analysis_publications/maps/maps.htm. Accessed 06/04/2012.

TCEQ also conducted a mail survey through the Barnett Shale area special inventory phase two study on natural gas fracturing operations west of Dallas. When available, results from the Barnett Shale study will be used to calculate production and midstream emissions. Through this process, local officials will continue to work with local oil and gas companies, drilling contractors, engine manufactures, and industry representatives to refine data inputs after the emission inventory protocol is submitted.

Figure 1-1: Lower 48 States Shale Plays



1.1 Purpose

The Clean Air Act (CAA) is the comprehensive federal law that regulates airborne emissions across the United States.[5] This law authorizes the U.S. Environmental Protection Agency (EPA) to establish National Ambient Air Quality Standards (NAAQS) to protect public health and the environment. Of the many air pollutants commonly found throughout the country, EPA has recognized six "criteria" pollutants that can injure health, harm the environment, and/or cause property damage. Air quality monitors measure concentrations of these pollutants throughout the country. San Antonio is currently in attainment of the "criteria" pollutants according to the NAAQS. However, there are concerns over the high concentrations of ground level ozone, one of the "criteria" pollutants, which local monitors are recording. Ozone is produced when organic compounds (VOC) and nitrogen compounds (NO_X) react in the presence of sunlight, especially in summer time.[6]

[5] US Congress, 1990. "Clean Air Act". Available online: http://www.epa.gov/air/caa/. Accessed: 07/19/2010.
[6] EPA, Sept. 23, 2011, "Ground-level Ozone". Available online: http://www.epa.gov/air/ozonepollution/. Accessed: 10/31/2011.

According to the EPA, “the health effects associated with ozone exposure include respiratory health problems ranging from decreased lung function and aggravated asthma to increased emergency department visits, hospital admissions and premature death. The environmental effects associated with seasonal exposure to ground-level ozone include adverse effects on sensitive vegetation, forests, and ecosystems.”[7] Currently, the ozone primary standard, which is designed to protect human health, is set at 75 parts per billion (ppb). The secondary standard, which is designed to protect the environment, is in the same form and concentration as the primary standard.

To meet air quality standards, local and state air quality planners need an accurate account of emissions and their sources in the region. The compilation of the emissions inventory (EI) needs extensive research and analysis, providing a vast database of regional pollution sources and emission rates. By understanding these varied sources that create ozone precursor pollutants, planners, political leaders, and common citizens can work together to protect heath and the environment. This assessment should provide key information on the impact of increased oil and gas production on local ozone readings.

Before an emission inventory is started, an IPP is completed describing how an emission inventory will be conducted. The plan is a detailed description of the need for the improvement, the data sources required, a discussion of standard methods/approaches used elsewhere, how the approach will be different and why, how primary data will be collected, any adjustments to the data, the expected accuracy of the results, and timeline for the emission inventory development. “Inventory Preparation Plans are used as a planning tool to guide inventory preparation and ensure that emission estimates are of high quality and are consistent with CAA requirements.” “EPA recommends that State and local agencies submit detailed IPPs which describe how the inventory is developed, what it includes, and what assumptions are being made.”[8]

“The IPPs should include descriptions of inventory objectives and general procedures. One of the first steps in developing the IPP is to define the purpose and scope of the inventory. This includes identifying items such as the base year for the inventory, the pollutants to be inventoried, the emissions sources and source categories, the geographical boundaries of the inventory, the spatial and temporal scales of the emissions, and the application of controls and regulations including rule effectiveness and rule penetration.”[9] The goal of this improvement protocol is to establish a foundation for a comprehensive emission inventory of oil and gas production activities in the Eagle Ford shale. By collecting local data, a comprehensive emission inventory of the Eagle Ford can be developed. Ozone precursor emissions sources and amounts from the Eagle Ford are unknown and there is no previous emission inventory of the Eagle Ford oil and gas development. The spatial and temporal allocation of oil and gas production will be collected to provide data for geo-code emissions.

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[7] EPA, September 16, 2009. “Fact Sheet: EPA to Reconsider Ozone Pollution Standards”, p. 1. Available online: http://www.epa.gov/air/ozonepollution/pdfs/O3_Reconsideration_FACT%20SHEET_091609.pdf. Accessed: 06/28/2010.

[8] Emissions Inventory Group Emissions, Monitoring and Analysis Division Office of Air Quality Planning and Standards, Aug. 2005. “Emissions Inventory Guidance for Implementation of Ozone and Particulate Matter National Ambient Air Quality Standards (NAAQS) and Regional Haze Regulations”. EPA-454/R-05-001. U.S. Environmental Protection Agency. Research Triangle Park, NC. p. 10. Available online: http://www.epa.gov/ttnchie1/eidocs/eiguid/eiguidfinal_nov2005.pdf. Accessed 06/04/2012.

[9] *Ibid*.

1.2 Inventory Pollutants

Ozone is a secondary pollutant because it forms as the result of chemical reaction between other pollutants, namely:

- Nitrogen Oxides (NO_X)
- Volatile Organic Compounds (VOC)
- Carbon monoxide (CO)

Emissions will be reported for annual and average ozone season county totals. After the emission inventory is completed and reviewed, emissions will be geo-coded to 4km grid system used by the region photochemical model. The photochemical modeling used to determine a regions ability to comply with the NAAQS depends on a large degree on accurately identifying and quantifying emission rates from these pollutants.

1.3 Base Year and Geographical Area Covered

The proposed Eagle Ford ozone precursor emission inventory will include the following 25 counties in 2011, 2015, and 2018. All the counties listed below are currently in attainment of all air quality regulatory standards. Any emissions directly or indirectly associated with Eagle Ford production outside of these counties will not be included in the emission inventory.

- Atascosa
- Bee
- Brazos
- Burleson
- De Witt
- Dimmit
- Fayette
- Frio
- Gonzales
- Grimes
- Houston
- Karnes
- La Salle
- Lavaca
- Lee
- Leon
- Live Oak
- Maverick
- Mcmullen
- Madison
- Milam
- Washington
- Webb
- Wilson
- Zavala

The location of the core area of Eagle Ford production is located in Karnes County with sections of the core area in Dewitt, Gonzales, Atascosa, and Live Oak counties (Figure 1-2). This area of the Eagle Ford contains the most intensive development and potential for future growth. Eagle Ford counties and the location of wells permitted are provided in Figure 1-3. Oil wells on schedule are marked in green, gas wells on schedule are marked in red, and permits are highlighted in light blue. Most of the wells are concentrated in the core area. There is also a significant number of wells in the southwest section of the Eagle Ford, while there is very few wells in the northern counties of the Eagle Ford.

There are over 200 oil and gas companies operating in Eagle Ford counties. Chesapeake Energy Corporation has the most acreage, at 600,000, in the Eagle Ford followed by EOG Resources, Inc. with 520,000 and Apache Corporation with 450,000.[10] Some of the companies that are operating in the Eagle Ford are listed on the following pages.[11]

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[10] David Fessler, Nov. 11, 2011, "The Bakken isn't the Only Big Shale Oil Play". Peak Energy Strategist. Available online: http://peakenergystrategist.com/archives/tag/eog-resources/. Accessed: 05/30/2012.

[11] Eagle Ford Shale News, NarketPlace, Jobs, May 30th, 2012. "Eagle Ford Shale Counties". Available online: http://www.eaglefordshale.com/counties/. Accessed: 05/30/2012.

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Figure 1-2: Eagle Ford Shale Hydrocarbon Map[12]

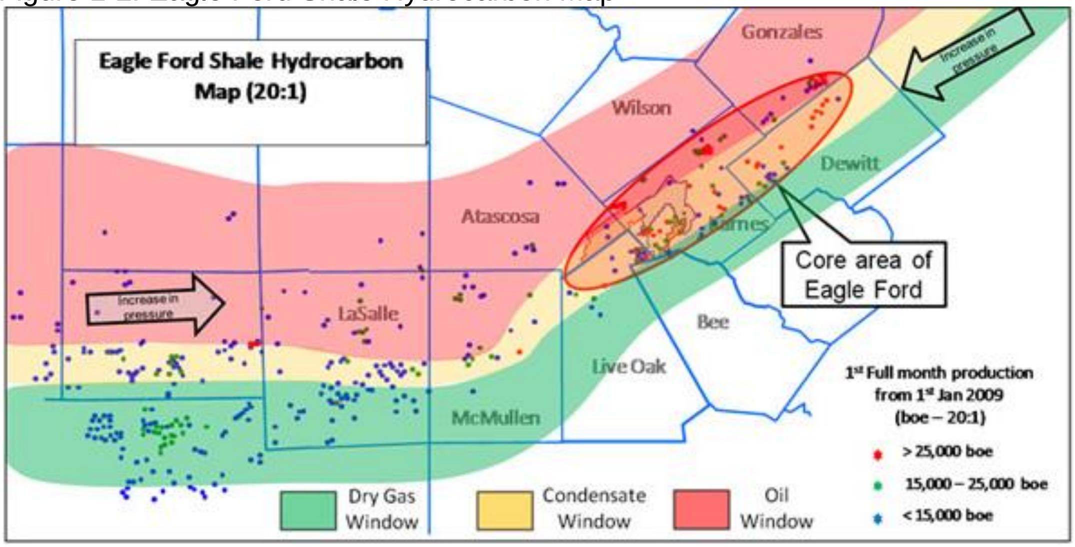
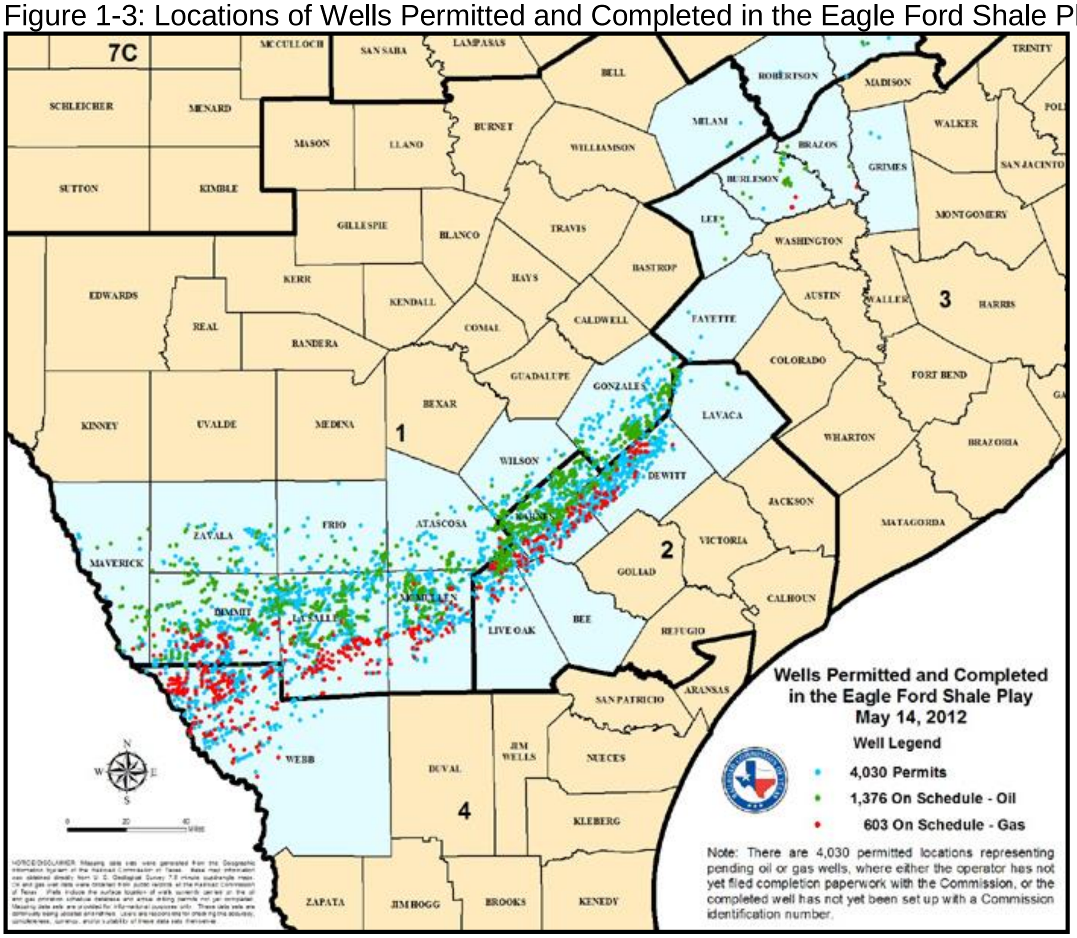


Figure 1-3: Locations of Wells Permitted and Completed in the Eagle Ford Shale Play[13]



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[12] Aurora Oil & Gas Limited. “Production Results”. Available online: http://www.auroraoag.com.au/irm/content/projects_productionresults.html. Accessed: 04/15/2012.

[13] Railroad Commission of Texas, May 14, 2012. “Wells Permitted and Completed in the Eagle Ford Shale Play”. Austin, Texas. Available online: http://www.rrc.state.tx.us/eagleford/images/EagleFordShalePlay201205-large.jpg. Accessed: 05/30/2012.

- Abraxas Petroleum
- Acock Operating
- Alamo Operating Co.
- Ampak Oil Co.
- Anadarko Petroleum
- Apache
- Aurora Resources
- AWP Operating
- Bayshore Energy
- Big Shell Oil & Gas
- Blackbrush Oil & Gas
- Blue Star Operating
- Botasch Operating
- Broad Oak Energy
- Buffco Production
- Cabot Oil & Gas
- Carrizo Oil & Gas
- Caskids Operating
- Chaparral Energy
- Chesapeake Energy
- Chevron
- Cheyenne Petroleum
- Cinco Natural Resources
- Civron Petroleum
- CML Exploration
- CMR Energy
- Comstock Oil & Gas
- ConocoPhillips
- Continental Operating
- Cornerstone
- Crimson Exploration
- Dan A. Hughes Company
- David H Arrington Oil & Gas
- Dawsey Operating
- Delta Exploration
- Denali Oil & Gas
- Devon E&P Company
- Dewbre Petroleum
- Edwin S. Nichols Exploration
- EF Energy
- El Paso Corporation
- Encana
- Enduring Resources
- Enervest
- EOG Resources
- Escondido Resources
- Espada Operating
- Express Oil
- ExxonMobil
- First Rock, Inc.
- Forest Oil
- Genesis Gas & Oil
- Geosouthern Energy
- Goodrich Petroleum
- Hidalgo E&P
- Holley Oil
- Hunt Oil
- Jack L. Phillips Company
- Jadela Oil Operating
- JB Oil & Gas
- Kaler Energy
- Killam Oil
- Lama Energy
- Laredo Energy
- Leexus Oil
- Legend Natural Resources
- Lewis Petroleum
- Lime Rock Resources
- LMP Petroleum
- Lucas Energy
- Marathon Oil
- Matador Resources
- McDay Energy
- McMinn Operating
- Milagro Exploration
- Murphy Oil
- Newfield Exploration
- Orca Operating
- Paloma Resources
- Peregrine Petroleum
- Petroquest Energy
- Pioneer Natural Resources
- Premier Energy
- Property Development Group
- Red Arrow Energy
- Redemption Oil & Gas
- Redwood Operating
- Regency Energy
- Riley Exploration
- Rio Grand Exploration
- Rio Tex, Inc.
- Rock Solid Operating
- Rosetta Resources
- Sabco Operating
- Sabinal Resources
- Sage Energy
- San Isidro Development
- Sanchez Oil & Gas
- Magnum Hunter Resources
- Shell Western E&P (Shell)
- Sien Operating
- St. Mary Land & Exploration
- South Oil
- Southern Bay Operating
- Spartan Operating
- Stephens Production
- Stonegate Production
- Strand Energy
- Suemaur Exploration & Prod.
- Swift Energy
- Talisman Energy
- T-C Oil Company
- Terra Ferma Operating
- Texas American Resources
- Texas International Operating
- Tidal Petroleum
- Union Gas
- US Enercorp
- Virtex Operating Co.
- Wapiti Operating
- WCS Oil & Gas Corporation
- Weber Energy
- Welder Exploration & Prod.
- Whiting Oil & Gas
- Winn Exploration
- Wynn-Crosby Operating
- XTO Energy
- ZaZa Energy

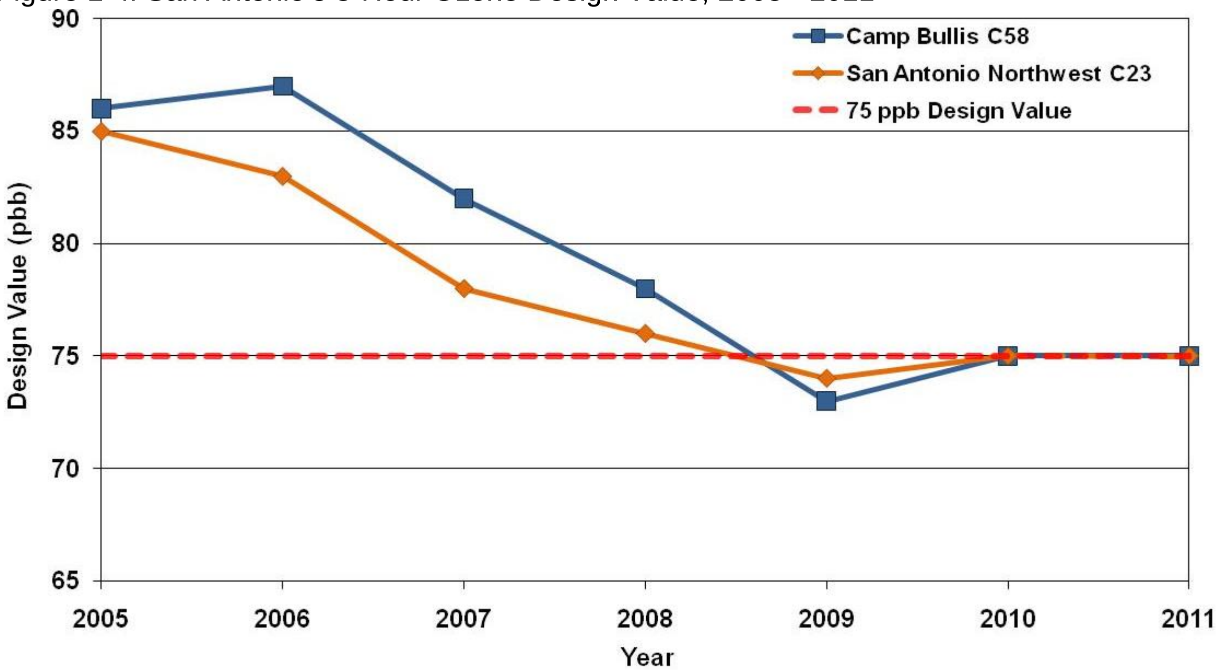
1.4 Local Ozone and Meteorological Conditions

There are currently 17 air quality monitors, CAMS, in the San Antonio region that records air pollution measurements including ozone levels. The data collected at these sites is processed for quality assurance by the Texas Commission on Environmental Quality

(TCEQ) and is accessible via the Internet.[14] The CAMS network in the San Antonio region includes both regulatory and non-regulatory monitors. Regulatory monitors meet EPA's requirements for equipment type, sitting criteria, and quality assurance. The San Antonio area includes three regulatory monitors owned by TCEQ: CAMS23, CAMS58, and CAMS59.

There was a significant decrease in San Antonio's ozone design value from 2005 to 2009: from 87 ppb in 2006 to 74 ppb in 2009. Although there was a decrease in ozone during these years, 26 days exceed the 75 ppb 8-hour ozone NAAQS in the last 4 years and the ozone design value has remain at the 75 ppb ozone standard for the last two years (Figure 1-4). San Antonio is in danger of violating the 75 ppb standard if ozone readings are higher in the next few years.

Figure 1-4: San Antonio's 8-Hour Ozone Design Value, 2005 - 2011



The Air Resources Laboratory of the NOAA maintains the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model and allows public use via the Internet at their Realtime Environmental Applications and Display System (READY) webpage.[15] This versatile model can be run as a trajectory (parcel displacement) or air dispersion model, using either forecast or archived meteorological data. The model and database are applicable across the United States, which provides a national reference for air trajectory and dispersion modeling needs. Using the HYSPLIT model, approximate paths of air coming into San Antonio can be determined. According to TCEQ, "meteorological dynamics that cause air to rise or fall, and that determine its path can affect air quality by carrying air

[14] TCEQ, "Select a Monitoring Site in Region 13 (San Antonio)". Available online: http://www.tceq.state.tx.us/cgi-bin/compliance/monops/select_summary.pl?region13.gif. Accessed: 04/13/2012.

[15] NOAA, Feb. 26, 2010. "Realtime Environmental Applications and Display sYstem (READY)". Available online: http://www.arl.noaa.gov/ready.html. Accessed: 01/12/2012.

pollutants many miles from their sources."[16] Given a final geographic destination for an air parcel, back trajectories show the path followed by the air parcel before reaching the destination. Back trajectories track air displacement over time, distance, and emission source regions.

Sixty nine percent (19 days) of the 48-hour 100-meter back trajectories ending at CAMS58 cross the Eagle Ford shale development on days exceeding the 8-hour ozone NAAQS from 2008 to 2011 (Table 1-1). Twelve (46%) of these back trajectories cross the Eagle Ford shale development in the southern portion of the Eagle Ford, Wilson County boundary or farther south, where most of the Eagle Ford development is occurring. In 2011, the majority of ozone exceedance days back trajectories, 7 out of 10 days, passed over the Eagle Ford before arriving at CAMS23 and CAMS58.

Table 1-1: Days of High Ozone Readings >75 ppb in San Antonio, 2008-2011

Year	Highest Regulatory Monitor	Date	Highest 8-hour Ozone Reading at a Regulatory Monitor	Does C58 48-hour 100-meter Back Trajectory Cross Eagle Ford*	Does C23 48-hour 100-meter Back Trajectory Cross Eagle Ford*
2008	C58	May 8	77	No	No
	C23	June 23	78	**Yes**	**Yes**
	C23	September 6	78	**Yes**	**Yes**
	C23	September 26	81	**Yes**#	**Yes**#
	C23	September 27	82	No	**Yes**#
	C23	September 28	78	**Yes**#	**Yes**#
	C59	September 30	79	No	No
	C23	October 1	81	No	No
	C58	October 2	78	**Yes**	**Yes**
2009	C23	May 28	76	**Yes**#	**Yes**#
	C58	May 30	77	**Yes**	**Yes**
	C23	June 5	90	No	No
2010	C58	May 28	86	**Yes**	**Yes**
	C23	August 27	80	**Yes**#	**Yes**#
	C23	August 28	87	**Yes**#	**Yes**#
	C58	October 16	78	**Yes**	**Yes**
2011	C23	May 16	78	No	No
	C23	June 6	79	**Yes**	**Yes**
	C23	August 27	76	**Yes**	**Yes**
	C23	August 28	77	**Yes**	No
	C58	August 29	76	**Yes**	**Yes**
	C23	September 7	87	No	No
	C23	September 10	84	No	**Yes**
	C23	September 11	78	**Yes**	**Yes**
	C23	October 2	78	**Yes**#	**Yes**
	C23	October 3	79	**Yes**	**Yes**

* 48-hour 100-meter back trajectory ending at each monitor during the highest peak 1-hour ozone reading

the back trajectory crosses only the northern portion (north of Wilson County) of the Eagle Ford Shale Development that is not heavily developed

[16] TCEQ, Air Monitoring, Sept. 24, 2009. "Air Trajectories: Where did the Air Come from and Where is It Going?". Available online: http://www.tceq.state.tx.us/compliance/monitoring/air/monops/airtraj.html. Accessed: 05/24/10.

Figure 1-5 illustrates back trajectories on high ozone days color coded by year for CAMS23 and CAMS58. As shown, there are a number of back trajectories that flow over the core area of Eagle Ford before arriving at the regulatory monitors in San Antonio. While there are back trajectories that travel over the Eagle Ford during every year, the majority of the back trajectories on high ozone days in 2011 flow over the heavily developed areas of the Eagle Ford. For CAMS23, 35% of back trajectories flow from the south and southeast on high ozone days, while CAMS58 had 31% of back trajectories from the same directions on high ozone days (Figure 1-6 and Figure 1-7).

When using the HYSPLIT model, limitations of trajectory analysis should be noted. TCEQ states that "it is important to point out that transport layer back trajectories for ozone episodes are based upon archived upper air data from meteorological models, and interpolated from a coarse grid which smoothes out the local perturbations and geographical details. Trajectories developed from transport layer winds do not necessarily represent the wind fields at the surface, especially on a day-to-day basis. Individual trajectories have error bars, which increase with time and distance, and so must be interpreted with caution. However, when a large number of trajectories for ozone episodes are analyzed statistically, they provide a reliable picture of the most likely flow patterns and source regions affecting an area."[17]

1.5 Modeling Domain Parameters

Development of input files and/or spatial surrogates for photochemical model emission processing shall be based on a grid system consistent with EPA's Regional Planning Organizations (RPO) Lambert Conformal Conic map projection with the following parameters:

- First True Latitude (Alpha): 33°N
- Second True Latitude (Beta): 45°N
- Central Longitude (Gamma): 97°W
- Projection Origin: (97°W, 40°N)
- Spheroid: Perfect Sphere, Radius: 6,370 km

All future TCEQ photochemical model emissions processing work, including the Eagle Ford emission inventory, will be based on the grid system listed above.

[17] Technical Support Section, Technical Analysis Division TCEQ, December 13, 2002. "Conceptual Model for Ozone Formation in the Houston-Galveston Area Appendix A to Phase I of the Mid Course Review Modeling Protocol and Technical Support Document". Austin, Texas. p. 21. Available online: http://www.tceq.state.tx.us/assets/public/implementation/air/am/docs/hgb/protocol/HGMCR_Protocol_Appendix_A.pdf. Accessed: 05/24/10.

Figure 1-5: CAMS23 and CAMS58 Back Trajectories on Days with 8-Hour Ozone > 75 ppb and the Location of Eagle Ford, 2008-2011

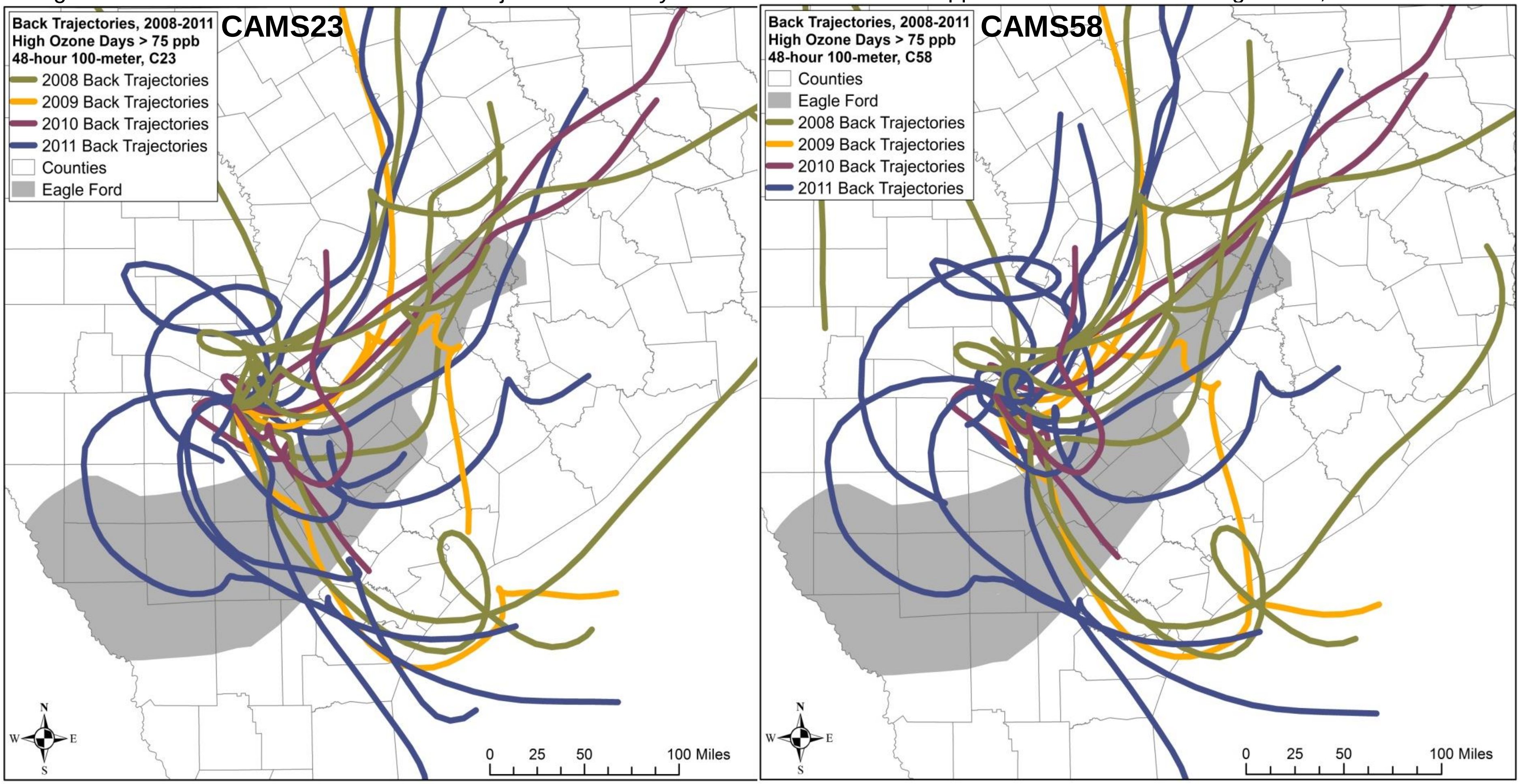
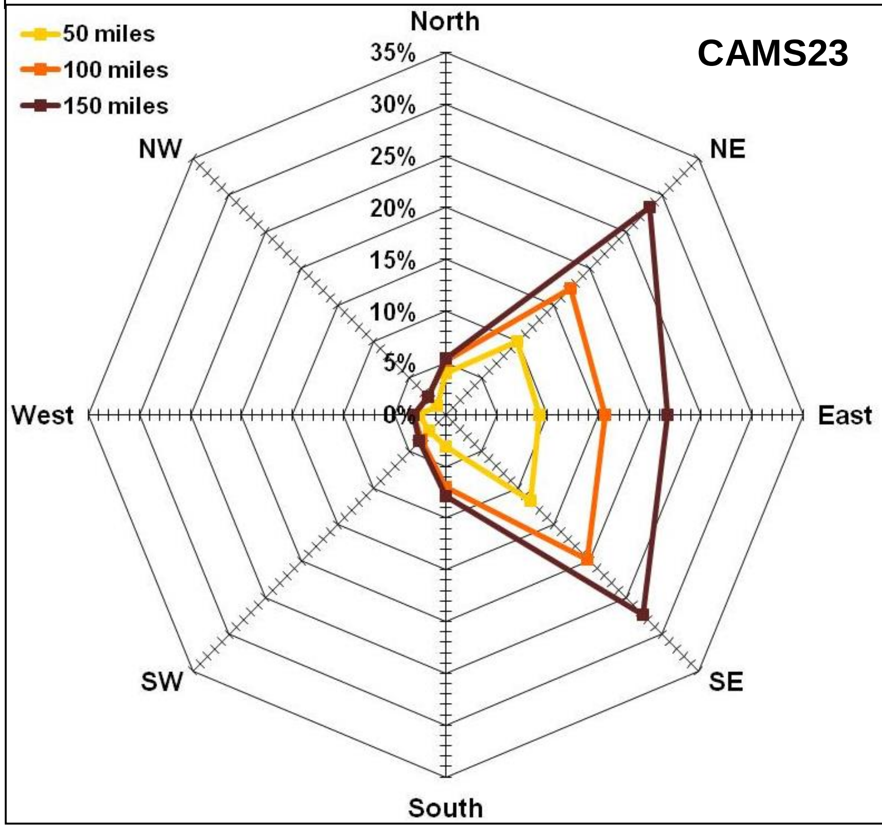
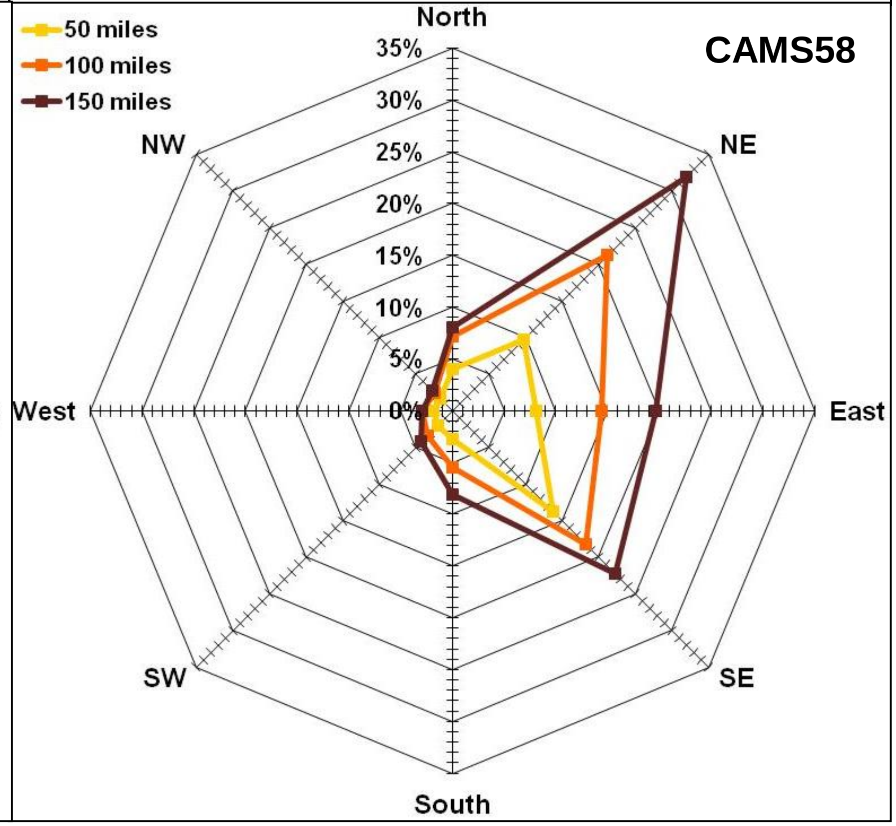


Figure 1-6: Statistical Analysis of San Antonio's 150-mile 48-hour Back Trajectory Wind Directions on High Ozone Days > 75 ppb, CAMS23, 2008-2011: Cumulative Frequency (Percent)	Figure 1-7: Statistical Analysis of San Antonio's 150-mile 48-hour Back Trajectory Wind Directions on High Ozone Days > 75 ppb, CAMS58, 2008-2011: Cumulative Frequency (Percent)
	

1.6 South Texas Geology and Hydrocarbon Horizons

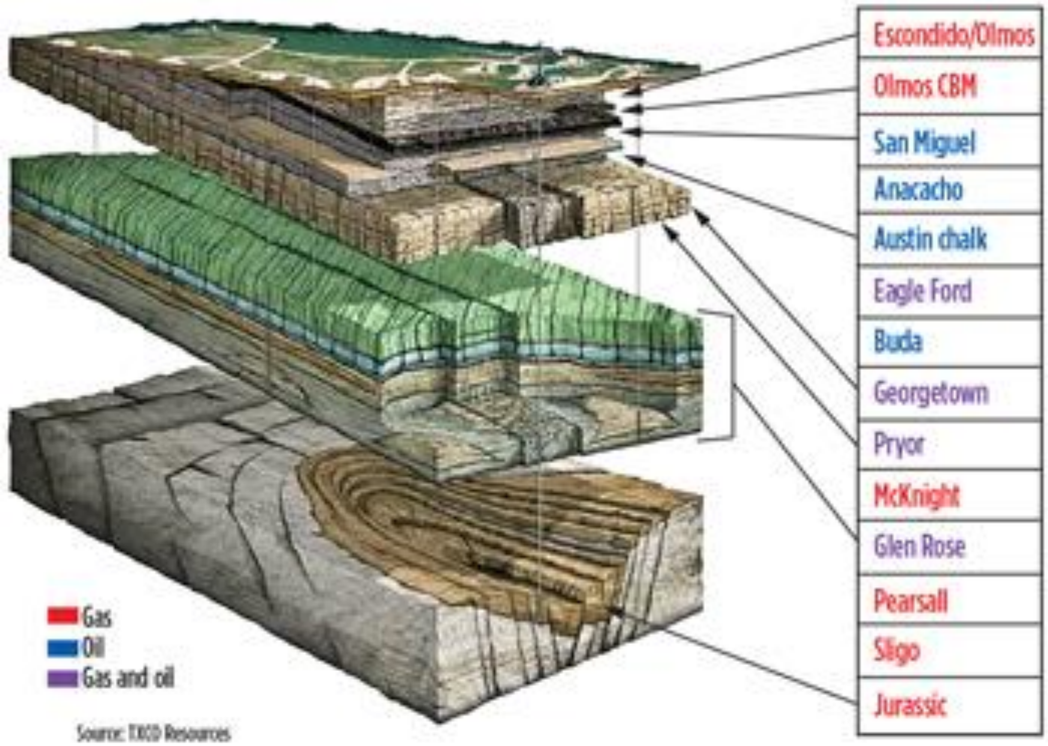
Halliburton states that “despite its geographic abundance and enormous production potential, gas shale presents a number of challenges – starting with the lack of an agreed-upon definition of what, exactly, comprises shale. Shale makes up more than half the earth’s sedimentary rock but includes a wide variety of vastly differing formations.” Within the oil and gas industry, “the generally homogenous, fine-grained rock can be defined in terms of its geology, geochemistry, geo-mechanics and production mechanism – all of which differ from a conventional reservoir, and can differ from shale to shale, and even within the same shale.” “All shale is characterized by low permeability, and in all gas-producing shales, organic carbon in the shale is the source. Many have substantial gas stored in the free state, with additional gas storage capacity in intergranular porosity and/or fractures. Other gas shales grade into tight sands, and many tight sands have gas stored in the adsorbed state.”[18]

“The Eagle Ford is a geological formation directly beneath the Austin Chalk Shale. It is considered to be the “source rock”, or the original source of hydrocarbons that are contained in the Austin Chalk above it.”[19] Figure 1-8 diagrams the horizons that contains natural gas and oil in south east Texas including the Eagle Ford.[20] “Producers drilled through the play for many years targeting the Edwards Limestone formation along the Edwards Reef Trend. It was not until the discovery of several other shale plays that operators began testing the true potential of the Eagle Ford Shale.”[21] “The shale is more of a carbonate than a shale, but “shale” is the hot term of the day. The formation’s carbonate content can be as high as 70%. The play is more shallow and the shale content increases in the northwest portions of the play. The high carbonate content and subsequently lower clay content make the Eagle Ford more brittle and easier to stimulate through hydraulic fracturing or fracking.”[22]

The Eagle Ford shale “is 50 miles wide and 400 miles long. It is best identified in three parts, or windows, that also run from the northeast to southwest. To the southeast is the gas window, and as the name suggests this play is mainly natural gas. It is also the deepest part of the play reaching depths of 14,000 feet. The northwestern section is referred to as the oil window. This section produces mostly oil and is very shallow. The Eagle Ford is being drilled at depths around 4,000 feet. Sandwiched between the oil and gas windows is the Condensate or "wet gas" window. The Condensate window is much like the other two windows, except it produces a lot of wet and rich gas. A significant amount of oil is also garnered here. [23]

[18] Halliburton. “U.S. Shale Gas: An Unconventional Resource. Unconventional Challenges”. Available online: http://www.halliburton.com/public/solutions/contents/Shale/related_docs/H063771.pdf. Accessed: 04/20/2012.
[19] Eagle Ford Shale Now (EFSN), Nov. 1, 2011. “Eagle Ford Shale Overview”. Available online: http://shalegasnow.com/eagle-ford-shale. Accessed: 05/31/2012.
[20] David Michael Cohen, Managing Editor, June 2011. “Eagle Ford Texas’ Dark-Horse Resource Play Picks up Speed”. World Oil. Vol 232, No. 6. Available online: http://www.worldoil.com/June-2011-Eagle-Ford-Texas-dark-horse-resource-play-picks-up-speed.html. Accessed: 04/20/2012.
[21] Eagle Ford Shale News, MarketPlace, Jobs, May 31st, 2012. “Eagle Ford Shale Geology”. Available online: http://www.eaglefordshale.com/geology/. Accessed: 05/31/2012.
[22] *Ibid*.
[23] Michael Filloon, March 19, 2012. “Bakken Update: Well Spacing Defined, Production Outlined”. Available online: http://seekingalpha.com/article/442981-bakken-update-well-spacing-defined-production-outlined. Accessed 05/20/2012.

Figure 1-8: Horizons that Contain Natural Gas and Oil in South East Texas



“The high liquids content in the central portion of the Eagle Ford shale is economic. Much of these liquids are natural gas condensate, which is low density mixture of hydrocarbon liquids found in many natural gas fields. This condenses from raw natural gas when the temperature is reduced below the hydrocarbon dew point temperature of the raw gas. It should be noted natural gas wells can produce condensate as a byproduct, but condensate wells produce raw natural gas along with natural gas liquids. The condensing of natural gas increases its energy density and increasing its value. Liquefied natural gas can be transported via pipeline, or by ship all over the world.”[24] Other formations in south east Texas are also being hydraulic fractured to produce natural gas including the Austin Caulk and Pearsall formations.

1.7 Types of Operations In the Eagle Ford

There are three different types of wells in the Eagle Ford Shale development included in the emission inventory proposal.

1. Dry gas wells
2. Wet gas wells that produce condensate
3. Oil wells that can also produce casinghead gas

To produce hydrocarbons from these wells, there are 5 main phases in the Eagle Ford that can emit ozone precursor emissions.

- Exploration and Pad Construction: Exploration uses vibrator trucks to produce sound waves beneath the surface that are useful in the exploration for oil and natural gas. Construction of the drill pad requires clearing, grubbing, and grading, followed by placement of a base material by construction equipment and trucks. Reserve pits are also usually required at each well pad because the drilling and hydraulic

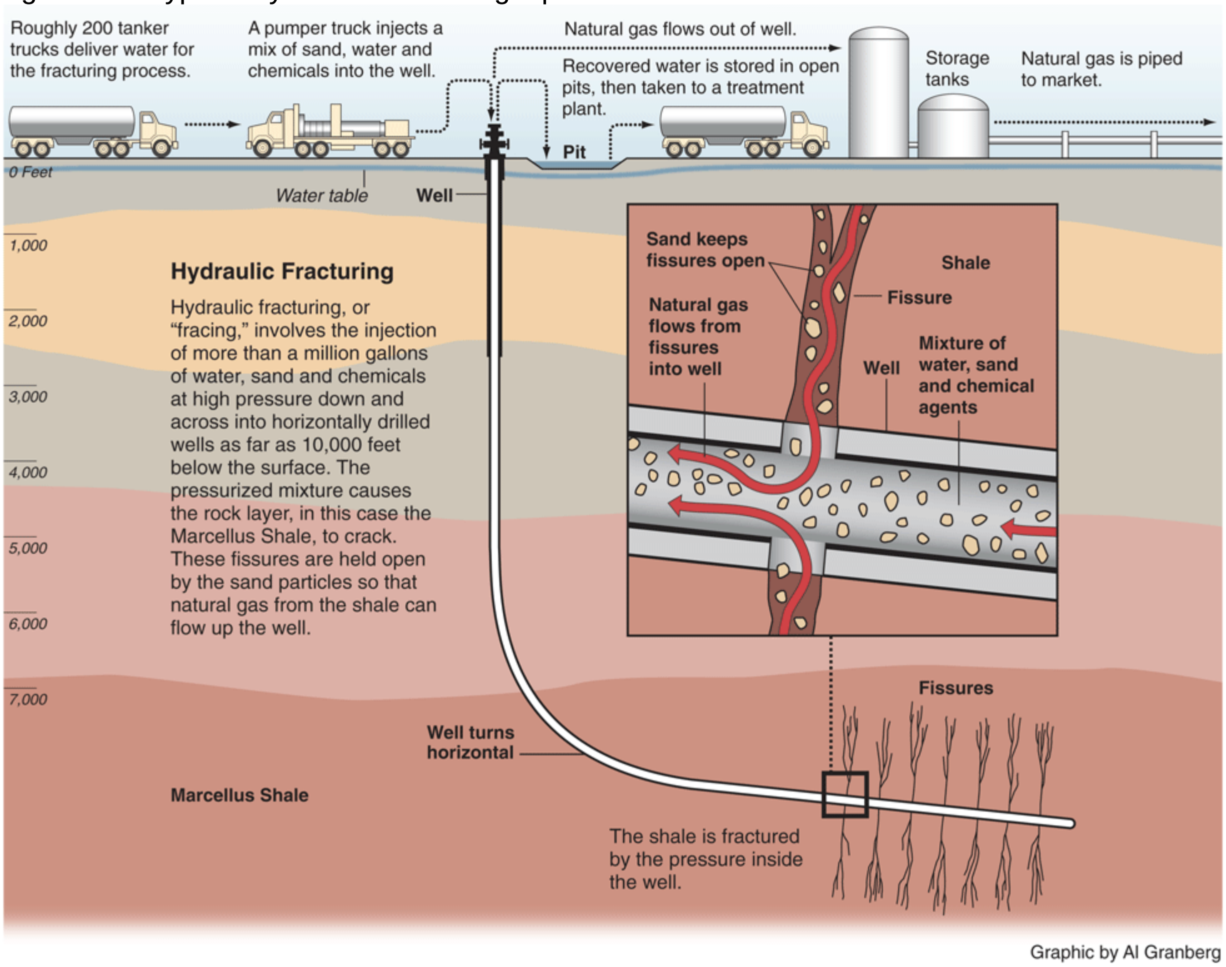
[24] *Ibid*.

fracturing process uses a large volume of fluid that is circulated through the well and back to the surface.

- Drilling Operation: "Drilling of a new well is typically a two to three week process from start to finish and involves several large diesel-fueled generators."[25] Other emission sources related to drilling operations includes construction equipment and trucks to haul supplies, equipment, fluids, and employees.
- Hydraulic Fracturing and Completion Operation: As shown in Figure 1-9, hydraulic fracturing "is the high pressure injection of water mixed with sand and a variety of chemical additives into the well to fracture the shale and stimulate natural gas production from the well. Fracking operations can last for several weeks and involve many large diesel-fueled generators"[26] "Once drilling and other well construction activities are finished, a well must be completed in order to begin producing. The completion process requires venting of the well for a sustained period of time to remove mud and other solid debris in the well, to remove any inert gas used to stimulate the well (such as CO_2 and/or N_2) and to bring the gas composition to pipeline grade".[27] In the Eagle Ford, vented gas from completion is usually flared.
- Production: Once the product is collected from the well, emission can occur at well sites from compressors, flares, heaters, and pneumatic devices. There can also be significant emissions from equipment leaks, storage tanks, and loading operations fugitives. Trucks are often used to transport product to processing facilities and refineries.
- Midstream Sources: Midstream sources in the Eagle Ford consist mostly of compressor stations and processing facilities, but other facilities can include cryogenic plants, saltwater disposal facilities, tank batteries, and other facilities. "The most significant emissions from compressors stations are usually from combustion at the compressor engines or turbines. Other emissions sources may include equipment leaks, storage tanks, glycol dehydrators, flares, and condensate and/or wastewater loading. Processing facilities generally remove impurities from the natural gas, such as carbon dioxide, water, and hydrogen sulfide. These facilities may also be designed to remove ethane, propane, and butane fractions from the natural gas for downstream marketing. Processing facilities are usually the largest emitting natural gas-related point sources including multiple emission sources such as, but not limited to equipment leaks, storage tanks, separator vents, glycol dehydrators, flares, condensate and wastewater loading, compressors, amine treatment and sulfur recovery units."[28]

[25] University of Arkansas and Argonne National Laboratory. "Fayetteville Shale Natural Gas: Reducing Environmental Impacts: Site Preparation". Available online: http://lingo.cast.uark.edu/LINGOPUBLIC/natgas/siteprep/index.htm. Accessed: 04/20/2012.
[26] *Ibid*.
[27] Amnon Bar-Ilan, Rajashi Parikh, John Grant, Tejas Shah, Alison K. Pollack, ENVIRON International Corporation. Nov. 13, 2008. "Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories". Novato, CA. p. 48. Available online: http://www.wrapair.org/forums/ogwg/documents/2008-11_CENRAP_O&G_Report_11-13.pdf. Accessed: 04/30/2012.
[28] Eastern Research Group Inc. July 13, 2011. "Fort Worth Natural Gas Air Quality Study Final Report". Prepared for: City of Fort Worth, Fort Worth, Texas. p. 3-2. Available online: http://fortworthtexas.gov/gaswells/?id=87074. Accessed: 04/09/2012.

Figure 1-9: Typical Hydraulic Fracturing Operation[29]



Below is a list of emission sources for each phase of operation in this proposal. Emission sources include non-road equipment, on-road vehicles, fugitive emissions, and flare combustion. Each company operating in the Eagle Ford can use different procedures and equipment during drilling, hydraulic fracturing, and production. Local data through survey and interviews with industry representatives will be collected during the emission inventory development to improve input data and emission calculations. TCEQ point source database will be checked to make sure there is no double counting of midstream sources or large wellhead compressors facilities.

[29] Journalism in the Public Interest, 2011. "What is Hydraulic Fracturing?". Propublica. Available online: http://www.propublica.org/special/hydraulic-fracturing-national. Accessed: 04/28/2012.

Phase	Emission Sources
Exploration and Pad Construction	• Seismic Trucks • Non-Road Equipment used for Pad Construction • Heavy Duty Trucks • Light Duty Trucks
Drilling Operation	• Electric Drill Rigs • Mechanical Drill Rigs • Other Non-Road Equipment used during drilling • Heavy Duty Trucks • Light Duty Trucks
Hydraulic Fracturing and Completion Operation	• Pump Trucks • Other Non-Road Equipment used during Hydraulic Fracturing • Heavy Duty Trucks • Light Duty Trucks • Completion Venting • Completion Flares
Production	• Wellhead Compressors • Heaters • Flares • Dehydrators Flash Vessels and Regenerator Vents • Storage Tanks • Fugitives (Leaks) • Loading Fugitives • Well Blowdowns • Pneumatic Devices • Heavy Duty Trucks • Light Duty Trucks
Mid-Stream Sources	• Compressor Station • Production Facilities • Other Mid-Stream Sources

Non-routine emissions, such as those generated during upsets or from maintenance, startup, and shutdown activities, will not be calculated in the emission inventory. The proposal does not include construction of mid-stream facilities, building offices, quarrying of fracturing sands, pipeline construction, etc. Generators and other equipment at camp houses and offices used by oil field workers are not part of the emission inventory proposal. Emission sources outside of the Eagle Ford shale region that are directly or indirectly affected by the shale development are not included. The protocol does not include trucks that bring supplies to mid stream sources, worker camps, and other facilities not located at the well head. Emissions from the production of cement, steel pipes, and other non-recycled material are not included in the emission inventory.

The emission inventory proposal does not include emissions from railroad activity related to Eagle Ford development. “Port San Antonio, which operates a rail yard that connects both Union Pacific (UP) and Burlington Northern Santa Fe (BNSF) lines, experienced a 53 percent uptick in traffic during 2011. More than half of its current rail activity at the privatized air base is now related to the shale”. During the first quarter of 2012, “UP’s petroleum-products loadings increased 63 percent”. “The industry also expects additional growth in industrial products and chemical shipments for the rest of this year and into 2013." [30] Railroads carry fracturing sands, pipelines, petroleum products, equipment, building materials, and other supplies to production sites in the Eagle Ford.

1.8 Local Industry Involvment

A partnership between the oil and gas industry and AACOG's technical air quality staff is critical for the successful development of an ozone precursors' emissions inventory. AACOG is working closely with local oil and gas industry, equipment manufacturers, and Texas Center for Applied Technology (TCAT) to collect improved local data, conduct surveys, and get industry input. The kick-off workshop for this effort occurred on May 21st, 2012 and the industries that were represented at the meeting included:

- Texas Oil & Gas Association
- Shell Exploration & Production Co.
- EOG Resources, Inc.
- Pioneer Natural Resources
- Plains Exploration & Production Company
- Chesapeake Energy Corporation
- Marathon Oil Company
- Texas Center for Applied Technology
- Energy Transfer
- ConoccoPhillips
- Carrizo Oil & Gas, Inc.

The workshop welcomed technical specialists in all phases of exploration, production, and distribution of natural resources in the Eagle Ford. The purpose of this effort was to begin the process of the development of an accurate emissions inventory of ozone precursors produced by oil and gas activities in the Eagle Ford. The industry was provided an overview of the region's regulatory ozone challenge and the AIR Committee, AACOG's ozone technical analysis and photochemical modeling responsibilities, and the contractual basis for the Eagle Ford Shale emission inventory. An overview of the current draft emission inventory protocol development was provided to industry representatives.

Local industry representatives recommended surveys to be sent out to targeted companies for each phase of the operation. Each survey will involve a specific aspect of the operations, for example an individual survey for drilling or hydraulic fracturing operations. Draft surveys could be reviewed by industry representatives to determine accuracy and completeness of the forms. Fuel usage or activity data can be collected from each company during the survey. Other sources of information could include gate logs of trucks entering production sites, schedules of truck deliveries, and logs of fuel and water carried by each truck. Industry was also interested in checking to see if data collected for EPA's Climate Change Regulatory Initiatives Subpart W[31] can be useful for the ozone precursor emission inventory.

Recommendation put forth in the meeting by industry included using Wyoming[32] and Pennsylvania[33] surveys of oil and gas operations as templates for conducting surveys in the

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[30] Sanford Nowlin, San Antonio Business Journal, April 27, 2012. "San Antonio is emerging as vital rail junction for Eagle Ford Shale". San Antonio, Texas. Available online: http://www.bizjournals.com/sanantonio/print-edition/2012/04/27/san-antonio-is-emerging-as-vital-rail.html. Accessed 05/01/2012.

[31] U.S. Environmental Protection Agency, May 21, 2012. "Climate Change Regulatory Initiatives Subpart W – Petroleum and Natural Gas Systems". Available online: http://www.epa.gov/climatechange/emissions/subpart/w.html. Accessed 06/04/2012.

[32] Wyoming Department of Environmental Quality. "Oil and Gas Production Site Emission Inventory Forms". Available online: http://deq.state.wy.us/aqd/Oil%20and%20Gas%20Production%20Site%20Emission%20Inventory%20Forms.asp. Accessed 06/04/2012.

Eagle Ford. Collecting location data of operations and comparing different fields in the Eagle Ford was another recommendation of industry representatives. As discussed during the meeting, there was a recommendation for a strong data validation process when conducting the emission inventory. As part of this process, Texas Oil and Gas Association (TXOGA)[34] could be used as a “data aggregator” to work proprietary data into a public format. AACOG will continue to involve the industry in all aspects of the emission inventory development.

1.9 Data Sources

There are a variety of data sources used to estimate emissions from Eagle Ford oil and gas production. Whenever possible, local data will be used to calculate emissions and project future production. To get local data, interviews will be conducted with oil and gas industry representatives and surveys will be sent to producers in the Eagle Ford. Surveys for drill rigs and hydraulic fracturing are provided in Appendix G.

Counts of drill rigs operating in the Eagle Ford and number of wells drilled are provided by Schlumberger. Similarly, well characteristics and production amounts were collected from Schlumberger and the Railroad Commission of Texas. Non-road equipment will be calculated using local industry data, emission factors from TexN model, manufactures, and TCEQ, and the results from TCAT surveys. Compressor engines emissions will be based on TCEQ Barnett Shale Special Inventory (Table 1-2).

Area sources emissions calculations will relay on data produce by TCEQ’s Barnett Shale special inventory. Other sources for area emissions include local industry data, ERG’s Texas emission inventory, ENVIRONS CENRAP emission inventory, and AP42 emission factors for flares (Table 1-3). Proposed on-road data sources, as listed in Table 1-4, are from NCTCOG study in the Barnett Shale, TxDOT study also in the Barnett Shale, and ENVIRON’s Colorado report. Emission factors for heavy duty and light duty trucks are produced by the MOVES model and provide by the EPA. If updated data becomes available from local surveys or industry, data sources and methodologies will be updated and noted in the final emission inventory.

1.10 TxLED

NO_X emission estimates for all diesel equipment will be reduced by 6.2% to account for Texas Low Emission Diesel (TxLED) supplied in the following 19 counties in the Eagle Ford[35].

- Atascosa
- Bee
- Brazos
- Burleson
- De Witt
- Fayette
- Goliad
- Gonzales
- Grimes
- Houston
- Karnes
- Lavaca
- Lee
- Leon
- Live Oak
- Madison
- Milam
- Washington
- Wilson

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[33] Pennsylvania Department of Environmental Protection. “DEP to Gather Air Emissions Data about Natural Gas Operations”. Available online: http://www.dep.state.pa.us/dep/deputate/airwaste/aq/emission/emission_inventory.htm. Accessed 06/04/2012.

[34] Texas Oil & Gas Association. Available online: http://www.txoga.org/. Accessed 06/04/2012.

[35] Eastern Research Group, Inc. July 15, 2009. “Drilling Rig Emission Inventory for the State of Texas”. Prepared for: Texas Commission on Environmental Quality. Austin, Texas. p. 6-18. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820783985FY0901-20090715-ergi-Drilling_Rig_EI.pdf. Accessed: 04/09/2012.

Table 1-2: Data Sources for Non-Road Equipment Emissions

Source Category	Population	Horsepower	Hours/Fuel Usage	Load Factor (LF)	Emission Factors
Seismic Trucks	Local Industry Data	Equipment Manufactures	Local Industry Data	TexN Model	TexN Model
Pad Construction Eq.	San Juan Inventory (Colorado)	San Juan Inventory (Colorado)	San Juan Inventory (Colorado)	TexN Model	TexN Model
Electric Drill Rigs	Local Industry Data	Local Industry Data	Local Industry Data	Local Industry Data/ TexN Model	TCEQ
Mechanical Drill Rigs	Local Industry Data	Local Industry Data	Local Industry Data	Local Industry Data/ TexN Model	TexN Model
Other Non-Road Eq. used during Drilling	Local Industry Data	Local Industry Data	Based on Time to Drill a well	TexN Model	TexN Model
Pump Trucks	TCAT Survey	TCAT Survey	ENVIRON (Haynesville)	Local Industry Data	TCEQ
Other Non-Road Eq. used during Fracturing	TCAT Survey	TCAT Survey, Local Industry Data, & TexN Model	Based on Time to Fracture a well	TexN Model	TexN Model
Wellhead Compressors	Barnett Shale Special Inventory	Barnett Shale Special Inventory	Barnett Shale Special Inventory	Barnett Shale Special Inventory	Barnett Shale Special Inventory
Compressor Stations, Production facilities, Cryogenic Plants, etc.	Emissions from TCEQ Permit Data and Barnett Shale Special Inventory				

Table 1-3: Data Sources for Fugitives, Flaring, Breathing Loss, and Loading Emissions

Source Category	Amount and Heat Content	Activity/Population	Emission Factors
Completion Venting	ERG's Texas EI (Western Gulf)	Local Industry Data	ERG's Texas EI (Western Gulf)
Flaring	ENVIRON CENRAP EI (Western Gulf)	ENVIRON CENRAP EI (Western Gulf) and Local Industry Data	AP-42 Section 13.5
Heaters	ERG Texas EI and ENVIRON CENRAP EI (Western Gulf)	Barnett Shale Special Inventory	Barnett Shale Special Inventory
Flaring	ENVIRON CENRAP EI (Western Gulf)	-	AP-42 Section 13.5
Dehydrators	-	-	ERG Texas EI
Storage Tanks	-	Barnett Shale Special Inventory	Barnett Shale Special Inventory
Fugitives from Natural Gas Wells	-	Barnett Shale Special Inventory	Barnett Shale Special Inventory
Fugitives from Oil Wells		ERG Texas EI	ERG Texas EI
Loading Loss	-	-	AP42 and Local Meteorological Data
Blowdowns	ENVIRON CENRAP EI (Western Gulf)	ENVIRON CENRAP EI (Western Gulf)	ERG's Texas EI (Western Gulf)
Pneumatic Devices	-	ENVIRON CENRAP EI (Western Gulf)	ERG Texas EI

Table 1-4: Data Sources for On-Road Vehicles Emissions

Vehicle Type	Process	Number of Vehicles	Distance Traveled or Hours Idling	Emission Factors
Heavy Duty Trucks	On-Road	TxDOT (Barnett) and NCTCOG (Barnett)	Railroad Commission	MOVES Model
	Idling	TxDOT (Barnett) and NCTCOG (Barnett)	ENVIRON Colorado Report	MOVES Model
Light Duty Trucks	On-Road	ENVIRON Colorado Report	Railroad Commission	MOVES Model
	Idling	ENVIRON Colorado Report	ENVIRON Colorado Report	EPA based on MOVES model

1.11 Quality Check/Quality Assurance

"An overall QA program comprises two distinct components. The first component is that of quality control (QC), which is a system of routine technical activities implemented by inventory development personnel to measure and control the quality of the inventory as it is being developed. The QC system is designed to:

1. Provide routine and consistent checks and documentation points in the inventory development process to verify data integrity, correctness, and completeness;
2. Identify and reduce errors and omissions;
3. Maximize consistency within the inventory preparation and documentation process; and
4. Facilitate internal and external inventory review processes.

QC activities include technical reviews, accuracy checks, and the use of approved standardized procedures for emission calculations. These activities should be included in inventory development planning, data collection and analysis, emission calculations, and reporting."[36]

Equations, data sources, and methodology will be check throughout the development of the emission inventory. "Simple QA procedures, such as checking calculations and data input, can and should be implemented early and often in the process. More comprehensive procedures should target:

- Critical points in the process;
- Critical components of the inventory; and
- Areas or activities where problems are anticipated"[37]

Special emphases will be put on critical components, such as drill rigs and hydraulic fracturing pumps, for quality checks. Eagle Ford data developed through the emission inventory process will be compared to previous data sets from other shale oil and gas emission inventories.

When errors and omissions are identified they will be correct immediately and all documentation will be updated with the corrections. All emission inventory calculation methodology will be documented and described in detail so external officials and other interested parties can replicate the results. For every emission inventory source, documentation will be consistent and will contain data sources, methodology, formulas, and results. When the emission inventory is completed, documentations and spreadsheets will be sent to local industry, TCEQ, and other interested parties for review. Categories indicating major differences between the inventories are flagged for review. Reviews of the methodologies used in the different inventories will be conducted for these flagged categories. Documentation will be provided describing reasons for choosing a particular method. Sample size, sources, and statistical significance of the surveys will be calculated and documented. From the surveys, profiles may be established to estimate emissions for the inventory area.

1.12 Timeline and Data Availabilitity

The Eagle Ford emission inventory will be provided in an organized electronic format that can be readily incorporated into photochemical models. Once the inventory protocol is approved, the final Eagle Ford emission inventory will be completed.

[36] Eastern Research Group, Inc, Jan. 1997. "Introduction: The Value of QA/QC'. Quality Assurance Committee Emission Inventory Improvement Program, U.S. Environmental Protection Agency. p. 1.2-1. Available online: http://www.epa.gov/ttn/chief/eiip/techreport/volume06/vi01.pdf. Accessed 06/04/2012.

[37] *Ibid*., p. 1.2-2.

2 PREVIOUS STUDIES

2.1 Barnett Shale Area Special Inventory

TCEQ conducted a two phase ozone precursor emission survey of Barnett Shale operations. As part of the first phase, TCEQ's Emissions Assessment Section (EAS) conducted a special inventory "to determine the location, number, and type of emissions sources located at upstream and midstream oil and gas operations associated with the Barnett Shale formation. As of June 16, 2010, the TCEQ has received special inventory data from companies that account for more than 99 percent of the 2009 production in the Barnett Shale formation. Specifically, data for 9,123 upstream leases/facilities and 519 midstream sites/facilities has been received. It should be noted that midstream sites/facilities process or transport gas from formations other than the Barnett Shale formation".[38]

In phase two, the TCEQ requested companies to provide air emissions data and related information for calendar year 2009. The inventory collected data on "equipment and production information for emission sources associated with Barnett Shale oil and gas production, transmission, processing and related activities; air emissions authorizations for these sources; coordinates of sources located within one-quarter mile of the nearest receptor; and annual 2009 emissions for nitrogen oxides, volatile organic compounds, and hazardous air pollutants."[39] The survey was sent to all companies that had calendar year 2009 operations from the Barnett Shale formation included oil and gas production, transmission, processing, and related activities such as saltwater disposal.[40]

Through this process, TCEQ collected detailed information on production and midstream emission sources in the Barnett Shale including data on compressors, storage tanks, loading fugitives, production fugitive, heaters, and other sources. The special inventory will provide the parameters for calculating emissions from compressor engine, storage tanks, heaters, and fugitive emissions in the Eagle Ford. The survey did not collected emissions from pad construction, drilling, hydraulic fracturing, completion, and on-road vehicles. These sources can emit significant amounts of ozone precursor emissions. The special inventory relies on the companies to report all sources and emissions from production. Since the study is based on dry gas shale, operations are significantly different for condensate and oil production in the Eagle Ford. Also, the results from the survey are based on calendar year 2009. Development, processes, and operations may have changed since because the industry is rapidly developing to increase production from shale plays across the United States.

2.2 Texas Center for Applied Technology (TCAT) Eagle Ford Survey

Eagle Ford emission inventory development process will review data gathered from a limited on-site survey conducted by the Texas Center for Applied Technology (TCAT) at Texas A&M University System with funds from the Research Partnership to Secure Energy for America (RPSEA). A team of environmental engineers and scientists with Texas A&M University (TAMU) "planned, coordinated, and traveled to a site in the Eagle-Ford area near

[38] TCEQ, Dec. 30, 2011. "Point Source Emissions Inventory". Austin, Texas. Available online: http://www.tceq.texas.gov/airquality/point-source-ei/psei.html. Accessed: 04/09/2012.
[39] *Ibid*.
[40] Julia Knezek, Emissions Inventory Specialist Air Quality Division, TCEQ, October 12, 2010. "Barnett Shale Phase Two, Special Inventory Workbook Overview". Presented to Assistance Workshop, Will Rogers Memorial Center. Available online: http://www.tceq.state.tx.us/assets/public/implementation/air/ie/pseiforms/workbookoverviewrevised.pdf. Accessed. 042/07/2012.

Laredo, Texas to begin work on a project to collect air emissions data and to begin developing a methodology for estimating/measuring emissions from the natural gas production process. In this effort, TCAT teamed with the TAMU Global Petroleum Research Institute (GPRI) and the TAMU Energy Engineering Institute (EEI). This project was conducted as part of the Environmentally Friendly Drilling (EFD) Program managed by the Houston Advance Research Center (HARC) in partnership with TAMU."[41]

Graduate students observed and record operations, schedules, and equipment types at a hydraulic fracturing site in the Eagle Ford. Well site managers also participated in the survey to determine if operations are typical for each well site the company drills or owns. Since the TCAT survey was only conducted at one well pad for two wells, the results are not statistically significant. Further on the ground surveys are planned, but may not be completed in time to be incorporated into the Eagle Ford emission inventory. Activity data and engine characteristics from hydraulic fracturing survey are compared to other studies.

2.3 Characterization of Oil and Gas Production Equipment and Develop a Methodology to Estimate Statewide Emissions

The purpose of ERG emission inventory was to "identify and characterize area source emissions from upstream onshore oil and gas production sites that operated in Texas in 2008 and to develop a 2008 base year air emissions inventory from these sites."[42] The study found that the main source of NO_X emissions from oil and gas production are compressor engines, while the main source of VOC emissions are oil and condensate storage tanks.[43]

"In addition to compiling the emissions inventory, other objectives of this project were to identify the emission source types operating at oil and gas production sites, to develop a methodology for estimating area source emissions from oil and gas production sites based on the oil and gas produced at the county level, to develop survey materials that may be used to obtain detailed information needed to estimate emissions, and to identify the producers of oil and gas for each county."[44] The emission inventory only included emission sources from production such as lifts, storage tanks, fugitives, loading fugitives, heaters, compressors, well completion, and pneumatic pumps. Data from this report will be used to compare results from other studies.

2.4 Drilling Rig Emission Inventory for the State of Texas

ERG developed "a comprehensive emissions inventory for drilling rig engines associated with onshore oil and gas exploration activities occurring in Texas in 2008. During the data collection phase of this project, information was solicited from respondents regarding fracturing activities." "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

[41] Texas Center for Applied Technology (TCAT), Nov. 2011. "Environmentally Friendly Drilling Systems Program Hydraulic Fracturing Phase Emissions Profile (Air Emissions Field Survey No. 1)". San Antonio, Texas. p. 2.
[42] Mike Pring, Daryl Hudson, Jason Renzaglia, Brandon Smith, and Stephen Treimel, Eastern Research Group, Inc. Nov. 24, 2010. "Characterization of Oil and Gas Production Equipment and Develop a Methodology to Estimate Statewide Emissions". Prepared for: Texas Commission on Environmental Quality Air Quality Division. Austin, Texas. p. iv. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820784003FY1026-20101124-ergi-oilGasEmissionsInventory.pdf. Accessed: 04/10/2012.
[43] *Ibid*., pp. v-vi.
[44] *Ibid*.. p. v.

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 generalized to the inventory as a whole."[45]

"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 phone and email surveys, ERG obtained 45 drilling rig profiles representative of over 1,500 wells drilled in Texas in 2008."[46] Although this is an excellent study on drill rig operations, activity rates, horsepower, and engine operations has significantly changed since this report was completed and the results cannot be used to estimate current drill rig emissions. The report did not provide a specific breakdown for drilling activities in the Eagle Ford or other shales in Texas. ERG recently updated this report on August 12, 2011 and projected the emissions to 2040.[47]

2.5 Development of an Emission Inventory for Natural Gas Exploration and Production in the Haynesville Shale and Evaluation of Ozone Impacts

One of the few shale gas emission inventories that analyzed emissions in a photochemical modeling is ENVIRON's report on the Haynesville shale. In the report "an emission inventory of NO_X, VOC and CO for Haynesville Shale natural gas exploration and production activities was developed."[48] Emission inventory categories included drill rigs, hydraulic fracturing, completion, compressor engines, other production emissions, and midstream sources.

"Well production data, the historical record of activity in the nearby Barnett Shale and other available literature were used to project future activity in the Haynesville Shale. Future year annual natural gas production for the years 2009-2020 was estimated for three scenarios corresponding to aggressive, moderate, and limited development of the Haynesville Shale. Constraints on available infrastructure and potential variability in well productivity and economics were also considered. Activity/equipment data from other oil and gas emission inventory studies were used to develop an emission inventory for ozone precursors for each of the three production scenarios."[49] When put into the May-June 2005 photochemical model, the maximum increase in 8-hour ozone was 8.9 ppb under the low scenario and 16.7 ppb under the high scenario.[50]

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[45] Eastern Research Group, Inc. July 15, 2009. "Drilling Rig Emission Inventory for the State of Texas". Prepared for: Texas Commission on Environmental Quality. Austin, Texas. p. 1-1. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820783985FY0901-20090715-ergi-Drilling_Rig_EI.pdf. Accessed: 04/09/2012.

[46] *Ibid*. p. 1-1.

[47] ERG, August 15, 2011. "Development Of Texas Statewide Drilling Rigs Emission Inventories For The Years 1990, 1993, 1996, And 1999 Through 2040". Austin, Texas. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5821199776FY1105-20110815-ergi-drilling_rig_ei.pdf. Accessed 09/21/2012.

[48] John Grant, Lynsey Parker, Amnon Bar-Ilan, Sue Kemball-Cook, and Greg Yarwood, ENVIRON International Corporation. August 31, 2009. "Development of an Emission Inventory for Natural Gas Exploration and Production in the Haynesville Shale and Evaluation of Ozone Impacts". Novato, CA. Available online: http://www.netac.org/UserFiles/File/NETAC/9_29_09/Enclosure_2b.pdf. Accessed: 04/19/2012.

[49] *Ibid*.

[50] Susan Kemball-Cook, Amnon Bar-Ilan, John Grant, Lynsey Parker, Jaegun Jung, Wilson Santamaria, and Greg Yarwood, ENVIRON. September 28, 2010. "An Emission Inventory for Natural

Unfortunately, there was little local data used to estimate emissions in the study because there was no industry participation in the report. The activity levels and load factors for drill rigs maybe over estimated and horsepower needed for hydraulic fracturing is under estimated. In contrast to the future projection developed by ENVIRON, drilling and hydraulic fracturing activities have decline in the Haynesville Shale formation because of the decrease in natural gas prices and drilling operations moving to the more profitable Eagle Ford shale. Since the Eagle Ford has significant deposits of crude oil and condensate, procedures, activity rates, engine characteristics, and production can be significantly different.

2.6 City of Fort Worth Natural Gas Air Quality Study

"The city of Fort Worth is home to extensive natural gas production and exploration as it lies on top of the Barnett Shale, a highly productive natural gas shale formation in north-central Texas. As the Barnett Shale formation is located beneath a highly populated urban environment, extraction of natural gas from it has involved exploration and production operations in residential areas, near public roads and schools, and close to where the citizens of Fort Worth live and work. Due to the highly visible nature of natural gas drilling, fracturing, compression, and collection activities, many individual citizens and community groups in the Fort Worth area have become concerned that these activities could have an adverse effect on their quality of life. In response to these concerns, on March 9, 2010, the Fort Worth City Council adopted Resolution 3866-03-2010 appointing a committee to review air quality issues associated with natural gas exploration and production. This committee was composed of private citizens, members of local community groups, members of environmental advocacy groups, and representatives from industry. The committee was charged to make recommendations to the City Council on a scope of work for a comprehensive air quality assessment to evaluate the impacts of natural gas exploration and production, to evaluate proposals submitted in response to a solicitation for conducting this study, and to ultimately choose a qualified organization to conduct the study."[51]

Emission source testing was conducted by EGR "to determine how much air pollution is being released by natural gas exploration in Fort Worth, and if natural gas extraction and processing sites comply with environmental regulations. The point source testing program occurred in two phases, with Phase I occurring from August through October of 2010, and Phase II occurring in January and February of 2011. Under the point source testing program, field personnel determined the amount of air pollution released at individual well pads, compressor stations, and other natural gas processing facilities by visiting 388 sites, includes two repeat visits, and testing the equipment at each site for emissions using infrared cameras, toxic vapor analyzers (TVAs), Hi Flow Samplers, and evacuated canisters to collect emission samples for laboratory analysis.[52] The sites visited included 375 wells pads, 1 drilling operation, 1 hydraulic fracturing operation, 1 completion operation, 8 compressor stations, 1 processing facility, and 1 saltwater treatment facility.[53]

FLIR™ infrared cameras were used to survey all equipment in natural gas service at each

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Gas Development in the Haynesville Shale and Evaluation of Ozone Impacts." Presented at the 19th International Emission Inventory Conference. Slide 16. Available online: http://www.epa.gov/ttnchie1/conference/ei19/session2/kemball_cook_pres.pdf. Accessed 06/04/2012.

[51] Eastern Research Group Inc. July 13, 2011. "Fort Worth Natural Gas Air Quality Study Final Report". Prepared for: City of Fort Worth, Fort Worth, Texas. p. xii. Available online: http://fortworthtexas.gov/gaswells/?id=87074. Accessed: 04/09/2012.

[52] *Ibid*., p. 3-98

[53] *Ibid*. pp. 3-3 – 3-4.

point source site visited.[54] "Emissions were only estimated from piping and instrumentation equipment leaks, storage tanks, and compressors, which contribute the majority of emissions from natural gas-related facilities. Other sources of emissions, including but not limited to, storage tank breathing and standing losses, glycol dehydrator reboiler vents, wastewater and/or condensate loading, and flaring were not calculated."[55] Sampling of drilling and hydraulic fracturing operation was not statistically significant because only one site of each was surveyed.

2.7 Other Studies

ENVIRON improved the "oil and gas area source inventories for the 2002 base year and 2018 future year for the entire Central States Regional Air Partnership (CENRAP) region, encompassing the oil and gas producing states of Texas, Louisiana, Oklahoma, Arkansas, Kansas, and Nebraska" in a 2008 report. The work consisted of three principal tasks: identification of major CENRAP basins, literature review and limited industry survey of oil and gas production, and develop recommendations. A detailed set of data was developed "to aid CENRAP and each individual CENRAP state DEQ in generating improved emissions inventory calculations for oil and gas area sources within the CENRAP domain". The calculation methodologies and input data developed "are intended for broad, regional inventories of oil and gas and therefore contain some broad assumptions to make these regional emissions inventory calculations tractable."[56]

An oil and gas mobile sources pilot study also conducted by ENVIRON to provided "an emission inventory of criteria pollutants from mobile sources associated with onshore oil and gas development in the Piceance Basin of Northwestern Colorado. This study builds on several past inventory projects that have examined emissions from oil and gas development activities both in the Piceance Basin and in the Intermountain West generally." "This study attempts to estimate these emissions and compare them to the existing point and area source inventories in the Rocky Mountain region. Survey forms were developed requesting detailed data on off-road equipment and on-road vehicles used for various phases of oil and gas production, including well construction, well drilling, well completions (including fracturing), and production operations".[57]

Other on-road mobile emission inventories include NCTCOG "study to assess truck traffic in the Barnett Shale. The goal of this effort is to gather information regarding potential air quality and roadway impacts from on-road sources associated with natural gas drilling and extraction. This data will help improve the accuracy of transportation and air quality modeling. It will also help determine whether there is a need for future funding to help reduce ozone-forming pollution, which would assist efforts to comply with federal air quality standards or address road maintenance needs. As part of this project, NCTCOG is requesting feedback from industry participants, including natural gas operators and truck

[54] *Ibid*. pp. 3-7 – 3-9.
[55] *Ibid*. p. 3-23.
[56] Amnon Bar-Ilan, Rajashi Parikh, John Grant, Tejas Shah, Alison K. Pollack, ENVIRON International Corporation. Nov. 13, 2008. "Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories". Novato, CA. p. 62-63. Available online: http://www.wrapair.org/forums/ogwg/documents/2008-11_CENRAP_O&G_Report_11-13.pdf. Accessed: 04/30/2012.
[57] Amnon Bar-Ilan, John Grant, Rajashi Parikh, Ralph Morris, ENVIRON International Corporation, July 2011. "Oil and Gas Mobile Sources Pilot Study". Novato, California. p. ES1. Available online: http://www.wrapair2.org/documents/2011-07_P3%20Study%20Report%20(Final%20July-2011).pdf. Accessed: 04/12/2012.

contractors. NCTCOG study on trucking emission in the Barnett is schedule to be completed August 2012."[58]

An evaluation of upstream oil and gas storage tank project flash emissions models were conducted by Hy-Bon Engineering Company from July to September 2008. They reported the results of a six month study to determine the VOC emissions from oil and condensate storage facilities with production rates between 10 to 1,979 barrels per day. Flow measurements were conducted at each test site to determine the total vented tank emission rate. Total flow measurements were made at twenty-three of the sites was in West Texas and thirteen sites in North Texas.[59]

Another study of upstream oil and gas tank emission measurements, conducted by ENVIRON in July 2010, measured "emission rates of volatile organic compounds (VOC) from breathing, working, and flash loss emissions from tank batteries at designated sites located in the Dallas-Fort Worth (DFW) area. Tank vent gas samples were collected and analyzed in order to determine tank-specific product compositions and component concentrations. VOC emission rates from the tank battery were continuously measured over 24-hour periods. Liquid samples were collected from the pressurized separators at the tank batteries and analyzed for input to Exploration and Production (E&P) TANK software.[60]

Al Armendariz wrote an emission inventory on natural gas production in the Barnett shale area and listed opportunities for cost-effective improvements. "Emission sources from the oil and gas sector in the Barnett Shale area were divided into point sources, which included compressor engine exhausts and oil/condensate tanks, as well as fugitive and intermittent sources, which included production equipment fugitives, well drilling and fracing engines, well completions, gas processing, and transmission fugitives. The air pollutants considered in this inventory were smog-forming compounds (NO_X and VOC), greenhouse gases, and air toxic chemicals."[61]

Cornell University's report on the "Indirect Emissions of Carbon Dioxide from Marcellus Shale Gas Development" provides an estimation of emissions "associated with the shale gas life-cycle focusing on the Marcellus shale as a case study". The report calculates "all GHG emissions from land clearing, resource consumption, and diesel consumed in internal-combustion engines (mobile and stationary) during well development."[62] The report gives

[58] North Central Texas Council of Governments. "Barnett Shale Truck Traffic Survey". Dallas, Texas. Available online: http://www.nctcog.org/trans/air/barnettshale.asp. Accessed 05/04/2012.
[59] Butch Gidney and Stephen Pena, Hy-Bon Engineering Company, Inc., July 16, 2009. "Upstream Oil and Gas Storage Tank Project Flash Emissions Models Evaluation". Midland, Texas. p. 5. Available online: http://www.bdlaw.com/assets/attachments/TCEQ%20Final%20Report%20Oil%20Gas%20Storage%20Tank%20Project.pdf. Accessed: 04/25/2012.
[60] ENVIRON International Corporation, August 2010. "Upstream Oil and Gas Tank Emission Measurements TCEQ Project 2010 – 39". Prepared for: Texas Commission on Environmental Quality, Austin, Texas. p. 1. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820784004FY1025-20100830-environ-Oil_Gas_Tank_Emission_Measurements.pdf. Accessed: 04/12/2012.
[61] Al Armendariz. Jan. 26, 2009. "Emissions from Natural Gas Production in the Barnett Shale Area and Opportunities for Cost-Effective Improvements". Prepared for Environmental Defense Fund. Austin, Texas. Available Online: http://www.edf.org/sites/default/files/9235_Barnett_Shale_Report.pdf. Accessed: 04/19/2012.
[62] Santoro, R.L.; R.W. Howarth; A.R. Ingraffea. 2011. Indirect Emissions of Carbon Dioxide from Marcellus Shale Gas Development. A Technical Report from the Agriculture, Energy, & Environment Program at Cornell University. June 30, 2011. p. ii. Available online:

detailed data on the activity rates, engine characteristics, and population of on-road and non-road equipment used during well construction.

A report was developed "to assist the EPA Office of Policy, Economics, and Innovation (OPEI) in assessing environmental impacts associated with oil and gas production in Region 8." According to the report, "unconventional oil and gas resources generally require more wells, greater energy and water consumption, and more extensive production operations per unit of gas recovered than conventional oil and gas resources, due to factors such as closer well spacing and greater well service traffic."[63] Other emission inventories of oil and gas production include "Tumbleweed II Exploratory Natural Gas Drilling Project" in Utah[64] and "Pinedale Anticline Project" in Wyoming.[65] TCEQ developed a "2007 Southeast Texas Compressor and Dehydrator Survey"[66] and DFW Compressor Engine Project that provided ambient measurements downwind of gas compressor engines.

http://www.eeb.cornell.edu/howarth/IndirectEmissionsofCarbonDioxidefromMarcellusShaleGasDevelopment_June302011%20.pdf Accessed: 04/02/2012.

[63] EPA Region 8, Sept. 2008. "An Assessment of the Environmental Implications of Oil and Gas Production: A Regional Case Study" Working Draft. pp. ES1-ES3. Available online: http://www.epa.gov/sectors/pdf/oil-gas-report.pdf. Accessed: 05/02/2012.

[64] U.S. Department of the Interior, Bureau of Land Management. June 2010. "Tumbleweed II Exploratory Natural Gas Drilling Project". East City, Utah. DOI-BLM-UTG010-2009-0090-EA. Available online: http://www.blm.gov/pgdata/etc/medialib/blm/ut/lands_and_minerals/oil_and_gas/november_2011.Par.24530.File.dat/. Accessed: 04/12/2012.

[65] U.S. Department of the Interior, Bureau of Land Management, Sept. 2008. "Final Supplemental Environmental Impact Statement for the Pinedale Anticline Oil and Gas Exploration and Development Project: Pinedale Anticline Project Area Supplemental Environmental Impact Statement". Sheyenne, Wyoming. Available online: http://www.blm.gov/wy/st/en/info/NEPA/documents/pfo/anticline/seis.html. Accessed: 04/12/2012.

[66] TCEQ. "Area-Source Emissions: Southeast Texas Survey of Compressor Engines and Dehydrators". Available online: http://tceq.texas.gov/airquality/areasource/ASEI.html?force_web. Accessed 06/05/2012.

3 EXPLORATION AND PAD CONSTRUCTION

3.1 Seismic Exploration

According to Chesapeake Energy, sesismic exploration is "an investment in subsurface information, lowers risk, provides confident geologic information, and leads to greater drilling accuracy"[67] "Seismic exploration helps scientist pinpoint ideal drilling locations within oil and natural gas reservoirs." "Seismic field data is used to generate 3-D pictures of underground formations and geologic features. These images allow geophysicists and geologists to study the composition of underground formations in a particular area."[68]

Seismic imaging uses an energy source, such as vibrator trucks, to produce sound waves beneath the surface that are useful in the exploration for oil and natural gas. "The images generated through this process can be used to estimate the probability of producing formations and their characteristics. As a result, this technology has raised the success rate of exploration efforts by ensuring more accurate placement of drill sites, resulting in more productive wells".[69] In the Eagle Ford, "three to four vibe trucks will travel to a specific location where the lines of geophones have been installed" and stay at each site for only a few hours.[70]

Figure 3-1: Seismic Survey Vibration Truck or Vibroseis Vehicle in the Eagle Ford shale play[71]

[67] Chesapeake Energy, Oct. 20, 2011. "Barnett Shale Natural Gas Exploration and Production Primer". Presented at the National NGV Conference – Summit. Available online: http://www.cleanvehicle.org/conference/2011/images/ANGA-NGVA.pdf. Accessed: 04/23/2012.
[68] *Ibid*.
[69] Chesapeake Energy, 2012. "Seismic Exploration". Available online: http://www.askchesapeake.com/Eagle-Ford-Shale/About/Pages/Seismic-Exploration.aspx. Accessed: 03/27/2012.
[70] Marathon Oil Corporation. "Eagle Ford: Oil and Natural Gas Fact Book". Available online: http://www.marathonoil.com/content/documents/news/eagle_ford_fact_book_final.pdf. Accessed: 04/23/2012.
[71] The Eagle Ford Shale Blog. Sept. 26, 2011. "Photos of Eagle Ford Shale Oil Wells". Available online: http://eaglefordshaleblog.com/photos-of-eagle-ford-shale-activity/. Accessed: 04/02/2012.

Equation 3-1 will be used to calculate emissions from seismic trucks operation in the Eagle Ford.

Equation 3-1, Ozone season day seismic trucks emissions

$E_{Seismic.BC}$ = (NUM_{BC} / $WPAD_B$) x POP x HP x HRS x LF x EF / 907,184.74 grams per ton / 365 days/year

Where,

$E_{Seismic.BC}$ = Ozone season day NO_X, VOC, or CO emissions from seismic trucks in county B for Eagle Ford development well type C (gas or oil)

NUM_{BC} = Number of wells drilled in county B for Eagle Ford development well type C, from Table 4-1 (from Schlumberger Limited)

$WPAD_B$ = Number of Wells per Pad for county B, Table 3-2 (calculated from data provided by the Railroad Commission of Texas)

POP = Number of seismic trucks, 3 (from Marathon Oil Corporation in the Eagle Ford)

HP = Average horsepower seismic trucks, 400hp (based on average hp of seismic trucks from Equipment Manufactures)

HRS = Hours per pad construction, 2 hours per well pad (from Marathon Oil Corporation in the Eagle Ford)

LF = Load factor for off road trucks, 0.59 (from TexN Model)

EF = Emission factor for off road trucks, 3.713 g/hp-hr for NO_X, 0.238 g/hp-hr for VOC, or 1.222 g/hp-hr for CO (from TexN Model)

3.2 Well Pad Construction

3.2.1 Well Pad Construction Process

According to Marathon Oil, "once the wellsite has been identified and an access agreement has been signed, an area of land is cleared so that drilling, construction and production traffic can enter the site. As part of the clearing process, topsoil is removed and typically stored on site for use in the reclamation of the pad at a later date."[72] "The drill pad accommodates the drill rig, support trucks, waste storage, worker housing, fluid tanks, field office, generators, pumps and other necessary equipment. Construction of the drill pad typically requires clearing, grubbing, and grading, followed by placement of a base material (e.g., crushed stone)."[73]

Reserve pits are also usually required at each well pad because "the drilling process uses a large volume of drilling fluid that is circulated through the drill pipe and drill bit, then back to the surface. As the fluid returns to the surface, it carries the ground-up rock particles (drill cuttings). Some operators also construct separate auxiliary pits that collect fluids that fall onto the area directly beneath the rig."[74] "The pit can be about 200 yards wide and, and

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[72] Marathon Oil Corporation. "Eagle Ford: Oil and Natural Gas Fact Book". Available online: http://www.marathonoil.com/content/documents/news/eagle_ford_fact_book_final.pdf. Accessed: 04/23/2012.

[73] Haxen and Sawyer, Environmental Engineers & Scientists, Sept. 2009. "Impact Assessment of Natural Gas Production in the New York City Water Supply Watershed Rapid Impact Assessment Report" New York City Department of Environmental Protection. p. 27. Available online: http://www.nyc.gov/html/dep/pdf/natural_gas_drilling/rapid_impact_assessment_091609.pdf. Accessed: 04/20/2012.

[74] University of Arkansas and Argonne National Laboratory. "Fayetteville Shale Natural Gas: Reducing Environmental Impacts: Site Preparation". Available online: http://lingo.cast.uark.edu/LINGOPUBLIC/natgas/siteprep/index.htm. Accessed: 04/20/2012.

about 20-40 feet deep, may be dug to hold waste from the digging and later from the hydrofracturing."[75]

To build the pad sites and remove trees, heavy equipment is used including bulldozers, gravel trucks, and rollers. Chesapeake Energy states that the "typical horizontal well pad requires ~5 acres to construct (not including fresh water impoundments and access roads)"[76] and takes 4-6 weeks to complete[77]. BHP Billiton Petroleum (Petrohawk) found that "setting up a well site takes 2-4 weeks and includes: Construction of roads for the transport of heavy equipment such as the drill rig, leveling of the site, structures for erosion control, construction of lined pits to hold drilling fluids and drill cuttings, and placement of racks to hold the drill pipe and casing strings."[78] In the Marcellus Shale Play, there was 7.4 acres per pad including roads and utility corridors based on 1,108 horizontal well pads and 8,197 acres of total land disturbance for horizontal drilling.[79]

3.2.2 Non-Road Equipment Used During Well Pad Construction

The methodology proposed to estimation emissions from non-road equipment used during well pad construction incorporates information on equipment type, equipment population, horsepower, and activity data from previous studies. Several studies have estimated the amount, size, and time it takes to construct well pads (Table 3-1). A Cornell University study in the Marcellus determine the equipment needed to clear the land and construct the well pad was 6 grading dozers and 1 large excavator employed in clearing the well site over 3 days at 12 hours per day.[80] San Juan Public Lands Center had similar results for the activity hours it takes for pad construction, but the equipment types are different.

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[75] Jennifer J. Halpern. "What to expect in your Back 40.... An Incomplete Description of What Landowners can Expect when the Marcellus Natural Gas Drills Arrive". Available online: http://www.museumoftheearth.org/outreach.php?page=92387/846957/back_40. Accessed: 04/12/2012.

[76] Chesapeake Energy. "Chesapeake Energy Shale Operations Overview Pennsylvania". Available online: http://www.brightontwp.org/documents/ChesapeakeEnergy.pdf. Accessed: 04/20/2012.

[77] Chesapeake Energy, Oct. 11. "Marcellus Shale Natural Gas Development & Production". Slide 7. Available online: http://www.repbear.com/Display/SiteFiles/58/OtherDocuments/97_ChesapeakePowerPoint.pdf. Accessed: 04/12/2012.

[78] J. Michael Yeager, Group Executive and Chief Executive, Petroleum, Nov. 14, 2011. "BHP Billiton Petroleum Onshore US Shale Briefing". Available online: http://www.bhpbilliton.com/home/investors/reports/Documents/2011/111114_BHPBillitonPetroleumInvestorBriefing_Presentation.pdf. Accessed: 04/12/2012.

[79] All Consulting, Sept. 16, 2010. "NY DEC SGEIS Information Requests". Prepared for Independent Oil & Gas Association, Project no.: 1284. Available online: http://catskillcitizens.org/learnmore/20100916IOGAResponsetoDECChesapeake_IOGAResponsetoDEC.pdf. Accessed: 04/16/2012.

[80] Santoro, R.L.; R.W. Howarth; A.R. Ingraffea. 2011. Indirect Emissions of Carbon Dioxide from Marcellus Shale Gas Development. A Technical Report from the Agriculture, Energy, & Environment Program at Cornell University. June 30, 2011. p. 8. Available online: http://www.eeb.cornell.edu/howarth/IndirectEmissionsofCarbonDioxidefromMarcellusShaleGasDevelopment_June302011%20.pdf. Accessed: 04/02/2012.

Table 3-1: Non-Road Pad Construction Parameters from Previous Studies

Para-meters	TexN Model (Texas)	TexN Model (Eagle Ford Counties)	Cornell University, Marcellus Study	San Juan Public Lands Center, Colorado	ENVIRON Colorado	ENVIRON Southern Ute[81]	Jonah Infill, Wyoming	Tumble-weed II, Utah	Buys & Associates, Utah	Pinedale Anticline Project, Wyoming
Count per Site	Dozer		6	**1**	4	1	1	1	1	1
	Excavator		1	**-**		-	-	-	-	-
	Scraper		-	**2**		-	2	-	-	2
	Grader		-	**1**		1	1	1	1	1
	Backhoe		-	**-**		1	-	1	1	1
	Loader		-	**-**		-	-	-	1	1
	Roller		-	**-**		-	-	-	-	1
	Water Truck		-	**-**		-	-	-	-	1
	Dump Truck		-	**-**		-	-	-	-	1
Horse-power	Dozer	248	335	**210**	764.3 total HP	150	210	686	150	300
	Excavator	197	159	**-**		-	-	-	-	-
	Scraper	591	-	**700**		-	700	-	-	600
	Grader	170	-	**250**		135	250	158	135	300
	Backhoe	67	-	**-**		70	-	129	100	100
	Loader	152	-	**-**		-	-	-	150	200
	Roller	87	-	**-**		-	-	-	-	200
	Water Truck	908	-	**-**		-	-	-	-	210
	Dump Truck	908	-	**-**		-	-	-	-	330
Hours	Dozer		36	**40**	21.2 / equipment	24	40	100	140	104
	Excavator		36	**-**		-	-	-	-	-
	Scraper		-	**40**		-	40	-	-	104
	Grader		-	**40**		24	40	100	140	114
	Backhoe		-	**-**		24	-	100	140	76
	Loader		-	**-**		-	-	-	140	76
	Roller		-	**-**		-	-	-	-	95
	Water Truck		-	**-**		-	-	-	-	114
	Dump Truck		-	**-**		-	-	-	-	57

[81] ENVIRON, August 2009. "Programmatic Environmental Assessment for 80 Acre Infill Oil and Gas Development on the Southern Ute Indian Reservation". Novato, California. Appendix A, p. 63. Available online: http://www.suitdoe.com/Documents/Appendix_G_AirQualityTSD.pdf. Accessed: 04/25/2012.

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Para-meters	TexN Model (Texas)	TexN Model (Eagle Ford Counties)	Cornell University, Marcellus Study	San Juan Public Lands Center, Colorado	ENVIRON Colorado	ENVIRON Southern Ute[82]	Jonah Infill, Wyoming	Tumble-weed II, Utah	Buys & Associates, Utah	Pinedale Anticline Project, Wyoming
Fuel Type	Dozer	Diesel	Diesel	**Diesel**	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel
	Excavator	Diesel	Diesel	**-**		-	-	-	-	-
	Scraper	Diesel	-	**Diesel**		-	Diesel	-	-	Diesel
	Grader	Diesel	-	**Diesel**		Diesel	Diesel	Diesel	Diesel	Diesel
	Backhoe	Diesel	-	**-**		Diesel	-	Diesel	Diesel	Diesel
	Loader	Diesel	-	**-**		-	-	-	Diesel	Diesel
	Roller	Diesel	-	**-**		-	-	-	-	Diesel
	Water Truck	Diesel	-	**-**		-	-	-	-	Diesel
	Dump Truck	Diesel	-	**-**		-	-	-	-	Diesel
Load Factor	Dozer	0.59	0.5	**0.4**		0.4	0.4	0.4	0.4	0.4
	Excavator	0.59	0.5	**-**		-	-	-	-	-
	Scraper	0.59	-	**0.4**		-	0.4	-	-	0.4
	Grader	0.59	-	**0.4**		0.4	0.4	0.4	0.4	0.4
	Backhoe	0.21	-	**-**		0.4	-	0.4	0.4	0.4
	Loader	0.59	-	**-**		-	-	-	0.4	0.4
	Roller	0.59	-	**-**		-	-	-	-	0.4
	Water Truck	0.59	-	**-**		-	-	-	-	0.4
	Dump Truck	0.59	-	**-**		-	-	-	-	0.4

82 ENVIRON, August 2009. "Programmatic Environmental Assessment for 80 Acre Infill Oil and Gas Development on the Southern Ute Indian Reservation". Novato, California. Appendix A, p. 63. Available online: http://www.suitdoe.com/Documents/Appendix_G_AirQualityTSD.pdf. Accessed: 04/25/2012.

ENVIRON only provided total equipment population, total horsepower, and average activity rates per piece of equipment in Colorado. The horsepower and activity rate to clear the pad was a little lower than the other two studies, but the results were similar.[83] Other studies on non-road equipment used during well pad construction included Tumble-weed II in Utah[84], Buys & Associates in Utah[85], and Pinedale Anticline Project in Wyoming.[86] These studies had higher activity rates, between 57 to 140 hours per piece of equipment, to clear well pads.

A dozer, 2 scrappers, and a grader will be used to estimate emissions from well pad construction in the Eagle Ford. Forty hours are needed to construct each well pad which matches Jonah Infill results in Wyoming.[87] Emissions from road construction were not included because field research in the Eagle Ford determined there was minimal road construction to the well pad site. Often the trucks just through the field without a road to the well site.

3.2.3 Emissions from Well Pad Construction

Since there can be multiple wells on one well pad, it is important to determine the number of wells per pad in the Eagle Ford. By drilling multiple wells on a pad, the amount of construction equipment needed to prepare the pad for each well is reduced. Although Statoil uses 4-8 horizontal wells from each multi- well pad in the Eagle Ford,[88] Rosetta Resources is typically using three-well pad drilling,[89] Chesapeake Energy drills multiple wells

[83] Amnon Bar-Ilan, John Grant, Rajashi Parikh, Ralph Morris, ENVIRON International Corporation, July 2011. "Oil and Gas Mobile Sources Pilot Study". Novato, California. pp. 13. Available online: http://www.wrapair2.org/documents/2011-07_P3%20Study%20Report%20(Final%20July-2011).pdf. Accessed: 04/12/2012.

[84] U.S. Department of the Interior, Bureau of Land Management. June 2010. "Tumbleweed II Exploratory Natural Gas Drilling Project". East City, Utah. DOI-BLM-UTG010-2009-0090-EA. p. 6 of 29. Available online: http://www.blm.gov/pgdata/etc/medialib/blm/ut/lands_and_minerals/oil_and_gas/november_2011.Par.24530.File.dat/. Accessed: 04/12/2012.

[85] Buys & Associates, Inc., Sept. 2008. "APPENDIX J: Near-Field Air Quality Technical Support Document for the West Tavaputs Plateau Oil and Gas Producing Region Environmental Impact Statement". Prepared for: Bureau of Land Management Price Field Office Littleton, Colorado. Available online: http://www.blm.gov/ut/st/en/fo/price/energy/Oil_Gas/wtp_final_eis.html. Accessed: 04/20/2012.

[86] U.S. Department of the Interior, Bureau of Land Management, Sept. 2008. "Final Supplemental Environmental Impact Statement for the Pinedale Anticline Oil and Gas Exploration and Development Project: Pinedale Anticline Project Area Supplemental Environmental Impact Statement". Sheyenne, Wyoming. p. F42. Available online: http://www.blm.gov/pgdata/etc/medialib/blm/wy/information/NEPA/pfodocs/anticline/rd-seis/tsd.Par.13395.File.dat/07appF.pdf. Accessed: 04/12/2012.

[87] Amnon Bar-Ilan, ENVIRON Corporation, June 2010. "Oil and Gas Mobile Source Emissions Pilot Study: Background Research Report". UNC-EMAQ (3-12)-006.v1. Novato, CA. p. 16. Available online: http://www.wrapair2.org/documents/2010-06y_WRAP%20P3%20Background%20Literature%20Review%20(06-06%20REV).pdf. Accessed: 04/03/2012.

[88] Statoil. Oct. 10, 2010. "Statoil enters Eagle Ford". Available online: http://www.statoil.com/en/NewsAndMedia/News/2010/Downloads/Presentation%20Statoil%20enters%20Eagle%20Ford.pdf. Accessed: 04/12/2012.

[89] Statoil. Oct. 10, 2010. "Statoil enters Eagle Ford". Available online: http://www.statoil.com/en/NewsAndMedia/News/2010/Downloads/Presentation%20Statoil%20enters%20Eagle%20Ford.pdf. Accessed: 04/12/2012.

on a single pad[90], and Plains Exploration & Production Company (PXP) typical development plan is 2 wells per pad,[91] Dave Burnett of the Texas A & M University found that current practices typically have only 1 well per pad.[92] By examining Railroad Commission data on wells located in the Eagle Ford, there was an average of 1.4 wells per pad and the average distance to the nearest town was 13 miles (Table 3-2).[93]

Table 3-2: Distance to the Nearest Town and Number of Permitted Wells per Pad and Disposal Wells per Well Pad in the Eagle Ford by County

County	FIPS Code	Average Distance to Nearest Town (miles)	Number of Production Wells per Well Pad	Number of Disposal Wells per Well Pad
Atascosa	48013	15	1.3	1.0
Bee	48025	6	1.1	1.0
Brazos	48041	8	1.1	-
Burleson	48051	5	1.0	-
DeWitt	48123	6	1.4	1.0
Dimmit	48127	10	1.9	1.6
Fayette	48149	N/A	1.1	1.0
Frio	48163	16	1.1	1.2
Gonzales	48177	10	1.2	1.3
Grimes	48185	7	1.0	1.0
Houston	48225	N/A	1.0	1.0
Karnes	48255	6	1.3	1.1
La Salle	48283	12	1.4	1.4
Lavaca	48285	3	1.1	-
Lee	48287	7	1.0	-
Leon	48289	5	1.1	1.0
Live Oak	48297	15	1.1	-
Madison	48313	N/A	1.1	-
McMullen	48311	9	1.3	1.0
Maverick	48323	19	1.0	-
Milam	48331	2	1.1	-
Washington	48477	N/A	1.0	-
Webb	48479	32	1.4	3.0
Wilson	48493	10	1.1	-
Zavala	48507	10	1.2	-
Average		13	1.4	1.4

N/A – Data not available from the Railroad Commission files and there are few Eagle Ford wells in these counties. The average distance, 13 miles, will be used for counties without data.

Existing data in the TexN Model will be used to calculate emission factors for non-road equipment used by pad construction (Table 3-3). The TexN Model run specifications are:

- Analysis Year = 2011

[90] Chesapeake Energy, Feb. 17, 2012. "Chesapeake Energy Corporation". presented at Greater San Antonio Chamber of Commerce – Energy & Sustainability Committee.
[91] PXP - Plains Exploration & Production Company, Nov. 15, 2011. "Plains Exploration & Production Company - Shareholder/Analyst Call". Available online: http://seekingalpha.com/article/310040-plains-exploration-production-company-shareholder-analyst-call. Accessed: 04/15/2012.
[92] GE Oil & Gas, Sept. 23, 2010. "Environmentally Friendly Drilling: European Workshop".– Florence Learning Center. Available online: http://www.efdsystems.org/Portals/25/Report%202.pdf. Accessed: 04/15/2012.
[93] Data files provided by the Railroad Commission of Texas, Austin, Texas.

- Max Tech. Year = 2011
- Met Year = Typical Year
- Period = Annual
- Summation Type = Annual
- Post Processing Adjustments = All
- Rules Enabled = All
- Regions = Atascosa, Bee, Brazos, Burleson, De Witt, Dimmit, Edwards, Frio, Gonzales, Grimes, Houston, Karnes, La Salle, Lavaca, Lee, Leon, Live Oak, Maverick, Mcmullen, Milam, Webb, Wilson, Wood, Zavala Counties
- Sources = Equipment used at upstream and midstream oil and natural gas sites

Table 3-3: TexN 2011 Emission Factors and Parameters for Non-Road Equipment used during Pad Construction

Equipment Type	SCC	NO_X EF (g/hp-hr)	VOC EF (g/hp-hr)	CO EF (g/hp-hr)
Scraper	2270002018	2.514	0.160	1.375
Grader	2270002048	3.095	0.295	1.439
Dozer	2270002069	2.895	0.240	1.503

VOC, NO_X, and CO emissions from non-road equipment used for well pad construction will be calculated using the formula provided below based on local data and engine characteristics from the San Juan Public Lands Center study in Colorado.

Equation 3-2, Ozone season day non-road emissions for well pad construction

$E_{Pad.ABC}$ = NUM_{BC} x POP_A x HP_A x HRS x LF_A x EF_A / $WPAD_B$ / 907,184.74 grams per ton / 365 days/year

Where,

$E_{Pad.ABC}$ = Ozone season day NO_X, VOC, or CO emissions from non-road equipment type A used during well pad construction in county B for Eagle Ford development well type C (gas or oil)

NUM_{BC} = Number of wells drilled in county B for Eagle Ford development well type C, from Table 4-1 (from Schlumberger Limited)

POP_A = Number of non-road equipment type A, from Table 3-1(from San Juan Public Lands Center, Colorado)

HP_A = Average horsepower for non-road equipment type A, from Table 3-1 (from San Juan Public Lands Center, Colorado)

HRS = Hours per pad, 40 hours per well pad from Table 3-1 (from San Juan Public Lands Center, Colorado)

LF_A = Load factor non-road equipment type A, from Table 3-1 (from TexN Model)

EF_A = NO_X, VOC, or CO emission factor non-road equipment type A, from Table 3-3 (from TexN Model)

$WPAD_B$ = Number of Wells per Pad for county B, Table 3-2 (calculated from data provided by the Railroad Commission of Texas)

Emission can also be calculated based on diesel consumption at the pad site, but local data on diesel consumption is not available for pad construction by equipment type.

3.3 Well Pad Construction On-Road Emissions

Heavy duty diesel trucks carry equipment and light duty trucks transport employees and supplies to the well pad. Most of the studies found between 20 and 75 heavy duty truck trips are required for pad construction, while there was a wide variation in the number of trips by light duty trucks needed for pad construction (Table 3-4). ENVIRON's report in Colorado provided detailed information on activity rates, speeds, and idling hours need for each trip. There were 22.86 trips by heavy duty vehicles and 82.46 trips by light duty trucks to construct each well pad. The study found that idling times by heavy duty trucks was 0.40 hours for each trip and light duty trucks varied between 2.00 and 2.15 idling hours per trip.[94] In the Barnett shale development, TxDOT reported an average of 70 heavy duty truck loads are needed for pad construction.[95]

New York City Department of Environmental Protection study on the Marcellus finding of 20 to 40 heavy duty diesel trucks needed for pad construction was similar to ENVIRON's survey.[96] Other studies, including Cornell University report in the Marcellus[97], National Park Service in the Marcellus[98], and All Consulting also in the Marcellus[99], had similar results for the number of trips by heavy duty trucks. ENVIRON study for the southern Ute reported slightly more heavy duty trucks: 56 heavy duty truck loads.[100]

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[94] Amnon Bar-Ilan, John Grant, Rajashi Parikh, Ralph Morris, ENVIRON International Corporation, July 2011. "Oil and Gas Mobile Sources Pilot Study". Novato, California. pp. 11-12. Available online: http://www.wrapair2.org/documents/2011-07_P3%20Study%20Report%20(Final%20July-2011).pdf. Accessed: 04/12/2012.

[95] Richard Schiller, P.E. Fort, Worth District. Aug. 5, 2010. "Barnett Shale Gas Exploration Impact on TxDOT Roadways". TxDOT, Forth Worth. Slide 15.

[96] Haxen and Sawyer, Environmental Engineers & Scientists, Sept. 2009. "Impact Assessment of Natural Gas Production in the New York City Water Supply Watershed Rapid Impact Assessment Report". New York City Department of Environmental Protection. p. 47. Available online: http://www.nyc.gov/html/dep/pdf/natural_gas_drilling/rapid_impact_assessment_091609.pdf. Accessed: 04/20/2012.

[97] Santoro, R.L.; R.W. Howarth; A.R. Ingraffea. 2011. Indirect Emissions of Carbon Dioxide from Marcellus Shale Gas Development. A Technical Report from the Agriculture, Energy, & Environment Program at Cornell University. June 30, 2011. p. 8. Available online: http://www.eeb.cornell.edu/howarth/IndirectEmissionsofCarbonDioxidefromMarcellusShaleGasDevelopment_June302011%20.pdf. Accessed: 04/02/2012.

[98] National Park Service U.S. Department of the Interior, Dec. 2008. "Potential Development of the Natural Gas Resources in the Marcellus Shale: New York, Pennsylvania, West Virginia, and Ohio". p. 9. Available online: http://www.nps.gov/frhi/parkmgmt/upload/GRD-M-Shale_12-11-2008_high_res.pdf. Accessed: 04/22/2012.

[99] All Consulting, Sept. 16, 2010. "NY DEC SGEIS Information Requests". Prepared for Independent Oil & Gas Association, Project no.: 1284. Available online: http://catskillcitizens.org/learnmore/20100916IOGAResponsetoDECChesapeake_IOGAResponsetoDEC.pdf. Accessed: 04/16/2012.

[100] ENVIRON, August 2009. "Programmatic Environmental Assessment for 80 Acre Infill Oil and Gas Development on the Southern Ute Indian Reservation". Novato, California. Appendix A, p. 62. Available online: http://www.suitdoe.com/Documents/Appendix_G_AirQualityTSD.pdf. Accessed: 04/25/2012.

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Table 3-4: On-Road Vehicles used for Pad Construction Parameters from Previous Studies

Vehicle Type	Para-meter	Purpose	Cornell University Marcellus	San Juan Public Lands Center, Colorado	ENVIRON Colorado	ENVIRON Southern Ute	Jonah Infill, Wyoming	Tumble-weed II, Utah	Pinedale Anticline Project, Wyoming	Buys & Assoc-iates Utah	National Park Service, Marcellus	New York City, Marcellus	All Consulting Marcellus	TxDOT, Barnett
Heavy Duty Diesel Trucks (HDDV)	Number/ pad	Pad Cons.	45	16	22.86	56	8	10	240	7	10-45	20-40	45	**70**
		Road Cons.							88					
	Distance (miles)	Pad Cons.	200	12.5	13.57	9	9.5	49.5	10	168	-	-	-	-
		Road Cons.							10					
	Speed (mph)	Pad Cons.	-	20 (road)	17.15	20	20 (road)	-	35	-	-	-	-	-
		Road Cons.							35					
	Idling Hours/Trip	Pad Cons.	-	-	**0.40**	-	-	-	-	-	-	-	-	-
		Road Cons.												
Light Duty Trucks (LDT)	Number/ pad	Pad Cons.	-	24	**12.86**	56	12	2	160	28	-	-	90	-
		Road Cons.							58				-	
		Employee			**69.60**				-					
	Distance (miles)	Pad Cons.	-	12.5	100.00	9	9.5	49.5	10	168	-	-	-	-
		Road Cons.							10					
		Employee			119.45				-					
	Speed (mph)	Pad Cons.	-	25 (road)	20.0	30	30 (road)	-	35	-	-	-	-	-
		Road Cons.							35					
		Employee			18.58				-					
	Idling Hours/Trip	Pad Cons.	-	-	**2.00**	-	-	-	-	-	-	-	-	-
		Road Cons.												
		Employee			**2.15**									

For light duty vehicle, the Pinedale Anticline Project in Wyoming[101] had significantly more trips[102] than ENVIRON's survey, while San Juan Public Lands Center in Colorado[103], Tumble-weed II in Utah[104], Jonah Infill in Wyoming [105]. and Buys & Associates in Utah[106] studies found less light duty trucks compared to ENVIRON's report in Colorado. Since local data is not available, the number of trips by vehicle type and the idling time per vehicle trip will be taken from the TxDOT findings in the Barnett shale and ENVIRON's report's in Colorado.

Light duty truck emission factors are based on MOVES categories of gasoline and diesel passenger trucks and light commercial trucks (Table 3-5).[107] For heavy duty trucks, emissions factors from MOVES are calculated using local data and diesel short haul combination trucks. Combination short-haul trucks are classified in MOVES as trucks with majority of operation within 200 miles of home base.[108] Similar to the Pinedale Anticline Project in Wyoming, an average speed of 35 miles per hour will be used for both vehicle types because the 25 miles per hour used in other studies are too slow in rural area typical of the Eagle Ford. A complete list of all on-road emission factors are provided in Appendix

[101] U.S. Department of the Interior, Bureau of Land Management, Sept. 2008. "Final Supplemental Environmental Impact Statement for the Pinedale Anticline Oil and Gas Exploration and Development Project: Pinedale Anticline Project Area Supplemental Environmental Impact Statement". Sheyenne, Wyoming. p. F42. Available online: http://www.blm.gov/pgdata/etc/medialib/blm/wy/information/NEPA/pfodocs/anticline/rd-seis/tsd.Par.13395.File.dat/07appF.pdf. Accessed: 04/12/2012.

[102] U.S. Department of the Interior, Bureau of Land Management, Sept. 2008. "Final Supplemental Environmental Impact Statement for the Pinedale Anticline Oil and Gas Exploration and Development Project: Pinedale Anticline Project Area Supplemental Environmental Impact Statement". Sheyenne, Wyoming. pp. F39-F40. Available online: http://www.blm.gov/pgdata/etc/medialib/blm/wy/information/NEPA/pfodocs/anticline/rd-seis/tsd.Par.13395.File.dat/07appF.pdf. Accessed: 04/12/2012.

[103] BLM National Operations Center, Division of Resource Services, December, 2007. "San Juan Public Lands Center Draft Land Management Plan & Draft Environmental Impact Statement: Air Quality Impact Assessment Technical Support Document". Bureau of Land Management, San Juan Public Lands Center, Durango, Colorado. p. A-4. Available online: http://ocs.fortlewis.edu/forestplan/DEIS/pdf/120507_TSD&App%20A.pdf. Accessed: 04/03/2012.

[104] U.S. Department of the Interior, Bureau of Land Management. June 2010. "Tumbleweed II Exploratory Natural Gas Drilling Project". East City, Utah. DOI-BLM-UTG010-2009-0090-EA. p. 12 of 29. Available online: http://www.blm.gov/pgdata/etc/medialib/blm/ut/lands_and_minerals/oil_and_gas/november_2011.Par.24530.File.dat/. Accessed: 04/12/2012.

[105] Amnon Bar-Ilan, ENVIRON Corporation, June 2010. "Oil and Gas Mobile Source Emissions Pilot Study: Background Research Report". UNC-EMAQ (3-12)-006.v1. Novato, CA. p. 17. Available online: http://www.wrapair2.org/documents/2010-06y_WRAP%20P3%20Background%20Literature%20Review%20(06-06%20REV).pdf. Accessed: 04/03/2012.

[106] Buys & Associates, Inc., Sept. 2008. "APPENDIX J: Near-Field Air Quality Technical Support Document for the West Tavaputs Plateau Oil and Gas Producing Region Environmental Impact Statement". Prepared for: Bureau of Land Management Price Field Office Littleton, Colorado. Available online: http://www.blm.gov/ut/st/en/fo/price/energy/Oil_Gas/wtp_final_eis.html. Accessed: 04/20/2012.

[107] Office of Transportation and Air Quality, August 2010. "MOVES". U.S. Environmental Protection Agency, Washington, DC. Available online: http://www.epa.gov/otaq/models/moves/index.htm. Accessed: 04/02/2012.

[108] John Koupal, Mitch Cumberworth, and Megan Beardsley, June 9, 2004. "Introducing MOVES2004, the initial release of EPA's new generation mobile source emission model". U.S. EPA Office of Transportation and Air Quality, Assessment and Standards Division. Ann Arbor, MI. Available online: http://www.epa.gov/ttn/chief/conference/ei13/ghg/koupal.pdf. Accessed: 07/11/11.

A for 2011, 2015, and 2018. Idling Emissions factors for heavy duty trucks and light duty trucks were provided by EPA.[109]

Table 3-5 MOVES 2011 Ozone Season Day Emission Factors for On-Road Vehicles in Eagle Ford Counties

Vehicle Type	Fuel Type	Location	Speed	NO_X EF	VOC EF	CO EF
Light Duty Trucks	Diesel and Gasoline	On-Road	35 mph	1.33 g/mile	0.28 g/mile	9.18 g/mile
		Idling	-	11.11 g/hr	4.09 g/hr	N/A
Heavy Duty Trucks	Diesel	On-Road	35 mph	10.10 g/mile	0.51 g/mile	2.75 g/mile
		Idling	-	89.32 g/hr	11.67 g/hr	N/A

N/A – not calculated and not provided by EPA

On-road VOC, NO_X, and CO emission factors for vehicles will be calculated using the formula provided below, while idling emissions will be calculated using formula in Equation 3-4. The inputs into the formula will be based on local data, MOVES output emission factors, TxDOT, and data from ENVIRON's survey in Colorado. Railroad Commission of Texas data on average distance to the nearest town will be used as an approximation of the traveling distance for each heavy duty truck load and light duty vehicle trip by county because resources and housing are usually centrally located in towns.

Equation 3-3, Ozone season day on-road emissions during pad construction

$$E_{pad.road.ABC} = NUM_{BC} \times TRIPS_A \times (DIST_B \times 2) \times OEF_A / WPAD_B / 907{,}184.74 \text{ grams per ton} / 365 \text{ days/year}$$

Where,

$E_{pad.road.ABC}$ = Ozone season day NO_X, VOC, or CO emissions from on-road vehicles in county B for Eagle Ford development well type C (Gas or Oil)

NUM_{BC} = Number of wells drilled in county B for Eagle Ford development well type C, in Table 4-1 (from Schlumberger Limited)

$TRIPS_A$ = Number of trips for vehicle type A, 70 for heavy duty trucks (from TxDOT in the Barnett) and 82.46 for light duty trucks in Table 3-4 (from ENVIRON's Colorado report)

$DIST_B$ = Distance to the nearest town for county B, Table 3-2 (from Railroad Commission of Texas)

OEF_A = NO_X, VOC, or CO on-road emission factor for vehicle type A in Table 3-5 (from MOVES Model)

$WPAD_B$ = Number of Wells per Pad for county B, Table 3-2 (calculated from data provided by the Railroad Commission of Texas)

Equation 3-4, Ozone season day idling emissions during pad construction

$$E_{pad.idling.ABC} = NUM_{BC} \times TRIPS_A \times IDLE_A \times IEF_A / WPAD_B / 907{,}184.74 \text{ grams per ton} / 365 \text{ days/year}$$

Where,

$E_{pad.idling.ABC}$ = Ozone season day NO_X, VOC, or CO emissions from idling vehicles in county B for Eagle Ford development well type C (Gas or Oil)

NUM_{BC} = Number of wells drilled in county B for Eagle Ford development well type C, in Table 4-1 (from Schlumberger Limited)

109 Brzezinski, Office of Transportation and Air Quality, U.S. Environmental Protection Agency, Washington, DC, e-mail dated 05/19/2012.

$TRIPS_A$ = Number of trips for vehicle type A, 70 for heavy duty trucks (from TxDOT in the Barnett), 12.86 for light duty trucks for equipment, and 69.6 light duty trucks for employees in Table 3-4 (from ENVIRON's Colorado report)

$IDLE_A$ = Number of Idling Hours/Trip for vehicle type A, 0.4 hours for heavy duty trucks, 2.0 for light duty trucks for equipment, and 2.15 light duty trucks for employees (from ENVIRON's Colorado report)

IEF_A = NO_X, VOC, or CO idling emission factor for vehicle type A in Table 3-5 (from EPA based on the MOVES model)

$WPAD_B$ = Number of Wells per Pad for county B, Table 3-2 (calculated from data provided by the Railroad Commission of Texas)

If updated data becomes available from local surveys or industry, data and methodology will be updated.

4 DRILLING OPERATIONS

4.1 Drill Rigs

According to ERG "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."[110] A picture of an Eagle Ford drill rig near Tilden is provided in Figure 4-1[111], while a picture of a Magnum Hunter Resources drilling rig is shown in Figure 4-2.[112]

Figure 4-1: Eagle Ford Drill Rig near Tilden, Texas

Horizontal wells used for fracturing operations in the Eagle Ford "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. Once the

[110] Eastern Research Group, Inc. July 15, 2009. "Drilling Rig Emission Inventory for the State of Texas". Prepared for: Texas Commission on Environmental Quality. Austin, Texas. p. 3-3 – 3.5. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820783985FY0901-20090715-ergi-Drilling_Rig_EI.pdf. Accessed: 04/09/2012.

[111] John Davenport, San Antonio Express-News. "Hydraulic Fracturing". San Antonio, Texas. Available online: http://www.mysanantonio.com/slideshows/business/slideshow/Hydraulic-fracturing-15238.php#photo-1024113. Accessed: 04/27/2012.

[112] Lowell Georgia. "Oil and Gas Investor". Available online: http://www.epmag.com/Production-Drilling/Eagle-Ford-Output-Continues-Soar_90533. Accessed: 04/02/2012.

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."[113]

Marathon Oil Corporation provides a detailed explanation of the process involved in drilling a well in the Eagle Ford. "Once a site has been prepared, the drilling rig moves in, a process that will require numerous trucks carrying various parts of the rig. Once the operation begins, the drill bit is lowered into the hole by adding sections of drill pipe at the surface. This pipe is pumped full of drilling fluid, or "mud," which travels down the pipe, through the bit, and back to the surface, carrying rock pieces, called cuttings. The mud has several functions. As it passes out of the drill bit, it lubricates the cutting surface, reduces friction and wear and keeps the drill bit cooler. Additionally, it carries rock cuttings away from the drill bit and back to the surface for separation and disposal. While traveling back up the hole, the mud also provides pressure to prevent the hole from caving in on itself."[114]

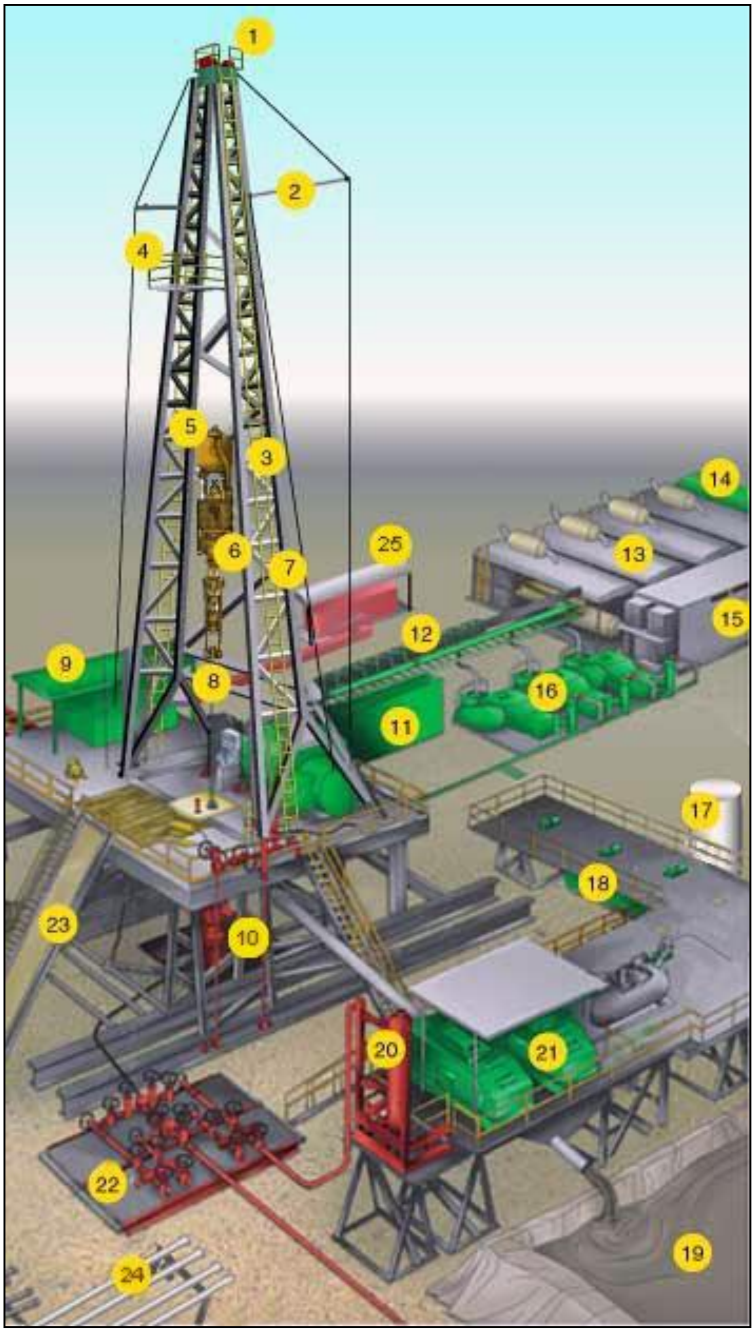
Figure 4-2: Magnum Hunter Resources Drilling Rig in the Eagle Ford

Drilling is "stopped at certain depths to place steel casing into the ground to protect the hole as well as surrounding rock layers and underground aquifers. The casing is fixed in place by pumping cement down the inside of the casing and up the outside between the steel

[113] Eastern Research Group, Inc. July 15, 2009. "Drilling Rig Emission Inventory for the State of Texas". Prepared for: Texas Commission on Environmental Quality. Austin, Texas. p. 3-3 – 3.5. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820783985FY0901-20090715-ergi-Drilling_Rig_EI.pdf. Accessed: 04/09/2012.
[114] Marathon Oil Corporation. "Eagle Ford: Oil and Natural Gas Fact Book". p. 10-11. Available online: http://www.marathonoil.com/content/documents/news/eagle_ford_fact_book_final.pdf. Accessed: 04/01/2012.

casing and the surrounding rock. Drilling operations are halted until the cement hardens." "Once the hole has been drilled to the target depth, workers remove the drill pipe and run tools into the well to evaluate the target rock layer. Once that evaluation is complete, a final casing segment is installed and cemented in place."[115] The Occupational Safety and Health Administration provided the typical drill rig components shown in Figure 4-3.[116] The main sources of ozone precursor emissions are the engines and generator sets used to provide power to the drill rig.

Figure 4-3: Drill Rig Components



1. Crown Block and Water Table
2. Catline Boom and Hoist Line
3. Drilling Line
4. Monkeyboard
5. Traveling Block
6. Top Drive
7. Mast
8. Drill Pipe
9. Doghouse
10. Blowout Preventer
11. Water Tank
12. Electric Cable Tray
13. Engine Generator Sets
14. Fuel Tanks
15. Electric Control House
16. Mud Pump
17. Bulk Mud Components Storage
18. Mud Pits
19. Reserve Pits
20. Mud Gas Separator
21. Shale Shaker
22. Choke Manifold
23. Pipe Ramp
24. Pipe Racks
25. Accumulator

4.1.1

[115] *Ibid*.
[116] Occupational Safety and Health Administration. "Drilling Rig Components". Available online: http://www.osha.gov/SLTC/etools/oilandgas/illustrated_glossary.html. Accessed: 04/26/2012.

4.1.1 Number of Wells drilled in the Eagle Ford

The number of Eagle Ford drill rigs "doubled in one year, accounting for nearly half of all U.S. rig growth in 2011. For three straight quarters, the Eagle Ford has led the charge as the fastest growing unconventional play, as measured by rigs".[117] Although drill rigs are not permanent on an individual pad site, when the operation is completed the drill rig will often be moved to a nearby pad site to drill another well and the rig will often remain in the Eagle Ford.

Number of production wells drilled in 2011 are provided by Schlumberger Limited including county, spud date, well type, well direction, proposed depth, and purpose[118], while the Railroad Commission provided data on the number of disposal wells drilled in 2011 (Table 4-1). There were 2,415 Eagle Ford oil, natural gas, and disposal wells drilled in 2011 with a total combined depth of 28,994,120 feet. The most active counties are Webb County with 375 wells, Dimmit County with 341 wells, Karnes County with 321 wells, and La Salle County with 314 wells. The counties in the San Antonio MSA that have active drill rigs in the Eagle Ford, Atascosa County and Wilson County, had a total of 110 Eagle Ford wells drilled in 2011. As shown in Figure 4-4, natural gas wells are concentrated in the southern Eagle Ford counties and Dewitt County. Oil Wells are targeted in Gonzales County, Karnes County and the strip of counties between Dimmit County and McMullen County (Figure 4-5).

4.1.2 Mechanical and Electric Drill Rigs Operating in the Eagle Ford

"Today's new drilling realities require more power than conventional wells and have given rise to the development of the AC/DC SCR drill rig powered by multiple generator sets. These economic realities require generator sets to deliver high specific power, low fuel consumption and less maintenance. Oil and gas drill rigs tend to be classified by the type of power used to operate the equipment on the rig. There are mechanical rigs, hydraulic rigs, DC/DC electrical rigs and AC/DC electrical rigs."[119]

"Mechanical rigs use dedicated diesel engines to provide motive force for the mud pumps, drawworks, rotary drill table and other loads through a system of clutches and transmissions. Hydraulic rigs have dedicated diesel engines running hydraulic pumps, which, in turn, provide power to the necessary equipment. DC/DC electric rigs use dedicated diesel-electric direct-current generators to power DC motors that run the equipment. While mechanical, hydraulic and DC/DC systems are still used for conventional and shallower wells, they can be costly to operate and maintain, and lack flexibility. In addition, these older systems are less reliable. Since individual engines are dedicated to single functions such as driving the mud pump or operating the drawworks, a failure on any one engine can halt drilling altogether."[120]

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[117] Steve Toon February 1, 2012. "Boom Days In The Eagle Ford". The Champion Group". Available online: http://www.championgroup.com/news/boom-days-in-the-eagle-ford/. Accessed: 04/20/2012.
[118] Schlumberger Limited. "STATS Rig Count History". Available online: http://stats.smith.com/new/history/statshistory.htm. Accessed: 04/21/2012.
[119] Steve Besore, Oil & Gas Applications, MTU Detroit Diesel, Inc. "How to Select Generator Sets for Today's Oil and Gas Drill Rigs". Detroit, Michigan. Available online: http://www.mtu-online.com/fileadmin/fm-dam/mtu-usa/mtuinnorthamerica/white-papers/WhitePaper_EDP.pdf. Accessed: 04/20/2012.
[120] *Ibid*.

Table 4-1: Average Depth of Horizontal and Disposal Wells in Eagle Ford Counties, 2011

County	FIPS Code	Type of well	Number of Well	Mean Depth (Feet)	Standard Dev. (Feet)	Confidence Interval (Feet)	Percent of Mean	Total Depth (Feet)
Atascosa	48013	Oil	47	12,368	3,085	882	7.1%	581,317
		Gas	21	12,489	1,728	739	5.9%	262,267
		Disposal	6	8,400	1,144	915	10.9%	50,400
Bee	48025	Oil	-	-	-	-	-	-
		Gas	3	18,667	4,041	4,573	24.5%	56,000
		Disposal	1	8,400	-	-	-	8,400
Brazos	48041	Oil	21	9,132	1,305	558	6.1%	191,765
		Gas	2	9,500	1,414	1,960	20.6%	19,000
		Disposal	-	-	-	-	-	-
Burleson	48051	Oil	12	7,998	1,356	767	9.6%	95,970
		Gas	1	7,800	-	-	-	7,800
		Disposal	-	-	-	-	-	-
DeWitt	48123	Oil	50	14,577	2,608	723	5.0%	728,850
		Gas	156	15,418	3,177	498	3.2%	2,405,238
		Disposal	3	6,283	3,153	3,568	56.8%	18,850
Dimmit	48127	Oil	209	9,078	1,805	245	2.7%	1,897,257
		Gas	118	9,037	1,476	266	2.9%	1,066,335
		Disposal	13	6,227	2,528	1,374	22.1%	80,950
Fayette	48149	Oil	13	14,131	2,777	1,509	10.7%	183,700
		Gas	1	9,000	-	-	-	9,000
		Disposal	1	6,500	-	-	-	6,500
Frio	48163	Oil	55	9,235	2,801	740	8.0%	507,948
		Gas	11	10,845	3,641	2,151	19.8%	119,290
		Disposal	7	7,771	2,696	1,997	25.7%	54,400
Gonzales	48177	Oil	160	12,619	1,293	200	1.6%	2,018,960
		Gas	6	13,417	492	393	2.9%	80,500
		Disposal	4	7,020	1,143	1,120	16.0%	35,100
Grimes	48185	Oil	7	9,362	465	344	3.7%	65,535
		Gas	4	11,825	1,234	1,209	10.2%	47,300
		Disposal	1	5,510	-	-	-	5,510
Houston	48225	Oil	1	8,660	-	-	-	8,660
		Gas	2	14,300	1,838.5	2,548	17.8%	28,600
		Disposal	1	10,000	-	-	-	10,000
Karnes	48255	Oil	247	12,537	1,479	184	1.5%	3,096,618
		Gas	64	16,016	3,599	882	5.5%	1,025,025
		Disposal	9	7,895	857	560	7.1%	78,950
La Salle	48283	Oil	155	10,698	2,182	344	3.2%	1,658,126
		Gas	149	13,314	2,781	447	3.4%	1,983,852
		Disposal	10	8,429	3,254	2,017	23.9%	84,285
Lavaca	48285	Oil	11	12,983	1,717	1,015	7.8%	142,810
		Gas	-	-				-
		Disposal	-	-	-			-
Lee	48287	Oil	11	8,754	1,101	650	7.4%	96,290
		Gas	1	12,925		-	-	12,925
		Disposal	-	-	-	-	-	-
Leon	48289	Oil	13	9,223	2,845	1,547	16.8%	119,900
		Gas	18	18,033	3,241	1,497	8.3%	324,600
		Disposal	2	9,600	1,273	1,764	18.4%	19,200
Live Oak	48297	Oil	14	18,193	4,013	2,102	11.6%	254,700
		Gas	78	15,083	3,714	824	5.5%	1,176,502
		Disposal	-	-	-			-
Madison	48313	Oil	20	10,241	2,768	1,213	11.8%	204,814
		Gas	2	11,000	2,828	3,920	35.6%	22,000
		Disposal	-	-	-	-	-	-

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County	FIPS Code	Type of well	Number of Well	Mean Depth (Feet)	Standard Dev. (Feet)	Confidence Interval (Feet)	Percent of Mean	Total Depth (Feet)
McMullen	48311	Oil	80	11,849	2,276	499	4.2%	947,894
		Gas	115	13,077	2,432	444	3.4%	1,503,828
		Disposal	5	8,906	2,053	1,799	20.2%	62,340
Maverick	48323	Oil	10	6,107	2,759	1,710	28.0%	61,071
		Gas	1	3,400	-	-	-	3,400
		Disposal	-	-	-	-	-	-
Milam	48331	Oil	2	12,000	-	-	-	24,000
		Gas	-	-	-	-	-	-
		Disposal	-	-	-	-	-	-
Washington	48477	Oil	1	12,000	-	-	-	12,000
		Gas	3	12,258	1,271	1,438	56.0%	36,775
		Disposal	-	-	-	-	-	-
Webb	48479	Oil	56	12,628	3,276	858	6.8%	707,150
		Gas	313	12,404	3,387	375	3.0%	3,882,562
		Disposal	6	3,000	-	-	-	18,000
Wilson	48493	Oil	35	11,307	2,780	921	8.1%	395,751
		Gas	-	-	-	-	-	-
		Disposal	-	-	-	-	-	-
Zavala	48507	Oil	29	9,022	1,970	717	7.9%	261,650
		Gas	12	9,017	3,087	1,746	19.4%	108,200
		Disposal	-	-	-	-	-	-
Total			2,415	12,006	3,339.3	133	1.1%	28,994,120

Figure 4-4: Number of Eagle Ford Gas Wells Drilled by County, 2011

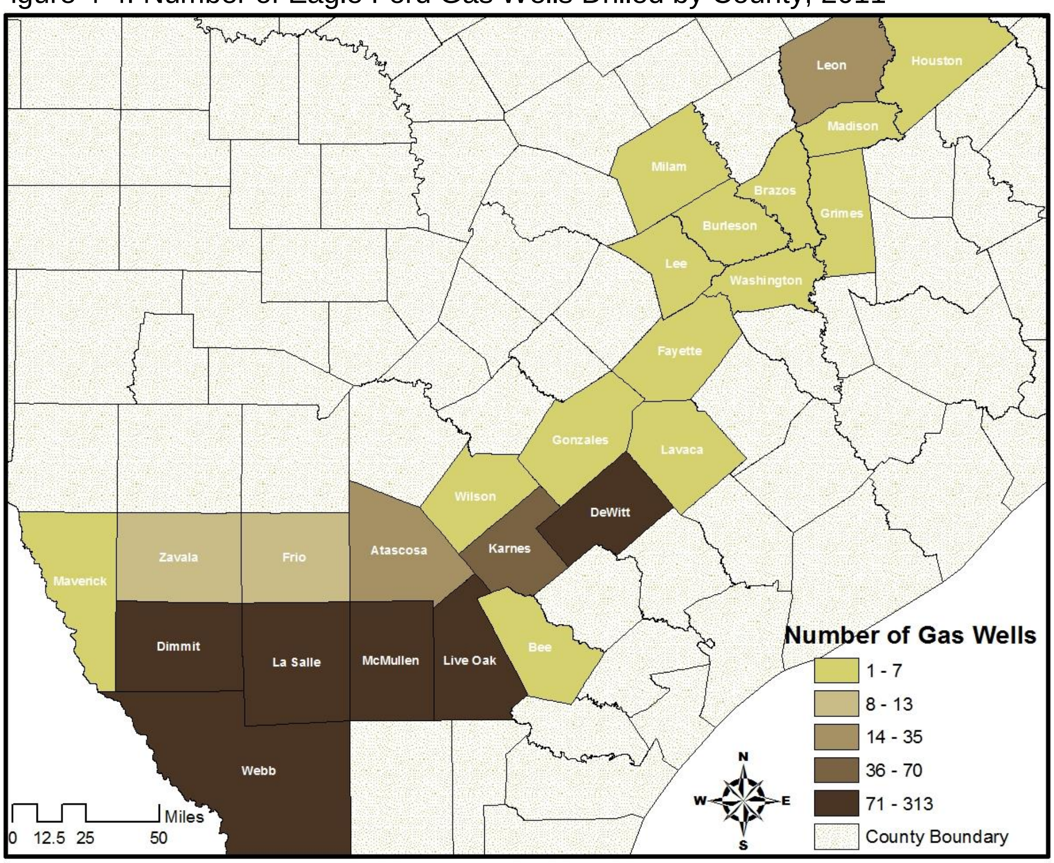
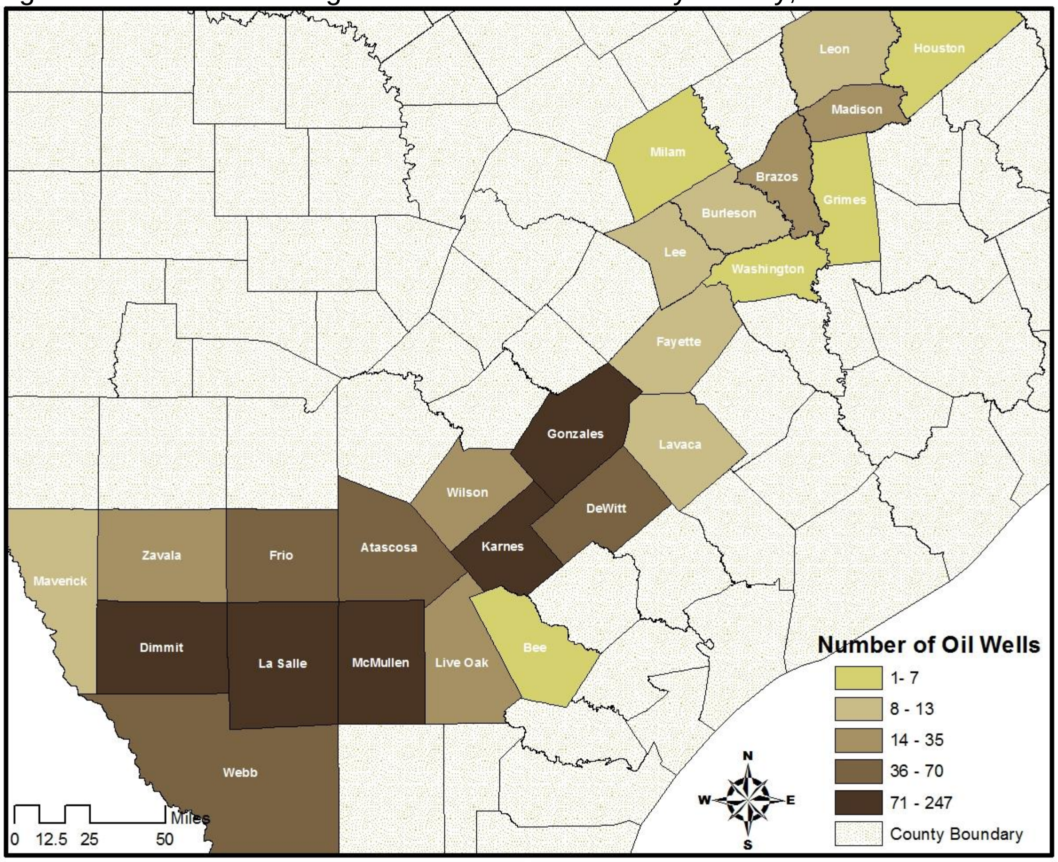


Figure 4-5: Number of Eagle Ford Oil Wells Drilled by County, 2011



"Today, the majority of the new oil and gas drill rigs are AC/DC electric rigs with SCR controls. These rigs use multiple diesel-electric generator sets running in parallel to produce the two to four megawatts of power needed at the drill site, including the power needed for camp loads such as lighting, heating and air conditioning for crew quarters. Power is generated as alternating current (AC) and then converted to direct current (DC) by a unit called an SCR (so called for the banks of silicon-controlled rectifier semiconductors that it contains)."[121] According to Helmerich & Payne, for "shale and unconventional plays, the more complex directional and horizontal wells, you need to begin with a platform that is A/C variable-frequency drive". "It's not a function of the (mechanical) rigs not being able to drill the well. It is a function of the rigs not being able to drill the well as efficiently and economically as an A/C drive rig."[122]

Data collected from 205 drill rigs operating in the Eagle Ford found 28 mechanical rigs and 177 electric rigs operated in 2011. Nabors Industries Ltd has 34 drill rigs in South Texas and only 2 of them are mechanical while the other 32 drill rigs are electrical.[123] Of the 14 rigs operated by Pioneer drilling in the Eagle Ford development, there are 4 mechanical and 10 electrical drill rigs.[124] Patterson-UTI operated 10 mechanical rigs and 21 electric rigs

[121] *Ibid*.
[122] Jerry Greenberg. May 4, 2011. "Shale Drilling: a Well-Oiled Machine". International Association of Drilling Contractors. Available online: http://www.drillingcontractor.org/shale-drilling-a-well-oiled-machine-9335. Accessed: 04/12/2012.
[123] Nabors Industries Ltd. http://www.nabors.com/Public/Index.asp?Page_ID=419. Accessed: 04/20/2012.
[124] Pioneer Drilling Company. "Drilling Service Rig Fleet". Available online: http://www.pioneerdrlg.com/rig-fleet.aspx?id=1. Accessed: 04/24/11.

during 2011 in the Eagle Ford[125]. Other companies, such as Helmerich & Payne[126], ENSIGN[127], Precision Drilling[128] and Trinidad Drilling[129] only operated electric rigs in the Eagle Ford. Below is the number of drill rigs used in Eagle Ford by drilling contractor during 2011.[130]

- H & P Drilling - 74 rigs
- Nabors Drilling - 46 rigs
- Patterson-Uti - 38 rigs
- Precision Drilling - 23 rigs
- Orion Drilling Co - 17 rigs
- Pioneer Drilling - 17 rigs
- Nomac Services - 16 rigs
- Trinidad Drilling - 12 rigs
- Ensign Drilling - 9 rigs
- Lewis Drilling - 9 rigs
- Rowan Drilling - 9 rigs
- Unit Drilling - 7 rigs
- Swanson Drilling - 6 rigs
- Big E Drilling - 5 rigs
- Scan Drilling - 5 rigs
- Coastal Drilling - 4 rigs
- Basin Drilling - 3 rigs
- Desta Drilling - 3 rigs
- Energy Drilling - 3 rigs
- Lantern Drilling - 3 rigs
- Unison Drilling - 3 rigs
- Bronco Drilling - 2 rigs
- Lyons Drilling - 2 rigs
- Xtreme Drilling - 2 rigs
- Allis Chambers - 1 rig
- Arrow Drilling - 1 rig
- Caspian Drilling - 1 rig
- Edde Drilling - 1 rig
- Justiss Drilling - 1 rig
- Keen Drilling - 1 rig
- Key Energy Drilling - 1 rig
- Latshaw Drilling - 1 rig
- Longhorn Drilling - 1 rig
- Mesa Drilling Co - 1 rig
- Nicklos Drilling - 1 rig
- Penn Energy - 1 rig
- Savanna Drilling - 1 rig
- Wisco Moran Drilling - 1 rig

4.1.3 Drill Rig Parameters

Table 4-2 shows drill rig parameters, including number of engines, horsepower, hours per well, used to calculate emissions from previous studies. The horsepower results from previous studies varied greatly; from 1,000 total hp in Armendariz Barnett study[131] to 4,428 hp in ERG's Fort Worth survey in the Barnett[132], 4,500 hp in Carnegie Mellon University research in the Marcellus[133] and 5,139 hp in ENVIRON's CENRAP Emission inventory.[134]

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[125] Patterson-UTI Drilling Company LLC. "Rig Locator System". Available online: http://patdrilling.com/rigs. Accessed: 04/19/2012.

[126] Helmerich & Payne."Rig Fleet". Available online: http://www.hpinc.com/RigFleet.html. Accessed: 04/18/2012.

[127] Ensign Energy Services Inc., 2012. "Ensign RigFinder". Available online: http://www.ensignenergy.com/_layouts/ensign.rigfinder/rigfinder.aspx. Accessed: 04/26/2012.

[128] Precision Drilling. "Find Rig by Location". Available online: http://rigs.precisiondrilling.com/rig_search_combo.asp. Accessed: 04/19/2012.

[129] Trinidad Drilling, 2012. Rig Fleet". Available online: http://www.trinidaddrilling.com/Services/RigFleet.aspx. Accessed: 04/25/2012.

[130] Schlumberger Limited. "STATS Rig Count History". Available online: http://stats.smith.com/new/history/statshistory.htm. Accessed: 04/21/2012

[131] Al Armendariz. Jan. 26, 2009. "Emissions from Natural Gas Production in the Barnett Shale Area and Opportunities for Cost-Effective Improvements". Prepared for Environmental Defense Fund. Austin, Texas. p. 18. Available Online: http://www.edf.org/sites/default/files/9235_Barnett_Shale_Report.pdf. Accessed: 04/19/2012.

[132] Eastern Research Group Inc. July 13, 2011. "Fort Worth Natural Gas Air Quality Study Final Report". Prepared for: City of Fort Worth, Fort Worth, Texas. Available online: http://fortworthtexas.gov/gaswells/?id=87074. Accessed: 04/09/2012.

[133] Allen L. Robinson, Carnegie Mellon University, Feb. 12, 2012. "Assessing air quality impacts of natural gas development and production in the Marcellus Shale Formation". Presented at 2012 MARAMA Science Meeting, Philadelphia PA. Slide 31. Available online: http://marama.org/presentations/2012_Science/Robinson_shale_Science2012.pdf. Accessed 05/20/2012.

[134] Amnon Bar-Ilan, Rajashi Parikh, John Grant, Tejas Shah, Alison K. Pollack, ENVIRON International Corporation. Nov. 13, 2008. "Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories". Novato, CA. p. 34. Available online:

Most of the studies predicted that it would take between 300 hours to 720 hours to drill a horizontal well, except ENVIRON's Haynesville study estimation of 1,500 hours per well.[135] ERG's drill rig emission inventory estimated the hours need to complete the drilling based on the hours it take each engine to drill 1,000 feet.[136] Other studies on drill rigs include Tumble-weed II in Utah[137], San Juan Public Lands Center in Colorado[138], ENVIRON Southern Ute emission inventory[139] and Cornell University report in the Marcellus[140].

Drill rig operations, capacity, technology, engines, horsepower, and activity rates have significantly changed in the last 2 years and parameters from previous studies will be updated with local data. Drill rigs in the Eagle Ford are often powered by 3 electrical diesel engines including ORION Drilling Company drill rigs[141]. For example, the latest drill rig, the Gemini 550, had the 3 engines powering a 1,200 hp ALTA Rig Drawworks, two 1,500 hp mud pump, and other mud system engines.[142] The average hp of rigs operated by Nabors is approximately 1,500 hp including the Pace F-series and Pace 1500.[143] Goodrich Petroleum uses Drawworks that can deliver at least 1,500 horsepower. "A 1,500-horsepower rig carries a premium over a 1,000-horsepower rig, but it speeds trips and puts less strain on the equipment." Companies prefer "to have at least 1,600-horsepower

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http://www.wrapair.org/forums/ogwg/documents/2008-11_CENRAP_O&G_Report_11-13.pdf. Accessed: 04/30/2012.

135 John Grant, Lynsey Parker, Amnon Bar-Ilan, Sue Kemball-Cook, and Greg Yarwood, ENVIRON International Corporation. August 31, 2009. "Development of an Emission Inventory for Natural Gas Exploration and Production in the Haynesville Shale and Evaluation of Ozone Impacts". Novato, CA. p. 32. Available online: http://www.netac.org/UserFiles/File/NETAC/9_29_09/Enclosure_2b.pdf. Accessed: 04/19/2012.

136 Eastern Research Group, Inc. July 15, 2009. "Drilling Rig Emission Inventory for the State of Texas". Prepared for: Texas Commission on Environmental Quality. Austin, Texas. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820783985FY0901-20090715-ergi-Drilling_Rig_EI.pdf. Accessed: 04/09/2012.

137 U.S. Department of the Interior, Bureau of Land Management. June 2010. "Tumbleweed II Exploratory Natural Gas Drilling Project". East City, Utah. DOI-BLM-UTG010-2009-0090-EA. p. 16 of 29. Available online: http://www.blm.gov/pgdata/etc/medialib/blm/ut/lands_and_minerals/oil_and_gas/november_2011.Par.24530.File.dat/. Accessed: 04/12/2012.

138 BLM National Operations Center, Division of Resource Services, December, 2007. "San Juan Public Lands Center Draft Land Management Plan & Draft Environmental Impact Statement: Air Quality Impact Assessment Technical Support Document". Bureau of Land Management, San Juan Public Lands Center, Durango, Colorado. p. A-8. Available online: http://ocs.fortlewis.edu/forestplan/DEIS/pdf/120507_TSD&App%20A.pdf. Accessed: 04/03/2012.

139 ENVIRON, August 2009. "Programmatic Environmental Assessment for 80 Acre Infill Oil and Gas Development on the Southern Ute Indian Reservation". Novato, California. p. 31. Available online: http://www.suitdoe.com/Documents/Appendix_G_AirQualityTSD.pdf. Accessed: 04/25/2012.

140 Santoro, R.L.; R.W. Howarth; A.R. Ingraffea. 2011. Indirect Emissions of Carbon Dioxide from Marcellus Shale Gas Development. A Technical Report from the Agriculture, Energy, & Environment Program at Cornell University. June 30, 2011. p. 8. Available online: http://www.eeb.cornell.edu/howarth/IndirectEmissionsofCarbonDioxidefromMarcellusShaleGasDevelopment_June302011%20.pdf. Accessed: 04/02/2012.

141 ORION Drilling Company LLC, April 12, 2011. "Three New Build Rigs for Eagle Ford". Available online: http://www.oriondrilling.com/three-new-build-rigs-for-eagle-ford/. Accessed: 04/20/2012.

142 ORION Drilling Company LLC. "Gemini 550". Available online: http://www.oriondrilling.com/wp-content/themes/oriondrilling/docs/specsheets/Gemini.pdf. Accessed: 04/20/2012.

143 Oil and Gas Journal. Feb. 01, 2010. "Special Report: Unconventional basins require new rig types". Available online: http://www.ogj.com/articles/print/volume-108/issue-4/technology/special-report-unconventional.html. Accessed: 04/28/2012.

pumps, especially when drilling long laterals. That horsepower is needed for mud hydraulics to keep the hole clean, and to drive the downhole motor and other equipment."[144]

MTU Detroit Diesel observed that "the number of generators needed by a rig varies with the depth of the drilling operation, but today drillers have to go deeper vertically and sometimes just as far horizontally, and that requires more power. Generator sets can easily be added to the AC/DC SCR-powered rig to match the power requirements, making this design the most flexible. The number of generator sets running at any one time can be varied, depending on total load, to save fuel."[145] When researching drill rigs operating in the Eagle Ford, there was an average of 3.17 generators with an average horsepower of 1,429 each for electric drill rigs and mechanical drill rigs has an average of 5.88 engines with 702 horsepower each. Number of engines, horsepower, and engine type for 102 drill rigs with local data are provided in Appendix A. New drill rigs and improved technology reduces the time it takes to drill 1,000 feet compared to what was reported in ERG's drill rig emission inventory.

Higher horsepower mud pumps is one of the reasons Unit drilling operations is reducing drill time in the Eagle Ford. "The pre-eminent factor for drilling horizontal wells, much more so than the hookload of the derrick or drawworks horsepower, is hydraulic horsepower." "During horizontal drilling with high rates of penetration and with a large volume of solids being removed during the process, a good mud system is necessary to remove the solids".[146] Latshaw Drilling states "improvements in rig designs, downhole motors, and fluids handling equipment are only a small part of a larger effort to improve drilling efficiency. Polychrystalline diamond compact bits, measurement-while-drilling tools and rotary steerables will continue to be major drivers".[147]

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[144] Colter Cookson, April 2011. "'High-Spec' Land Rigs, Drilling Equipment Advances Proving Key In Shale Plays ". The American Oil and Gas Reporter. Available online: http://www.aogr.com/index.php/magazine/cover-story/high-spec-land-rigs-drilling-equipment-advances-proving-key-in-shale-plays. Accessed: 04/02/2012.

[145] Steve Besore, Oil & Gas Applications, MTU Detroit Diesel, Inc. "How to Select Generator Sets for Today's Oil and Gas Drill Rigs". Detroit, Michigan. Available online: http://www.mtu-online.com/fileadmin/fm-dam/mtu-usa/mtuinnorthamerica/white-papers/WhitePaper_EDP.pdf. Accessed: 04/20/2012.

[146] Jerry Greenberg, May 4, 2011. "Shale Drilling: a Well-Oiled Machine". Drilling Contractor. Available online: http://www.drillingcontractor.org/shale-drilling-a-well-oiled-machine-9335. Accessed: 04/14/2012.

[147] Colter Cookson, April 2011. "'High-Spec' Land Rigs, Drilling Equipment Advances Proving Key In Shale Plays ". The American Oil and Gas Reporter. Available online: http://www.aogr.com/index.php/magazine/cover-story/high-spec-land-rigs-drilling-equipment-advances-proving-key-in-shale-plays. Accessed: 04/02/2012.

Table 4-2: Drill Rig Parameters from Previous Studies

Drill Rig Parameters	TexN Model. Generators, Eagle Ford Counties	ERG's Fort Worth Natural Gas Study, Barnett	ERG's Drilling Rig Emission Inventory (Horizontal/Directional drill rigs), Texas				Armendariz Barnett Shale
			Electrical	Mechanical			
			All	Draw Works	Mud Pumps	Generators	
# of Engines		3	2.03	2	2	2	
Horsepower	49.6	1,476	1,346	483	1,075	390	1,000 all engines
Hours per well		504	47.3 / 1,000 ft.	50.1 / 1,000ft.	36.4 / 1,000ft.	26.8 / 1,000ft.	300
Fuel Type	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel
LF	**0.43**	1.0	0.525	0.411	0.426	0.690	0.50
Average Age			2	15	6	10	

Drill Rig Parameters	ENVIRON, Haynesville Shale	ENVIRON Southern Ute	ENVIRON's CENRAP EI (Western Gulf Basin)	Tumble-weed II, Utah	San Juan Public Lands Center, Colorado	Cornell University Marcellus	Carnegie Mellon University Marcellus
# of Engines							
Horse-power	3,605 all engines	2,100 all engines	5,149 all engines	1,725 all engines	2,100 all engines	3,760 all engines	4,500 all engines
Hours per well	1,500	288	1,200	584	720	672	588
Fuel Type	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel
LF	0.67	0.42	0.67	0.4	0.42	0.5	0.58
Average Age							

Chesapeake Energy Corporation states that typical duration for drilling a horizontal well is 20 to 24 days in the Eagle Ford.[148] The drill rig runs 24 hours 7 days a week to maintain the integrity of the drill hole.[149] In 2011, one of the fastest Eagle Ford shale drilling operation took 13 days to drill 15,467 feet in or 20.17 hours/1,000 feet by EOG.[150] Spud-to-release time has decreased from 27 days to 15 days, "and pad development allows the rig to mobilize in hours rather than the previous five to seven days."[151] Other companies had similar results including Swift Energy Co. at 21 days per well.[152] Marathon has a "targeted spud-to-spud time is 25 days, with a typical spud to total depth of 15 days. Completions involve an average 5,000-foot lateral, 15 to 17 stages, and 250 to 300 feet between stages."[153] H&P Drilling Company averaged 9 days to drill approximately 13,500 feet based on the last 10 wells in the Eagle Ford in 2011.[154]

Rig zone found that majority of wells being drilled in the Eagle Ford are targeting horizontal laterals ranging from 5,000 to 7,000 feet.[155] Swift Energy Co. has found that 5,000-6,000 feet laterals is the most economic length[156], Rosetta Resources' wells have 5,300-5,500 foot laterals[157], Magnum Hunter Resources Corporation is drilling average lateral lengths of 5,753 feet[158], and ConocoPhillips had lateral lengths of 4,000 to 6,000 feet in the Eagle Ford[159]. Goodrich Petroleum averaged 5,679-foot laterals[160] and is targeting 9,000-foot long

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148 Chesapeake Energy, Feb. 17, 2012. "Chesapeake Energy Corporation". presented at Greater San Antonio Chamber of Commerce – Energy & Sustainability Committee.

149 Chesapeake Energy Corporation, 2012. "Part 1 – Drilling". Available online: http://www.askchesapeake.com/Barnett-Shale/Multimedia/Educational-Videos/Pages/Information.aspx. Accessed: 04/22/2012

150 Nov. 15, 2011. "Fastest Eagle Ford Shale Well Drilled By EOG". Available online: http://eaglefordshaleblog.com/2011/11/15/fastest-eagle-ford-shale-well-drilled-by-eog/. Accessed: 04/03/2012.

151 Steve Toon, Oil and Gas Investor, Oct. 1, 2011. "Eagle Ford Output Continues To Soar". E&P Buzz. Houston, Texas. Available online: http://www.epmag.com/Production-Drilling/Eagle-Ford-Output-Continues-Soar_90533. Accessed: 04/02/2012.

152 Colter Cookson, June 2011. "Operators Converge On Eagle Ford's Oil And Liquids-Rich Gas". The American Oil and Gas Reporter. Available online: http://www.laredoenergy.com/sites/default/files/0611LaredoEnergyEprint.pdf. Accessed: 04/02/2012.

153 Steve Toon February 1, 2012. "Boom Days In The Eagle Ford". The Champion Group". Available online: http://www.championgroup.com/news/boom-days-in-the-eagle-ford/. Accessed: 04/20/2012.

154 Helmerich & Payne, Inc., Feb 2012. "H&P Inc." presented at the Credit Suisse Energy Summit. Available online: http://idc.api.edgar-online.com/efx_dll/edgarpro.dll?FetchFilingConvPDF1?SessionID=nnXuFtmYWf79CIS&ID=8379673. Accessed: 04/20/2012.

155 Trey Cowan, June 20, 2011. "Costs for Drilling The Eagle Ford". Rigzone. Available online: http://www.rigzone.com/news/article.asp?a_id=108179. Accessed: 04/28/2012.

156 Colter Cookson, April 2011. "'High-Spec' Land Rigs, Drilling Equipment Advances Proving Key In Shale Plays ". The American Oil and Gas Reporter. Available online: http://www.aogr.com/index.php/magazine/cover-story/high-spec-land-rigs-drilling-equipment-advances-proving-key-in-shale-plays. Accessed: 04/02/2012.

157 Colter Cookson, June 2011. "Operators Converge On Eagle Ford's Oil And Liquids-Rich Gas". The American Oil and Gas Reporter. Available online: http://www.laredoenergy.com/sites/default/files/0611LaredoEnergyEprint.pdf. Accessed: 04/02/2012.

158 Magnum Hunter Resources Corporation, January 2012. "Corporate Presentation". Available online: http://www.magnumhunterresources.com/Magnum_Hunter_Resources.pdf. Accessed: 04/28/2012.

159 ConocoPhillips Company. "Eagle Ford: Ramping Up for the Future". Available online: http://www.conocophillips.com/EN/about/worldwide_ops/exploration/north_america/Pages/EagleFord-story.aspx. Accessed: 04/02/2012.

160 OilShaleGas, 2012. "Eagle Ford Shale – South Texas – Natural Gas & Oil Field". Available online: http://oilshalegas.com/eaglefordshale.html. Accessed: 04/14/2012.

laterals in the near future[161]. Laterals for other companies including Statoil at 3,000 – 5,500-foot laterals[162], Chesapeake Energy with 5,000 – 8,000 laterals[163], and BHP Billiton Petroleum is using 5,000 to 6,000 feet lateral lengths.[164] Diane Langley of drilling contractor reported "lateral sections are generally 3,000-9,000 ft but average 6,000-7,000 ft in length".[165] Helmerich & Payne found that horizontal laterals have increased in length an average of 30% to 50% between 2009 and 2011.[166] Table 4-3 shows that the average lateral is 5,490 feet for the top 10 drilling contractors in the Eagle Ford.[167] GIS databases provided by the Railroad Commission of Texas shows that almost all permitted Eagle Ford wells only had one lateral per well.[168]

Table 4-3: Top 10 Companies with Permits in the Eagle Ford, 2010.

Operator	Permit Count	Average Total Depth	Average Horizontal Length
Chesapeake	322	7,432	6,269
EOG	212	11,693	5,091
Anadarko	147	8,555	5,893
Petrohawk	103	13,636	6,116
Conoco	84	13,097	5,196
Lewis Petro Properties	77	14,833	5,295
Pioneer	74	16,729	5,030
Enduring Resources	60	14,323	5,144
Rosetta Resources	57	9,448	5,890
El Paso	47	10,066	4,977
Grand Total	1,183	11,981	5,490

161 Colter Cookson, April 2011. "'High-Spec' Land Rigs, Drilling Equipment Advances Proving Key In Shale Plays ". The American Oil and Gas Reporter. Available online: http://www.aogr.com/index.php/magazine/cover-story/high-spec-land-rigs-drilling-equipment-advances-proving-key-in-shale-plays. Accessed: 04/02/2012.
162 Statoil. Oct. 10, 2010. "Statoil enters Eagle Ford". Available online: http://www.statoil.com/en/NewsAndMedia/News/2010/Downloads/Presentation%20Statoil%20enters%20Eagle%20Ford.pdf. Accessed: 04/12/2012.
163 Chesapeake Energy, Feb. 17, 2012. "Chesapeake Energy Corporation". presented at Greater San Antonio Chamber of Commerce – Energy & Sustainability Committee.
164 J. Michael Yeager, Group Executive and Chief Executive, Petroleum, Nov. 14, 2011. "BHP Billiton Petroleum Onshore US Shale Briefing". Available online: http://www.bhpbilliton.com/home/investors/reports/Documents/2011/111114_BHPBillitonPetroleumInvestorBriefing_Presentation.pdf. Accessed: 04/12/2012.
165 Diane Langley, July 6, 2011. "Drilling Mud Solutions: Cracking the Shale Code". Drilling Contractor. Available online: http://www.drillingcontractor.org/drilling-mud-solutions-cracking-the-shale-code-9940. Accessed: 04/14/2012.
166 Jerry Greenberg. May 4, 2011. "Shale Drilling: a Well-Oiled Machine". International Association of Drilling Contractors. Available online: http://www.drillingcontractor.org/shale-drilling-a-well-oiled-machine-9335. Accessed: 04/12/2012.
167 Ramona Hovey, SVP Analysis and Consulting, Feb. 23, 2011. "Eagle Ford Shale Overview". Energy Strategy Partners. Available online: http://texasalliance.org/admin/assets/Eagle_Ford_Shale_Overview_by_Ramona_Hovey,_Drilling_Info.pdf. Accessed: 04/14/2012.
168 Data provided by the Railroad Commission of Texas. Austin, Texas.

By using the following formula, the average time to drill a 17,645 foot Eagle Ford well is 20.40 hours/1,000 feet.

Equation 4-1, Average time to drill 1,000 feet in the Eagle Ford

HRS_{drill} = (DAY x 24 hours/day) / [DEP + (LENGTH x LNUM)] x 1,000 feet

Where,

HRS_{dril} = Hours per 1,000 feet drilled for drill rigs
DAY = Number of days to drill an Eagle Ford Well, 15 days (from Global Hunter Securities)
DEP = Average depth of the well in the Eagle Ford, 12,155 feet, Table 4-1 (from Schlumberger Limited)
LENGTH = Average length for a lateral well in the Eagle Ford, 5,490 feet, Table 4-3 (from Energy Strategy Partners)
LNUM = Number of Laterals per well, 1 (from Railroad Commission of Texas)

Sample Equation

HRS_{drill} = (15 days x 24 hours/day) / [12,155 feet + (5,490 feet x 1)] x 1,000 feet
= 20.40 hours/1,000 feet

4.1.4 Drill Rig Emission Calculation Methodology

The methodology used to estimation drill rig emissions relays on local equipment types, equipment population, horsepower, and activity rates. TCEQ TERP program emissions factors for generators ≥ 750 hp[169] will be used to estimate emissions from electric drill rigs, while existing data in the TexN Model will be used to calculate emission factors for mechanical drill rigs (Table 4-4). The emission factors highlighted in bold on Table 4-4 will be used to estimate emissions from drill rigs. VOC, NO_X, and CO emissions for electrical and mechanical drill rigs will be calculated using Equation 4-2 provided below.

The largest unknown when trying to estimate emissions from drilling rig engines is average engine load for each diesel generator. Industry experts determined that the load factor used in ERG's drill rig emission inventory were too high, therefore existing load factor, 0.43, in the TexN model will be used instead. Future improvements can include using fuel usage by the drill rigs and mud pumps; however fuel usage data is not available for well sites in the Eagle Ford. Furthermore, fuel usage is only recorded for total supplied at the well pad and not by engine.

Some operators in the Eagle Ford use a work over rig or a smaller rig to complete lateral lines once the horizontal part is drilled. The above equation takes into account these smaller rigs and emissions from these drill rigs will not be calculated separately. Armendariz study in Dallas found "some well sites in the D-FW are being drilled with electric-powered rigs, with electricity provided off the electrical grid." Engines emission estimates in the report were reduced by 25% "to account for the number of wells being drilled without diesel-engine power."[170] Drill rigs in the Eagle Ford will not include these reductions because none of the drill rigs located in the Eagle Ford operated off the electrical grid.

[169] TCEQ, April 24, 2010. "Texas Emissions Reduction Plan (TERP): Emissions Reduction Incentive Grants Program Technical Supplement No. 2, Non-Road Equipment". Austin, Texas. p. 5.
[170] Al Armendariz. Jan. 26, 2009. "Emissions from Natural Gas Production in the Barnett Shale Area and Opportunities for Cost-Effective Improvements". Prepared for Environmental Defense Fund. Austin, Texas. Available Online: http://www.edf.org/sites/default/files/9235_Barnett_Shale_Report.pdf. Accessed: 04/19/2012.

Table 4-4: Drill Rig 2011 Emission Factors from Previous Studies

Pollutant	TexN Model (Eagle Ford Counties)		ERG's Fort Worth Natural Gas Study, Barnett	ERG's Drilling Rig Emission Inventory, Texas	ENVIRON, Haynesville Shale	ENVIRON Southern Ute (Tier 2)[171]	Caterpillar Inc.[172]		TCEQ	
	Generators	Drill Rigs					(Tier 2)	(Tier 4 Interim 2011 Model Year)	Tier 2, (Engines ≥ 750 hp)	Tier 4 (gensets > 1,200 hp)
NO_X EF	5.00 g/hp-hr	**5.13 g/hp-hr**	4.77 g/hp-hr	0.355 tons/ 1,000 ft.	8.0 g/bhp-hr	0.00900 lbs/hp-hr	6.1 g NO_X + HC/kw-hr	3.1 g/kw-hr	**4.56 g/bhp-hr**	0.50 g/bhp-hr
VOC EF	0.66 g/hp-hr	**0.48 g/hp-hr**	0.0145 g/hp-hr	0.0162 tons/ 1,000 ft	1.0 g/bhp-hr	0.00033 lbs/hp-hr		0.17 g of HC/kw-hr	**0.24 g/bhp-hr**	-
CO EF	**2.67 g/hp-hr**	**1.99 g/hp-hr**	2.61 g/hp-hr	0.0647 tons/ 1,000 ft	5.0 g/bhp-hr	0.00570 lbs/hp-hr	2.3 g /kw-hr	0.5 g /kw-hr	-	-

171 ENVIRON, August 2009. "Programmatic Environmental Assessment for 80 Acre Infill Oil and Gas Development on the Southern Ute Indian Reservation". Novato, California. p. 31. Available online: http://www.suitdoe.com/Documents/Appendix_G_AirQualityTSD.pdf. Accessed: 04/25/2012.

172 California Environmental Protection Agency Air Resources Board, March 30, 2011. "New Off-Road Compression-Ignition Engines: Caterpillar Inc.".

Equation 4-2, Ozone season day drill rig emissions for each well

$E_{RIG.ABC}$ = PER_A x NUM_{BC} x [(DEP_{BC} + (LENGTH x LNUM)] x ENG_A x HP_A x HRS_{dril} / 1,000 feet x LF_A x EF x (1 – PER) / 907,184.74 grams per ton / 365 days/year

Where,

$E_{RIG.ABC}$	= Ozone season day NO_X, VOC, or CO emissions from drill rig type A in county B for Eagle Ford development well type C (Gas, Oil, or Disposal)
PER_A	= Percentage of Drill rigs type A, 86.3 percent electrical and 13.7 percent mechanical drill rigs in the Eagle Ford, 2011 (from local data in Appendix A)
NUM_{BC}	= Number of wells drilled in county B for Eagle Ford development well type C, from Table 4-1 (from Schlumberger Limited)
DEP_{BC}	= Average depth of the well for county B for Eagle Ford development well type C, from Table 4-1 (from Schlumberger Limited)
LENGTH	= Average length for a lateral distance, 5,490 feet for production wells and 0 feet for disposal wells, Table 4-3 (from Energy Strategy Partners)
LNUM	= Number of Laterals per well, 1 (from Railroad Commission of Texas)
ENG_A	= Number of Engines per drill rig Type A. 3.17 for electrical and 5.88 for mechanical drill rigs (from local data in Appendix A)
HP_A	= Drill rig type A average horsepower, 1,429 hp for electrical and 702 hp for mechanical drill rigs (from local data in Appendix A)
HRS_{dril}	= Hours per 1,000 feet drilled for drill rigs, 20.40 hours/1,000 feet from Equation 4-1
LF_A	= Load factor for drill rig Type A, 0.35 (from local industry data)
EF	= NO_X, VOC, or CO emission factor, Table 4-4 (from TCEQ TERP program for electric rigs and TexN Model for diesel drill rigs for mechanical)
PER	= Percent of Drill rigs operating using electricity from the power grid, 0%

Further research will be conducted to increase the accuracy of the drilling parameters and drill rig emission calculation methodology. If fuel usage for drill rigs is provided from the survey located in Appendix G, emission calculation methodology will be updated.

4.2 Other Drilling Non-Road Equipment

Other nonroad equipment used at drill sites includes cement pumps, excavator, and cranes. According to Caterpillar, "cementing is the process of pumping cement down a well bore to anchor the casing". Cementing is usually done with trucks that have "two engines of approximately 400 hp (300 kW) each".[173] This is similar to Weir, a leading supplier of pump engines, estimate of 600 – 1,000 total hp for well service pumps used in cementing, acidizing, and coiled tubing applications.[174] Cornell University report in the Marcellus also found that well sites need cement pumps with a total horsepower of 750.[175]

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[173] Caterpillar, 2006. "Application and Installation Guide: Petroleum Applications". Available online: http://www.blanchardmachinery.com/public/files/docs/PowerAdvisoryLibrary/CatAppInstGuide/PetroleumAppsLEBW4995-00.pdf. Accessed: 04/20/2012.

[174] WEIR, June 21, 2011. "2011 Capital Markets Day: Weir Oil & Gas Upstream". London, England. Slide 48. Available online: http://www.weir.co.uk/PDF/2011-06-21-WeirCapitalMarketsDay-pres.pdf. Accessed 05/20/2012.

[175] Santoro, R.L.; R.W. Howarth; A.R. Ingraffea. 2011. Indirect Emissions of Carbon Dioxide from Marcellus Shale Gas Development. A Technical Report from the Agriculture, Energy, & Environment Program at Cornell University. June 30, 2011. p. 8. Available online: http://www.eeb.cornell.edu/howarth/IndirectEmissionsofCarbonDioxidefromMarcellusShaleGasDevelopment_June302011%20.pdf. Accessed: 04/02/2012.

Existing data in the TexN Model will be used to calculate emission factors for other non-road equipment used during the drilling process (Table 4-5). Existing horsepower data in the TexN model will be used to calculate excavator and crane emissions because local data is not available. VOC, NO_X, and CO emissions for other non-road equipment used during drilling will be calculated using Equation 4-3.

Table 4-5: TexN 2011 Emission Factors and Parameters for other Non-Road Equipment used during Drilling

Parameters	Excavator	Crane	Cement Pump
Count per Site	1	1	2
Horsepower	197	230	400
Fuel Type	Diesel	Diesel	Diesel
Load Factor	0.59	0.43	0.43
NO_X EF (g/hp-hr)	4.687	3.659	4.996
VOC EF (g/hp-hr)	0.360	0.283	0.626
CO EF (g/hp-hr)	1.931	1.067	2.702

Equation 4-3, Ozone season day emissions from other non-road equipment used during drilling for each well

$$E_{Nonroad.ABC} = NUM_{BC} \times POP_A \times HP_A \times HRS_{drill} \times [DEP_{BC} + (LENGTH \times LNUM)] / 1{,}000 \text{ feet} \times LF_A \times EF / 907{,}184.74 \text{ grams per ton} / 365 \text{ days/year}$$

Where,

$E_{Nonroad.ABC}$ = Ozone season day NO_X, VOC, or CO emissions from non-road equipment type A in county B for Eagle Ford development well type C (Gas or Oil)

NUM_{BC} = Number of wells drilled in county B for Eagle Ford development well type C, from Table 4-1 (from Schlumberger Limited)

POP_A = Number of non-road equipment type A, from Table 4-5 (local data)

HP_A = Non-road equipment type A average horsepower, from Table 4-5 (TexN model for the excavator and crane, local data for cement pump)

HRS_{drill} = Hours per 1,000 feet drilled for drill rigs, 20.40 hours/1,000 feet from Equation 4-1

DEP_{BC} = Average depth of the well for county B for Eagle Ford development well type C, from Table 4-1 (from Schlumberger Limited)

LENGTH = Average length for a lateral distance, 5,490 feet, Table 4-3 (from Energy Strategy Partners)

LNUM = Number of Laterals per well, 1 (from Railroad Commission of Texas)

LF_A = Load factor for non-road equipment type A, from Table 4-5 (from TexN Model)

EF = NO_X, VOC, or CO emission factor non-road equipment type A, from Table 4-5 (from TexN model)

4.3 Fugitive emissions from Drilling Operations

Fugitive emissions from drilling operations will not be included in the emission inventory because no fugitive emissions associated with drilling activities were detected by Eastern Research Group study in Fort Worth.[176] Although only one natural gas well drilling operation was surveyed, local data is not available to make estimations of fugitive emissions from drilling operations in the Eagle Ford.

Storage ponds used to hold drill cuttings, mud, and fluids can be a potential source of VOC emissions. However, emissions from storage ponds are also not included because data is not available from storage ponds used during the drilling process. If updated data becomes available, this category will be included in the final emission inventory.

4.4 Drilling On-Road Emissions

Energy in Depth, consisting of a coalition led Independent Petroleum Association of America, states that it takes approximately 35-45 semi trucks (10,000 foot well) to move and assemble the rig (Table 4-6).[177] This result is very similar to TxDOT findings that 44 heavy duty trucks are needed to move a rig in the Barnett Shale.[178] TxDOT also states that an additional 73 heavy duty trucks are need to move drilling rig equipment and deliver supplies. The results are similar to most other studies that predicted between 80 and 235 truck trips are needed including Cornell University report in the Marcellus[179], Buys & Associates research in Utah[180], and Jonah Infill field study in Wyoming.[181] FlexRig 4S drill rigs used by Helmerich and Payne can be moved with 16 trucks and three cranes, for a total of about 42 loads.[182] Data from NCTCOG of governments on the number of heavy duty truck trips, 132, in the Barnett will be used to estimate emission in the Eagle Ford.[183]

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176 Eastern Research Group Inc. July 13, 2011. "Fort Worth Natural Gas Air Quality Study Final Report". Prepared for: City of Fort Worth, Fort Worth, Texas. p. 3-102. Available online: http://fortworthtexas.gov/gaswells/?id=87074. Accessed: 04/09/2012.

177 Energy in Depth: A coalition led by Independent Petroleum Association of America. Available online: http://www.energyindepth.org/rig/index.html. Accessed: 04/18/2012.

178 Richard Schiller, P.E. Fort, Worth District. Aug. 5, 2010. "Barnett Shale Gas Exploration Impact on TxDOT Roadways". TxDOT, Forth Worth. Slide 15.

179 Santoro, R.L.; R.W. Howarth; A.R. Ingraffea. 2011. Indirect Emissions of Carbon Dioxide from Marcellus Shale Gas Development. A Technical Report from the Agriculture, Energy, & Environment Program at Cornell University. June 30, 2011. p. 8. Available online: http://www.eeb.cornell.edu/howarth/IndirectEmissionsofCarbonDioxidefromMarcellusShaleGasDevelopment_June302011%20.pdf. Accessed: 04/02/2012.

180 Buys & Associates, Inc., Sept. 2008. "APPENDIX J: Near-Field Air Quality Technical Support Document for the West Tavaputs Plateau Oil and Gas Producing Region Environmental Impact Statement". Prepared for: Bureau of Land Management Price Field Office Littleton, Colorado. Available online: http://www.blm.gov/ut/st/en/fo/price/energy/Oil_Gas/wtp_final_eis.html. Accessed: 04/20/2012.

181 Amnon Bar-Ilan, ENVIRON Corporation, June 2010. "Oil and Gas Mobile Source Emissions Pilot Study: Background Research Report". UNC-EMAQ (3-12)-006.v1. Novato, CA. pp. 17-18. Available online: http://www.wrapair2.org/documents/2010-06y_WRAP%20P3%20Background%20Literature%20Review%20(06-06%20REV).pdf. Accessed: 04/03/2012.

182 Nov. 21, 2010. "A Tour of Titan Operating's FlexRig 4 Drilling Rig". Available online: http://www.whosplayin.com/xoops/modules/news/article.php?storyid=1893. Accessed: 04/20/2012.

183 North Central Texas Council of Governments. "Barnett Shale Truck Traffic Survey". Dallas, Texas. Slide 9. Available online: http://www.nctcog.org/trans/air/barnettshale.asp. Accessed 05/04/2012.

Table 4-6: On-Road Vehicles used for during Drilling from Previous Studies

Vehicle Type	Para-meter	Purpose	Cornell University, Marcellus	San Juan Public Lands Center, Colorado	Tumble-weed II, Utah	ENVIRON Colorado	ENVIRON Southern Ute	Jonah Infill, Wyoming	Pinedale Anticline Project, Wyoming	Buys & Associates Utah	National Park Service, Marcellus	New York City, Marcellus[184]	All Consulting Marcellus	NCTCOG. Barnett	TxDOT Barnett
HDDV	Number/ well	Drilling Rig	30	20	106	115.1	13	180	26.3	69	45	40	95	**132**	44
		Drilling Eq.	50				15		360		50-100	40-200+	140		73
	Distance (miles)	Drilling Rig	200	12.5	49.5	23.1	10	9.5	10	168	-	-	-	-	-
		Drilling Eq.	200				10		10						
	Speed (mph)	Drilling Rig	-	20 (road)	-	16.65	20	20 (road)	35	-	-	-	-	-	-
		Drilling Eq.					20		35						
	Idling Time	Drilling Rig	-	-	-	**0.7**	-	-	-	-	-	-	-	-	-
		Drilling Eq.													
LDT	Number/ well	Drilling Rig	-	25	8	**68.1**	213	60	8.8	69	-	-	140	-	-
		Drilling Eq.							540						
		Employee				**66**			-				140		
	Distance (miles)	Drilling Rig	-	40	49.5	84.15	10	9.5	10	168	-	-	-	-	-
		Drilling Eq.							10						
		Employee				118.85			-						
	Speed (mph)	Drilling Rig	-	30 (road)	-	18.43	30	30 (road)	35	-	-	-	-	-	-
		Drilling Eq.							35						
		Employee				18.43			-						
	Idling Hours/ trip	Drilling Rig	-	-	-	**1.55**	-	-	-	-	-	-	-	-	-
		Drilling Eq.													
		Employee				**2.1**									

184 Haxen and Sawyer, Environmental Engineers & Scientists, Sept. 2009. "Impact Assessment of Natural Gas Production in the New York City Water Supply Watershed Rapid Impact Assessment Report" New York City Department of Environmental Protection. p. 47. Available online: http://www.nyc.gov/html/dep/pdf/natural_gas_drilling/rapid_impact_assessment_091609.pdf. Accessed: 04/20/2012.

ENVIRON finding of 134 light duty truck trips needed for drilling operations in Colorado[185] will be used to calculate emissions from light duty trucks. The results are lower than ENVIRON findings of 213 light duty vehicles in Southern Ute [186], All Consulting vehicle count of 280 light duty vehicles in the Marcellus[187], and Pinedale Anticline Project determination of 548.8 light duty trucks in Wyoming[188]. On the other hand, San Juan Public Lands Center in Colorado[189] and Tumble-weed II in Utah[190] predicted fewer light duty vehicles.

VOC, NO_X, and CO emissions for heavy duty trucks and light duty trucks used during drilling will be calculated in Equation 4-4 for on-road emissions and Equation 4-5 for idling emissions. The inputs into the formula will be based on local data, MOVES output emission factors, NCTCOG truck counts, and data from ENVIRON's survey in Colorado.

Equation 4-4, Ozone season day on-road emissions during drilling operations

$E_{Dill.road.ABC}$ = NUM_{BC} x $TRIPS_A$ x ($DIST_B$ x 2) x OEF_A / 907,184.74 grams per ton / 365 days/year

Where,

$E_{Drill.road.ABC}$ = Ozone season day NO_X, VOC, or CO emissions from on-road vehicles in county B for Eagle Ford development well type C (Gas or Oil)

NUM_{BC} = Number of production wells drilled in county B for Eagle Ford development well type C, in Table 4-1 (from Schlumberger Limited)

$TRIPS_A$ = Number of trips for vehicle type A, 132 for heavy duty trucks (from NCTCOG in the Barnett), 68.1 for light duty trucks for equipment, and 66 light duty trucks for employees in Table 4-6 (from ENVIRON's Colorado report)

185 Amnon Bar-Ilan, John Grant, Rajashi Parikh, Ralph Morris, ENVIRON International Corporation, July 2011. "Oil and Gas Mobile Sources Pilot Study". Novato, California. p. 11. Available online: http://www.wrapair2.org/documents/2011-07_P3%20Study%20Report%20(Final%20July-2011).pdf. Accessed: 04/12/2012.

186 ENVIRON, August 2009. "Programmatic Environmental Assessment for 80 Acre Infill Oil and Gas Development on the Southern Ute Indian Reservation". Novato, California. Appendix A, p. 65. Available online: http://www.suitdoe.com/Documents/Appendix_G_AirQualityTSD.pdf. Accessed: 04/25/2012.

187 All Consulting, Sept. 16, 2010. "NY DEC SGEIS Information Requests". Prepared for Independent Oil & Gas Association, Project no.: 1284. Available online: http://catskillcitizens.org/learnmore/20100916IOGAResponsetoDECChesapeake_IOGAResponsetoDEC.pdf. Accessed: 04/16/2012.

188 U.S. Department of the Interior, Bureau of Land Management, Sept. 2008. "Final Supplemental Environmental Impact Statement for the Pinedale Anticline Oil and Gas Exploration and Development Project: Pinedale Anticline Project Area Supplemental Environmental Impact Statement". Sheyenne, Wyoming. pp. F45-F46. Available online: http://www.blm.gov/pgdata/etc/medialib/blm/wy/information/NEPA/pfodocs/anticline/rd-seis/tsd.Par.13395.File.dat/07appF.pdf. Accessed: 04/12/2012.

189 BLM National Operations Center, Division of Resource Services, December, 2007. "San Juan Public Lands Center Draft Land Management Plan & Draft Environmental Impact Statement: Air Quality Impact Assessment Technical Support Document". Bureau of Land Management, San Juan Public Lands Center, Durango, Colorado. p. A-6. Available online: http://ocs.fortlewis.edu/forestplan/DEIS/pdf/120507_TSD&App%20A.pdf. Accessed: 04/03/2012.

190 U.S. Department of the Interior, Bureau of Land Management. June 2010. "Tumbleweed II Exploratory Natural Gas Drilling Project". East City, Utah. DOI-BLM-UTG010-2009-0090-EA. p. 13 of 29. Available online: http://www.blm.gov/pgdata/etc/medialib/blm/ut/lands_and_minerals/oil_and_gas/november_2011.Par.24530.File.dat/. Accessed: 04/12/2012.

$DIST_B$ = Distance to the nearest town for county B, Table 3-2 (from Railroad Commission of Texas)
OEF_A = NO_X, VOC, or CO on-road emission factor for vehicle type A in Table 3-5 (from MOVES Model)

Equation 4-5, Ozone season day idling emissions during drilling operations

$E_{Dill.Idling.ABC}$ = NUM_{BC} x $TRIPS_A$ x $IDLE_A$ x IEF_A / 907,184.74 grams per ton / 365 days/year

Where,

$E_{Drill.Idling.ABC}$ = Ozone season day NO_X, VOC, or CO emissions from idling vehicles in county B for Eagle Ford development well type C (Gas or Oil)
NUM_{BC} = Number of production wells drilled in county B for Eagle Ford development well type C, in Table 4-1 (from Schlumberger Limited)
$TRIPS_A$ = Number of trips for vehicle type A, 117 for heavy duty trucks (from TxDOT in the Barnett), 68.1 for light duty trucks for equipment, and 66 light duty trucks in Table 4-6 (from ENVIRON's Colorado report)
$IDLE_A$ = Number of Idling Hours/Trip for vehicle type A, 0.4 hours for heavy duty trucks, 1.55 for light duty trucks for equipment, and 2.15 light duty trucks for employees in Table 4-6 (from ENVIRON's Colorado report)
IEF_A = NO_X, VOC, or CO idling emission factor for vehicle type A in Table 3-5 (from EPA based on the MOVES model)

5 HYDRAULIC FRACTURING AND COMPLETION OPERATIONS

5.1 Hydraulic Fracturing Description

"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." [191] "After fracturing is completed, the internal pressure of the geologic formation causes the injected fracturing fluids to rise to the surface where it may be stored in tanks or pits prior to disposal or recycling. Recovered fracturing fluids are referred to as flowback."[192]

"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.[193] According to Chesapeake Energy, "normally a hydraulic fracturing operation is only performed once during the life of a well".[194]

"Hydraulic fracturing is a well orchestrated yet logistically complex phase of the natural gas production process requiring a significant amount of planning/scheduling, materials, monitoring, equipment, and manpower. The complete multi-stage process involves perforation (or perfing) of the well casing from the end (or toe) of the well followed by plugging and hydraulic fracturing of that stage so that subsequent stages can be perforated, plugged, and fractured. The fracturing phase of the process can be broken down into three basic steps: Rig-Up Process, Hydraulic Fracturing and Perforating, and Rig-Down. After the well is drilled and cased it is ready to be fractured to stimulate production." "This process description describes one stage of the multi-stage hydraulic fracturing and perforating process. Additional stages simply repeat these steps."[195]

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[191] Chesapeake Energy, Jan. 2012. "Eagle Ford Shale Hydraulic Fracturing". Available online: http://www.chk.com/Media/Educational-Library/Fact-Sheets/EagleFord/EagleFord_Hydraulic_Fracturing_Fact_Sheet.pdf. Accessed: 04/27/2012.

[192] EPA, Dec. 07, 2011. "Hydraulic Fracturing Background Information". Available online: http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/wells_hydrowhat.cfm. Accessed: 04/23/2012.

[193] Eastern Research Group, Inc. July 15, 2009. "Drilling Rig Emission Inventory for the State of Texas". Prepared for: Texas Commission on Environmental Quality. Austin, Texas. p. 3-3 – 3.5. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820783985FY0901-20090715-ergi-Drilling_Rig_EI.pdf. Accessed: 04/09/2012.

[194] Chesapeake Energy, Jan. 2012. "Eagle Ford Shale Hydraulic Fracturing". Available online: http://www.chk.com/Media/Educational-Library/Fact-Sheets/EagleFord/EagleFord_Hydraulic_Fracturing_Fact_Sheet.pdf. Accessed: 04/27/2012.

[195] Texas Center for Applied Technology (TCAT), Nov. 2011. "Environmentally Friendly Drilling Systems Program Hydraulic Fracturing Phase Emissions Profile (Air Emissions Field Survey No. 1)". San Antonio, Texas. pp. 9-14.

5.1.1 Rig-Up Step

During the TCAT survey, the primary equipment that was used “was three (3) sand storage units, twelve (12) hydraulic fracturing pump trucks, two (2) small cranes, one (1) large 200 ton crane , four (4) fracturing water tanks, two (2) plug and perforating pump trucks, one (1) tank for plug and perforating water, four (4) water pumps, one (1) truck with a pulley system to run the perforating gun and plug, one (1) van to monitor operations, one (1) cooling room, several generators and light carts, two (2) flowback tanks, two (2) trailers for the site manager and cooks, and four (4) trucks carrying the missile (fracturing fluid manifold) and pipes for the rig up process.

After all the equipment is on site, the rig-up process begins. This process consists of positioning of all equipment and making all of the pipe connections necessary for the fracturing, plugging and perforating, and flowback processes. This is mostly done with manpower and vehicles but smaller cranes and lifts are also used to place pipe and the pump header (missile) equipment around the site. This process takes approximately one and a half days.”[196]

5.1.2 Hydraulic Fracturing and Perforating Steps

“Perforating is simply the use of a tube equipped with charges to perforate the well casing. Once a section is perforated it is then plugged to increase the effectiveness of the next stage of the hydraulic fracturing. Perforating and plugging are conducted using the large 200 ton crane hooked up to a slickline, which is a long pipe that is used to lubricate the perforating gun and plug. The perforating gun consists of several smaller guns (or charge sections). The number of guns is well dependent. The plug is a cylindrically shaped plug with a one inch hole in the middle that allows for better movement in the formation while the perforating is taking place. The slick line is a line connected to the pulley system stated above which connects to the perforating gun and plug. The perforating gun and plug are then connected and pulled up into the slick line.

After this, the top of the wellhead is removed and the slickline is attached to the top of the well head. It is bolted on using threads on the bottom of the slickline that match the top of the wellhead. Then the perforating gun controlled by the pulley system is dropped into the hole. Once the gun reaches the horizontal portion of the well, water is necessary to push it further down. To do this, the perforating/plug pump trucks (which are connected to the perforating/plug water tank via two (2) water pumps) pump water down the hole. The pumping typically starts at a rate of 3 barrels per min (bbl/min) and increases up to 12 bbl/min (as necessary) to push the perforating gun into position down hole. This typically this takes about 30 minutes.

Once the perforating gun is in place, a piston system in the gun pushes the plug off and sets it in place while the perforating gun is retracted to the location where the first cluster (smaller gun) is to be set off. The pulley truck pulls the gun back and sets off the first cluster by an electrical charge. It repeats this process until all the clusters have been set off. The gun is pulled back into the slickline and the slickline is removed from the wellhead. The complete perforating and plugging process takes about 2 hours. During this process, the truck is running continuously while the two (2) perforating/plugging trucks with the two (2) water pumps are running for about 30 minutes of that time.

After the perforating is completed, the well is ready to be fractured. The hydraulic fracturing process is not very complex but much preparation necessary to ensure proper flow. The

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[196] *Ibid*.

equipment used for this stage is two (2) water pumps (to pump water from the pond to the water tanks). A blender (used throughout the entirety of the hydraulic fracturing process), twelve (12) pump trucks are all running at rates near maximum output controlled by engineers. The hydraulic fracturing process generally takes between 3 and 3.5 hours total. The process begins at the hydraulic fracturing pond where water is pumped by the two (2) large water pumps to the water (leveling) tanks. From there, the water flows to the blender where it is mixed with a proppant (typically sand) and chemicals. The mixture contains mostly sand and water with a small amount of chemicals for various process controls (i.e., lubrication, corrosion inhibiting, microbial control, etc.). These constituents are constantly pumped into the blender from their storage containers. After the hydraulic fracturing fluid, called slickwater, is mixed, the fluid is pumped out of the blender to the pump trucks. These pump trucks are connected to the missile or pump manifold and pump the fluid through the missile manifold system. The fluid goes through the missile and into the wellbore at high pressures to fracture the formation which is kept open by the proppant (sand) in the slickwater. The proppant remains in the crevices after the water recedes back up the well to provide a highly porous pathway."[197] Figure 5-1 shows an example of the high pressure pump trucks used during hydraulic fracturing.

Figure 5-1: Hydraulic Fracturing High Pressure Pump Trucks[198]

5.1.3 Rig-Down Step

The rig-down step of the process simply refers to removal of all of the hydraulic fracturing and perforating/plugging equipment and vehicles from the site. "The perforating vehicles and equipment were first to leave the site while the fracturing continued. The hydraulic fracturing equipment was removed after the fracturing was concluded and during the flowback period. Flowback is simply the reversed flow of water from the well into the

[197] *Ibid*.

[198] John Davenport, San Antonio Express-News. "Hydraulic Fracturing". San Antonio, Texas. Available online: http://www.mysanantonio.com/slideshows/business/slideshow/Hydraulic-fracturing-15238.php#photo-1024121. Accessed: 04/27/2012.

hydraulic fracturing pond."[199] Aerial photographs of equipment used during hydraulic fracturing in the Eagle Ford are shown in Figure 5-2.

A layout of the equipment used during the hydraulic fracturing processed are provided in Figure 5-3.[200] Although it is simplified schematic of the process, it provides an overview of the equipment needed during the process including high pressure pump trucks, frac blenders, chemical storage trucks, fluid storage, sand storage units, and stimulation fluid storage.

5.2 Hydraulic Fracturing Pump Engines

5.2.1 Pump Engines Activity Data

The amount of time and engine load that frac pump engines operate during each frac stage can vary substantially based on various characteristics of the shale and what the operator feels is the best hydraulic fracturing design for maximum well production. Activity rates from previous studies varied between 3.7 hours used by ENVIRON in Colorado[201] to 120 hours from ERG's drill rig emission inventory in Texas.[202] All Consulting estimated that it takes 48 hours to hydraulic fracture a well with 8 frac stages in the Marcellus Shale Play[203], while Armendariz emission inventory in the Barnett Shale[204] and ENVIRON's Haynesville study both lists 54 hours (Table 5-1).[205]

[199] Texas Center for Applied Technology (TCAT), Nov. 2011. "Environmentally Friendly Drilling Systems Program Hydraulic Fracturing Phase Emissions Profile (Air Emissions Field Survey No. 1)". San Antonio, Texas. pp. 9-14.
[200] Chesapeake Energy. March 10th - 11th, 2011. Presented at EPA Hydraulic Fracturing Workshop. Slide 24. Available online: http://www.epa.gov/hfstudy/fracturedesigninhorizontalshalewells.pdf. Accessed 05/06/2012.
[201] Amnon Bar-Ilan, John Grant, Rajashi Parikh, Ralph Morris, ENVIRON International Corporation, July 2011. "Oil and Gas Mobile Sources Pilot Study". Novato, California. pp. 13. Available online: http://www.wrapair2.org/documents/2011-07_P3%20Study%20Report%20(Final%20July-2011).pdf. Accessed: 04/12/2012.
[202] Eastern Research Group, Inc. July 15, 2009. "Drilling Rig Emission Inventory for the State of Texas". Prepared for: Texas Commission on Environmental Quality. Austin, Texas. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820783985FY0901-20090715-ergi-Drilling_Rig_EI.pdf. Accessed: 04/09/2012.
[203] All Consulting, Sept. 16, 2010. "NY DEC SGEIS Information Requests". Prepared for Independent Oil & Gas Association, Project no.: 1284. Available online: http://catskillcitizens.org/learnmore/20100916IOGAResponsetoDECChesapeake_IOGAResponsetoDEC.pdf. Accessed: 04/16/2012.
[204] Al Armendariz. Jan. 26, 2009. "Emissions from Natural Gas Production in the Barnett Shale Area and Opportunities for Cost-Effective Improvements". Prepared for Environmental Defense Fund. Austin, Texas. p. 18. Available Online: http://www.edf.org/sites/default/files/9235_Barnett_Shale_Report.pdf. Accessed: 04/19/2012.
[205] John Grant, Lynsey Parker, Amnon Bar-Ilan, Sue Kemball-Cook, and Greg Yarwood, ENVIRON International Corporation. August 31, 2009. "Development of an Emission Inventory for Natural Gas Exploration and Production in the Haynesville Shale and Evaluation of Ozone Impacts". Novato, CA. p. 34. Available online: http://www.netac.org/UserFiles/File/NETAC/9_29_09/Enclosure_2b.pdf. Accessed: 04/19/2012.

Figure 5-2: Aerial Photography of Eagle Ford Well Frac Sites

Haliburton Well Frac Site, Christine, Texas[206]

Epley well site in McMullen County, Texas[207]

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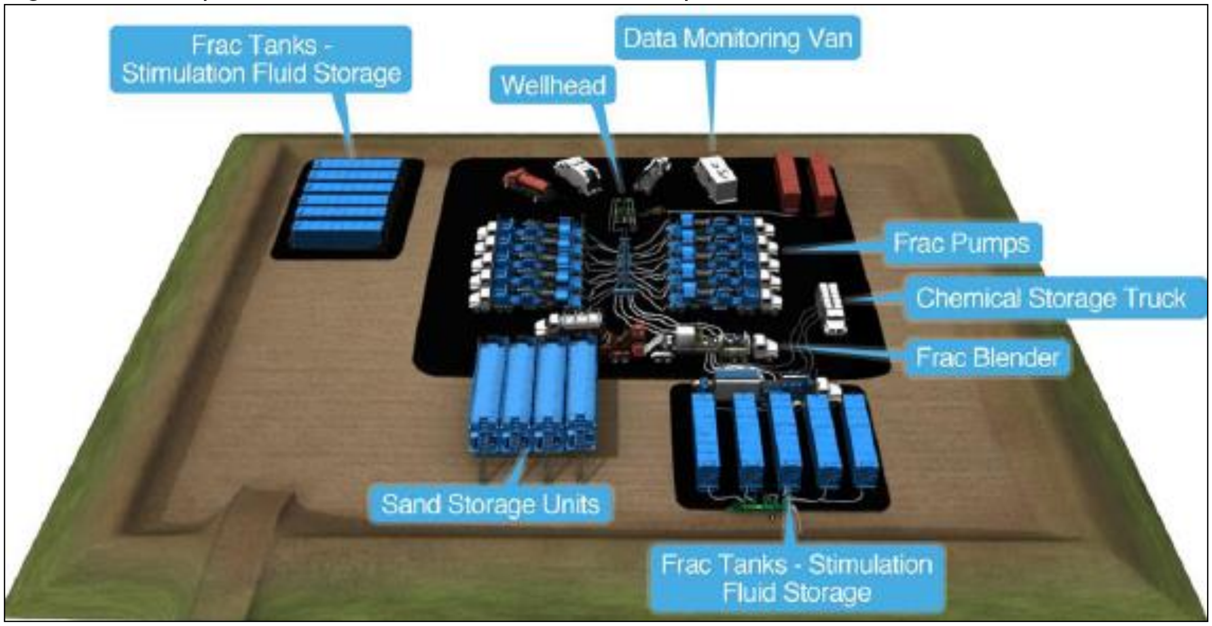
[206] Read Wing Aerials. Sept. 11, 2011. "Red Wing Aerials". San Antonio, Texas. Available online: http://www.redwingaerials.com/energy.html. Accessed: 04/02/2012.

[207] Doxa Energy Ltd. "Eagle Ford Shale Projects". Vancouver, B.C. Available online: http://www.doxaenergy.com/s/Eagle_Ford.asp. Accessed: 04/02/2012.

Figure 5-3: Simplified Location Schematic for Frac Operation



Raymond James & Associates estimates that it takes 5.3 days with an average of 11 stages to complete a frac job in 2011.[208] This result is similar to Chesapeake Energy's standard operating practice to complete fracturing within 3-5 days during daylight hours.[209] Using Chesapeake activity rate, the average number of hours to hydraulic fracture a well is between 36 and 60 (3-5 days at 12 hours per day). Pioneer Natural Resources averages 13.27 wells per year for each frac crew or one well every 27.5 days including moving the equipment, equipment setup, testing, and removal.[210] According to Rosetta Resources Inc, "early completions took eight days using the plug-and-perf method; today's completions pump three wells and 45 stages in just seven days.[211] This activity rate would average just 28 hours per well based on a 12 hour work day.

[208] J. Marshall Adkins, Collin Gerry, and Michael Noll, Jan. 10, 2011. "Energy: Industry Overview: We Don`t Hear Her Singing, the Pressure Pumping Party Ain't Over Yet". Raymond James & Associates. Available online: http://gesokc.com/sites/globalenergy/uploads/documents/Energy_by_Raymond_James.pdf. Accessed: 04/20/2012.

[209] Chesapeake Energy Corporation, 2012. "Part 1 – Drilling". Available online: http://www.askchesapeake.com/Barnett-Shale/Multimedia/Educational-Videos/Pages/Information.aspx. Accessed: 04/22/2012

[210] Feb 8, 2012. "Pioneer Natural Resources". Credit Suisse 2012 Energy Summit. Slide 31. Available online: http://media.corporate-ir.net/media_files/irol/90/90959/2012-02-08_Credit_Suisse_Conference.pdf. Accessed: 04/13/2012.

[211] Steve Toon, Feb. 1, 2012. "Boom Days In The Eagle Ford". The Champion Group". Available online: http://www.championgroup.com/news/boom-days-in-the-eagle-ford/. Accessed: 04/20/2012.

Table 5-1: Pump Engines Parameters used for Hydraulic Fracturing from Previous Studies

Pump Engine Parameters	TexN Model, Eagle Ford Counties	ERG's Fort Worth Natural Gas Study, Barnett	TCAT Survey, Eagle Ford	ERG's Drilling Rig Emission Inventory, Texas	ENVIRON, Haynesville Shale	Armendariz Barnett Shale	Cornell University, Marcellus Study	Tumble-weed II, Utah	ENVIRON, Colorado	Ohio EPA[212]	Pioneer Drilling, Eagle Ford[213]
Count per Site		12	**6**	5-7					6.0	15	
Horsepower	53	2,250	**2,250**	1,250 – 2,500	1,000 for all engines	1,000 for all engines	9,300 for all engines	1,025 for all engines	9,000 for all engines	1,125	50,000 for all engines
Hours		120		1 – 12	**54**	54	70	8	3.7	24-36	
Fuel Type	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	
LF	0.43	1.0	**0.30125**		0.5	0.5	1.0	0.65		-	

212 Michael Hopkins, Assistant Chief, Permitting, Ohio EPA. Nov. 29, 2011. “Air Permitting for Oil & Gas Well Sites”. Ohio. Slide 10. Available online: http://www.morpc.org/calendarfiles01/OEPAAirPerm112911.pdf. Accessed: 05/12/2012.
213 Business Wire, A Berkshire Hathaway Company, Feb 6, 2012. “Pioneer Natural Resources Reports Fourth Quarter 2011 Financial and Operating Results and Announces 2012 Capital Budget “. Available online: http://www.businesswire.com/news/home/20120206006456/en/Pioneer-Natural-Resources-Reports-Fourth-Quarter-2011. Accessed: 04/13/2012.

The number of frac stages per well has increased dramatically in the last few years: 11 stages in 2008, 15 stages in 2009, and 20 stages in 2010 in the Eagle Ford.[214] To provided an comparison with previous studies, data from Swift Energy was used to calculate the estimate the amount of time to frac each well. The company uses using 16-17 stage fracs with 300-350 foot spacing. In a 6,000 foot lateral frac line, Swift Energy "would pump about 340,000 pounds of sand and 7,500 bbl of frac water for each stage," [215] Since the company is using gel and slick water, they can pump the jobs at 65-80 barrels a minute. By using this data, we can estimate the amount of time pump engines need to hydraulic fracture a well with one lateral using the following equation.

Equation 5-1, Example calculation for hours per fracking for Swift Energy

$$HRS = (NFRAC \times BBL) / (BMIN \times 60 \text{ minutes/hour} \times LF)$$

Where,

HRS	= Hours per fracking
NFRAC	= Number of frac stages, 16.5 (from Swift Energy Company)
BBL	= Number of Barrels of frac water per stage, 7,500 (from Swift Energy Company)
LF	= Load factor for pumps, 0.30 from Table 5-1 (from surveys with local industry)
BMIN	= Barrels per minute, 72.5 (from Swift Energy Company)

Sample Equation

$$HRS = (16.5 \times 7{,}500) / (72.5 \text{ barrels/minute} \times 60 \text{ minutes/hour} \times 0.3)$$

$$HRS = 94.8 \text{ hours}$$

The 123,750 bbl used by Swift Energy for each lateral is similar to BHP Billiton Petroleum (Petrohawk) use of 100,000 barrels of water for fracing operations at each well.[216] Similarly, All Consulting in the Marcellus Shale Play found an average of 97,649 bbl of frac fluid used per well.[217] Chesapeake Energy uses approximately 6 million gallons of water (190,476 bbls) per well[218]. When the result from Equation 5-1, 94.8 hours, is compared to 54 hours for pump engines from ENVIRON's Haynesville Shale study, the hours estimated in the equation are higher. To estimate emissions from pump engines, a conservative estimation of 54 hours from ENVIRON's study will be used. Also, the number of hours it takes to complete hydraulic fracturing per well is decreasing as technology is improved.

214 Dwayne H. Warkentin, Madalena Ventures Inc. January 2012. "Incentivizing Suppliers". Presented at Buenos Aires Conference Available online: http://www.madalena-ventures.com/download/Madalena%20Shale%20Conference%20Jan%202012%20-%20Final.pdf. Accessed: 04/20/2012.

215 Colter Cookson, June 2011. "Operators Converge On Eagle Ford's Oil And Liquids-Rich Gas". The American Oil and Gas Reporter. Available online: http://www.laredoenergy.com/sites/default/files/0611LaredoEnergyEprint.pdf. Accessed: 04/02/2012.

216 J. Michael Yeager, Group Executive and Chief Executive, Petroleum, Nov. 14, 2011. "BHP Billiton Petroleum Onshore US Shale Briefing". Available online: http://www.bhpbilliton.com/home/investors/reports/Documents/2011/111114_BHPBillitonPetroleumInvestorBriefing_Presentation.pdf. Accessed: 04/12/2012.

217 All Consulting, Sept. 16, 2010. "NY DEC SGEIS Information Requests". Prepared for Independent Oil & Gas Association, Project no.: 1284. Available online: http://catskillcitizens.org/learnmore/20100916IOGAResponsetoDECChesapeake_IOGAResponsetoDEC.pdf. Accessed: 04/16/2012.

218 Chesapeake Energy, 2011. "Shale Operations Overview". Available online: http://www.ceao.org/e_conferences/winter/2011/Presentations/ChesapeakePresentation.pdf. Accessed: 04/14/2012.

5.2.2 Pump Engines Horsepower

Previous studies have estimations between 1,000 to 50,000 horsepower for all engines used during hydraulic fracturing. The Tumble-weed II project in Utah only estimate 1,025 hp for all engines[219] and Ohio EPA stated 1,125 hp[220], while Cornell University report in the Marcellus listed 9,300 hp[221]. Other studies had even higher horsepower estimations: average horsepower needed per frac job was 34,125 according to Raymond James & Associates.[222] For all engines needed during the hydraulic fraction, Pioneer Drilling uses up to 50,000 hp for each hydraulic fracturing job in the Eagle Ford.[223]

According to Randy LaFolletteat Shale Gas Technology BJ Services Company, injection rate and surface treating pressure requires a minimum of 20,000 hydraulic horsepower (HHP).[224] Weir, a leading supplier of pump engines, estimates that 17,000 – 30,000 frack hp is needed in the Bakken and Marcellus shale plays.[225] ERG drill rig emission inventory in Texas[226] and the TCAT's survey[227] listed 11,250 total hp used by pump engines during the hydraulic fracturing. TCAT also had an additional 2,240 hp from Perf & Plug Pump trucks. Total engine hp of 13,500 will be used to calculate pump engine emissions.

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219 U.S. Department of the Interior, Bureau of Land Management. June 2010. "Tumbleweed II Exploratory Natural Gas Drilling Project". East City, Utah. DOI-BLM-UTG010-2009-0090-EA. p. 17 of 29. Available online: http://www.blm.gov/pgdata/etc/medialib/blm/ut/lands_and_minerals/oil_and_gas/november_2011.Par.24530.File.dat/. Accessed: 04/12/2012.

220 Michael Hopkins, Assistant Chief, Permitting, Ohio EPA. Nov. 29, 2011. "Air Permitting for Oil & Gas Well Sites". Ohio. Slide 10. Available online: http://www.morpc.org/calendarfiles01/OEPAAirPerm112911.pdf. Accessed: 05/12/2012.

221 Santoro, R.L.; R.W. Howarth; A.R. Ingraffea. 2011. "Indirect Emissions of Carbon Dioxide from Marcellus Shale Gas Development. A Technical Report from the Agriculture, Energy, & Environment Program at Cornell University." June 30, 2011. p. 8. Available online: http://www.eeb.cornell.edu/howarth/IndirectEmissionsofCarbonDioxidefromMarcellusShaleGasDevelopment_June302011%20.pdf. Accessed: 04/02/2012.

222 J. Marshall Adkins, Collin Gerry, and Michael Noll, Jan. 10, 2011. "Energy: Industry Overview: We Don`t Hear Her Singing, the Pressure Pumping Party Ain't Over Yet". Raymond James & Associates. Available online: http://gesokc.com/sites/globalenergy/uploads/documents/Energy_by_Raymond_James.pdf. Accessed: 04/20/2012.

223 Business Wire, A Berkshire Hathaway Company, Feb 6, 2012. "Pioneer Natural Resources Reports Fourth Quarter 2011 Financial and Operating Results and Announces 2012 Capital Budget ". Available online: http://www.businesswire.com/news/home/20120206006456/en/Pioneer-Natural-Resources-Reports-Fourth-Quarter-2011. Accessed: 04/13/2012.

224 Randy LaFollette, Manager, Shale Gas Technology BJ Services Company, Sept. 9, 2010. "Key Considerations for Hydraulic Fracturing of Gas Shales". Slide 32. Available online: http://www.pttc.org/aapg/lafollette.pdf. Accessed 05/04/2012.

225 WEIR, June 21, 2011. "2011 Capital Markets Day: Weir Oil & Gas Upstream". London, England. Slide 43. Available online: http://www.weir.co.uk/PDF/2011-06-21-WeirCapitalMarketsDay-pres.pdf. Accessed 05/20/2012.

226 Eastern Research Group, Inc. July 15, 2009. "Drilling Rig Emission Inventory for the State of Texas". Prepared for: Texas Commission on Environmental Quality. Austin, Texas. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820783985FY0901-20090715-ergi-Drilling_Rig_EI.pdf. Accessed: 04/09/2012.

227 Texas Center for Applied Technology (TCAT), Nov. 2011. "Environmentally Friendly Drilling Systems Program Hydraulic Fracturing Phase Emissions Profile (Air Emissions Field Survey No. 1)". San Antonio, Texas. pp. 9-14.

Table 5-2: Pump Engines 2011 Emission Factors from Previous Studies

Pollutant	TexN Model. Generators Eagle Ford Counties	ERG's Fort Worth Natural Gas Study, Barnett	TCAT Survey, Eagle Ford	ENVIRON, Haynesville Shale EI	EPA (kW > 900)[228]				Caterpillar Inc.[229]		TCEQ	
					Tier 1	Tier 2	Tier 4 Interim	Tier 4	(Tier 2)	(Tier 4 Interim 2011 Model Year)	Tier 2, (Engines ≥ 750 hp)	Tier 4 (gensets > 1,200 hp)
NO_X EF	5.00 g/hp-hr	4.77 g/hp-hr	1.34E-02 lb/hp-hr	8.0 g/bhp-hr	9.2	6.4	0.67	0.67	6.1 g NO_X + HC/kw-hr	3.1 g/kw-hr	**4.56 g/bhp-hr**	0.50 g/bhp-hr
VOC EF	0.66 g/hp-hr		7.07E-04 lb/hp-hr	1.0 g/bhp-hr	1.3		0.40	0.19		0.17 g of HC/kw-hr	**0.24 g/bhp-hr**	-
CO EF	**2.67 g/hp-hr**	2.61 g/hp-hr	2.47E-03 lb/hp-hr	5.0 g/bhp-hr	11.4	3.5	3.5	3.5	2.3 g /kw-hr	0.5 g /kw-hr	-	-

228 EPA, Jan. 7, 2011. "Nonroad Compression-Ignition Engines - Exhaust Emission Standards". Available online: http://epa.gov/oms/standards/nonroad/nonroadci.htm. Accessed: 05/15/2012.
229 California Environmental Protection Agency Air Resources Board, March 30, 2011. "New Off-Road Compression-Ignition Engines: Caterpillar Inc.".

5.2.3 Pump Engine Emission Calculation Methodology

Pump engines emission factors from previous studies are provided in Table 5-2. TCEQ's TERP emission factors for Tier 2 Engines > 750 hp are 4.56 g of NO_X/hp-hr and 0.24 g of VOC/hp-hr,[230] whereas Caterpillar Inc. emission factors for Tier 4 Interim 2011 Model Year > 560 kW are 3.1 g NO_X/kw-hr and 0.17 g HC/kw-hr.[231] The emission factors from TERP will be used to calculate pump engine emissions. Through local industry contacts, engine load of 30% will be used to calculate VOC, NO_X, and CO emissions.

Equation 5-2, Ozone season day pump engine emissions for each well

$$E_{Pump.BC} = NWEL_{BC} \times PUMP \times HP \times HRS \times LF \times EF / 907{,}184.74 \text{ grams per ton} / 365 \text{ days/year}$$

Where,

$E_{Pump.BC}$	= Ozone season day NO_X, VOC, or CO emissions from pump trucks in county B for Eagle Ford development well type C (Gas or Oil)
$NWEL_{BC}$	= Number of production wells drilled in county B for Eagle Ford development well type C, Table 4-1 (from Schlumberger Limited)
PUMP	= Number of pump trucks per fracking operation, 5 trucks, Table 5-1 (from TCAT Eagle Ford Survey, ERG's Fort Worth Natural Gas Study, local data, and aerial imagery)
HP	= Pump trucks average horsepower, 2,250 hp, Table 5-1 (from TCAT Eagle Ford Survey and ERG's Drilling Rig Emission Inventory for the State of Texas)
HRS	= Hours per hydraulic fracturing operation, 54 hours, Table 5-1 (from ENVIRON's Haynesville Shale report)
LF	= Load factor for generators used by the pumps, 0.30125, Table 5-1 (from local industry provided in the TCAT Eagle Ford survey)
EF	= NO_X, VOC, or CO emission factor for generators, Table 5-2 (from TCEQ TERP program for Engines ≥ 750 hp)

If local data on pump engines is provided from the survey located in Appendix G, emission calculation methodology will be updated.

5.2.4 Perf & Plug Pump Trucks

"Traditional multi-stage fracturing treatments include the common "perf-and-plug" method. This technique requires multiple trips in and out of the well to accomplish individual components of an overall fracture-stimulation completion. Perf-and-plug uses a perforating assembly to initiate a fracture by using shaped explosives. Once the perforation has been created, the assembly is run out of the hole and the wellhead is rigged up to pump trucks so that proppant can be injected into the fractured zone. Once completed, the pumping equipment is detached and a new perforating assembly coupled with a mechanical plug is run into the hole and set to isolate the treated zone from the next highest zone targeted for stimulation. There, the perforation assembly is triggered to initiate a fracture in the new target zone, which is run back out of the hole to allow for the pumping of proppant into the fracture. This process continues until all zones within the well have been treated."[232]

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[230] TCEQ, April 24, 2010. "Texas Emissions Reduction Plan (TERP): Emissions Reduction Incentive Grants Program Technical Supplement No. 2, Non-Road Equipment". Austin, Texas. p. 5.
[231] California Environmental Protection Agency Air Resources Board, March 30, 2011. "New Off-Road Compression-Ignition Engines: Caterpillar Inc.".
[232] Halliburton, 2012. "CobraMax® Extreme Multistage Fracturing". Available online: http://www.halliburton.com/ToolsResources/default.aspx?navid=1204&pageid=2411. Accessed: 04/12/2012

To calculate emissions from Perf & Plug pump trucks, the same methodology for pump engines in Equation 5-2 will be used. TCAT survey found two Perf & Plug pump trucks with 2,240 hp are used to hydraulic fracturing 2 wells. [233] Further research needs to be complete because these engines usually run fewer hours than other hydraulic pumps and may have different load factors. Also, some horizontal wells use different technology to perforate lateral lines used to release product.

5.3 Other Hydraulic Fracturing Non-Road Equipment

Other equipment, such as water pumps (Figure 5-4), blender truck (Figure 5-5), sand kings, blow out control system, forklifts, generators, bulldozer, backhoe, high pressure water cannon, and cranes, are needed to complete the hydraulic fracturing of the well. "Blenders are the equipment used to prepare the slurries and gels commonly used in stimulation treatments. The blender should be capable of providing a supply of adequately mixed ingredients at the desired treatment rate. Modern blenders are computer controlled, enabling the flow of chemicals and ingredients to be efficiently metered and requiring a relatively small residence volume to achieve good control over the blend quality and delivery rate."[234] Sand kings deliver proppant "to location and delivers it to the blender for mixing with the fracturing fluid".[235]

Data from the TCAT Eagle Ford survey, located in Table 5-3, will be used to estimate equipment population and horsepower for other non-road equipment used during hydraulic fracturing. The few other studies that collected data on the other equipment used during hydraulic fraction did not include horsepower or equipment counts. The best data available on other non-road equipment is the TCAT survey conducted in the Eagle Ford. Six diesel powered 13.6 hp light towers were included in the TCAT Survey, but emissions from light towers not included in the emission inventory because no activity data is available.

Existing data in the TexN Model will be used to calculate emission factors for other non-road equipment used during the hydraulic fracturing process (Table 5-4). Existing horsepower data in the TexN model will be used to calculate emissions from the small generator and small crane because local data is not available. Industrial data on blenders will be used to estimate average horsepower because survey data is not available. VOC, NO_X, and CO emissions for other non-road equipment used during hydraulic fracturing will be calculated using Equation 5-3.

[233] Texas Center for Applied Technology (TCAT), Nov. 2011. "Environmentally Friendly Drilling Systems Program Hydraulic Fracturing Phase Emissions Profile (Air Emissions Field Survey No. 1)". San Antonio, Texas. pp. 9-14.
[234] Caterpillar, 2006. "Application and Installation Guide: Petroleum Applications". Available online: http://www.blanchardmachinery.com/public/files/docs/PowerAdvisoryLibrary/CatAppInstGuide/PetroleumAppsLEBW4995-00.pdf. Accessed: 04/20/2012.
[235] Randy LaFollette, Manager, Shale Gas Technology, BJ Services Company, Sept. 9, 2010. "Key Considerations for Hydraulic Fracturing of Gas Shales". Slide 32. Available online: http://www.pttc.org/aapg/lafollette.pdf. Accessed 05/20/2012.

Figure 5-4: A Water Pump used during Hydraulic Fracturing[236]

Figure 5-5: A Blender Truck used during Hydraulic Fracturing[237]

[236] Texas Center for Applied Technology (TCAT), Nov. 2011. “Environmentally Friendly Drilling Systems Program Hydraulic Fracturing Phase Emissions Profile (Air Emissions Field Survey No. 1)”. San Antonio, Texas. p. 37.
[237] *Ibid*. p. 35.

Table 5-3: Hydraulic Fracturing Other Non-Road Equipment Parameters from TCAT Survey

Equipment Type	SCC	Population	Horsepower
Blender Truck	2270010010	1	634 (Industry Data) [238]
Water Pumps	2270006010	5	384
Sand Kings	2270010010	3	78
Blow Out Control System	2270010010	1	12.6
Forklifts	2270003020	1	110
Generators	2270006005	5	87.4
Generators	2270006005	1	50 (from TexN Model)
Bulldozer	2270002069	1	99
Backhoe	2270002066	1	88
High Pressure Water Cannon	2270010010	1	200
Crane (large)	2270002045	1	517
Crane (small)	2270002045	1	230 (from TexN Model)

Table 5-4: TexN 2011 Emission Factors and Parameters for other Non-Road Equipment used During Hydraulic Fracturing

Equipment Type	Fuel Type	SCC	LF	NO_X EF (g/hp-hr)	VOC EF (g/hp-hr)	CO EF (g/hp-hr)
Blender, Sand Kings, Blow Out, and Water Cannon	Diesel	2270010010	0.43			
Water Pumps	Diesel	2270006010	0.43	4.996	0.626	2.702
Forklifts	Diesel	2270003020	0.59	2.987	0.254	2.694
Generators	Diesel	2270006005	0.59	5.001	0.658	2.670
Bulldozer	Diesel	2270002069	0.59	2.895	0.240	1.503
Backhoe	Diesel	2270002068	0.59	5.036	1.252	6.151
Crane	Diesel	2270002045	0.59	3.659	0.283	1.067

[238] Examples of blender trucks are located at these web sites http://www.j4oilfield.com/PDF/2011_J4_Brochure_Full_Online.pdf, 665 hp, http://www.dragonproductsltd.com/pumps/fe-mobile-blending.html, 515 hp, http://www.drillquest.net/pdf/items/datasheet-1367.pdf, 410 hp, http://www.slb.com/~/media/Files/sand_control/catalogs/scps_04_equipment.ashx, 325 hp http://www.drillquest.net/buy.php?cat=2080, 410 hp, http://www.cvatanks.com/wp-content/uploads/2011/07/OG.pdf, 650 hp, http://www.stewartandstevenson.com/Literature/documents/STIMULATION_BROCHURE.pdf, 330-1450 hp, http://www.marineturbine.com/blender.asp, 1,400 hp, http://higherlogicdownload.s3.amazonaws.com/SPE/9944f188-7d04-423e-b223-18ceee84e37f/UploadedImages/SPE%20YP%20Oct%2027%202011.pdf, 420 hp

Equation 5-3, Ozone season day emissions from other non-road equipment used during hydraulic fracturing

$E_{Nonroad.ABC}$ = NUM_{BC} x POP_A x HP_A x HRS x LF_A x EF / 907,184.74 grams per ton / 365 days/year

Where,

$E_{Nonroad.ABC}$ = Ozone season day NO_X, VOC, or CO emissions from non-road equipment type A in county B for Eagle Ford development well type C (Gas or Oil)
NUM_{BC} = Number of production wells drilled in county B for Eagle Ford development well type C, from Table 4-1 (from Schlumberger Limited)
POP_A = Number of non-road equipment type A, from Table 5-3 (TCAT Survey, Eagle Ford)
HP_A = Non-road equipment type A average horsepower, from Table 5-3 (TCAT Survey, Eagle Ford and TexN Model)
HRS = Hours per hydraulic fracturing operation – 54 hours, from Table 5-1 (from ENVIRON's Haynesville Shale report)
LF_A = Load factor non-road equipment type A, from Table 5-3 (from TexN Model)
EF = NO_X, VOC, or CO emission factor non-road equipment type A, from Table 5-4 (from TexN Model)

5.4 Hydraulic Fracturing Fugitive Emissions

Fugitive emissions from hydraulic fracturing will not be included in the emission inventory because no emissions associated with hydraulic fracturing activities were detected by Eastern Research Group study in Fort Worth.[239] Although only one natural gas hydraulic fracturing operation was surveyed in Fort Worth, data is not available to make estimations of fugitive emissions from hydraulic fracturing operations in the Eagle Ford.

Storage ponds used to hold fracturing fluid during flowback can be a potential source of VOC emissions. However, emissions from storage ponds are not included because there are no emission factors for storage ponds available. If updated data becomes available, this category will be included in the final emission inventory.

5.5 Hydraulic Fracturing On-Road Emissions

Heavy duty trucks are needed to provide equipment, water, sand/ proppant, chemicals, and supplies, while trucks are sometimes also needed to remove flowback from the well site. Previous studies, listed in Table 5-5, found between 15 and 2,100 trucks are needed during the hydraulic fracturing and completion of the well site. Jonah Infill in Wyoming[240] and NCTCOG[241] found between 400 and 440 heavy duty truck trips are needed during hydraulic fracturing. A Cornell University report determined that 790 heavy duty trucks are used in the Marcellus.[242] These results are similar to All Consulting vehicle count of 868 heavy duty

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[239] Eastern Research Group Inc. July 13, 2011. "Fort Worth Natural Gas Air Quality Study Final Report". Prepared for: City of Fort Worth, Fort Worth, Texas. p. 3-102. Available online: http://fortworthtexas.gov/gaswells/?id=87074. Accessed: 04/09/2012.

[240] Amnon Bar-Ilan, ENVIRON Corporation, June 2010. "Oil and Gas Mobile Source Emissions Pilot Study: Background Research Report". UNC-EMAQ (3-12)-006.v1. Novato, CA. p. 17. Available online: http://www.wrapair2.org/documents/2010-06y_WRAP%20P3%20Background%20Literature%20Review%20(06-06%20REV).pdf. Accessed: 04/03/2012.

[241] North Central Texas Council of Governments. "Barnett Shale Truck Traffic Survey". Dallas, Texas. Slide 9. Available online: http://www.nctcog.org/trans/air/barnettshale.asp. Accessed 05/04/2012.

[242] Santoro, R.L.; R.W. Howarth; A.R. Ingraffea. 2011. Indirect Emissions of Carbon Dioxide from Marcellus Shale Gas Development. A Technical Report from the Agriculture, Energy, & Environment

trucks[243] and Park Service average of 695 heavy duty trucks in the Marcellus.[244] Data from TxDOT in the Barnett Shale, 807 heavy duty trucks, will be used for calculating emissions. When calculating truck trips, TxDOT assumes that 50% of the freshwater is provided by pipeline. This is similar to what some companies are doing in the Eagle Ford. For example, Rosetta "has built water gathering pipelines to eliminate the need to truck water to the fracturing crew". [245]

The number trips by light duty vehicles ranged from 30 found in the San Juan Public Lands Center study in Colorado[246] to All Consulting estimation of 461 in the Marcellus. Most of the studies found approximately 140 light duty vehicle trips are needed including ENVIRON Southern Ute[247], and Buys & Associates research in Utah[248]. To calculate on-road vehicle emissions, the number of light duty vehicles and idling rates will be based on ENVIRON's survey in Colorado.[249] Hydraulic fracturing on-road VOC, NO_X, and CO emissions for heavy duty trucks and light duty trucks will be calculated using Equation 5-4 and Equation 5-5.

Program at Cornell University. June 30, 2011. p. 8. Available online: http://www.eeb.cornell.edu/howarth/IndirectEmissionsofCarbonDioxidefromMarcellusShaleGasDevelopment_June302011%20.pdf. Accessed: 04/02/2012.

[243] All Consulting, Sept. 16, 2010. "NY DEC SGEIS Information Requests". Prepared for Independent Oil & Gas Association, Project no.: 1284. Available online: http://catskillcitizens.org/learnmore/20100916IOGAResponsetoDECChesapeake_IOGAResponsetoDEC.pdf. Accessed: 04/16/2012.

[244] National Park Service U.S. Department of the Interior, Dec. 2008. "Potential Development of the Natural Gas Resources in the Marcellus Shale: New York, Pennsylvania, West Virginia, and Ohio". p. 9. Available online: http://www.nps.gov/frhi/parkmgmt/upload/GRD-M-Shale_12-11-2008_high_res.pdf. Accessed: 04/22/2012.

[245] Colter Cookson. June, 2011. "Operators Converge On Eagle Ford's Oil and Liquids-Rich Gas". The American Oil and Gas Reporter. p. 3. Available online: http://www.laredoenergy.com/sites/default/files/0611LaredoEnergyEprint.pdf. Accessed: 04/12/2012.

[246] BLM National Operations Center, Division of Resource Services, December, 2007. "San Juan Public Lands Center Draft Land Management Plan & Draft Environmental Impact Statement: Air Quality Impact Assessment Technical Support Document". Bureau of Land Management, San Juan Public Lands Center, Durango, Colorado. p. A-9. Available online: http://ocs.fortlewis.edu/forestplan/DEIS/pdf/120507_TSD&App%20A.pdf. Accessed: 04/03/2012.

[247] ENVIRON, August 2009. "Programmatic Environmental Assessment for 80 Acre Infill Oil and Gas Development on the Southern Ute Indian Reservation". Novato, California. Appendix A, p. 68. Available online: http://www.suitdoe.com/Documents/Appendix_G_AirQualityTSD.pdf. Accessed: 04/25/2012.

[248] Buys & Associates, Inc., Sept. 2008. "APPENDIX J: Near-Field Air Quality Technical Support Document for the West Tavaputs Plateau Oil and Gas Producing Region Environmental Impact Statement". Prepared for: Bureau of Land Management Price Field Office Littleton, Colorado. Available online: http://www.blm.gov/ut/st/en/fo/price/energy/Oil_Gas/wtp_final_eis.html. Accessed: 04/20/2012.

[249] Amnon Bar-Ilan, John Grant, Rajashi Parikh, Ralph Morris, ENVIRON International Corporation, July 2011. "Oil and Gas Mobile Sources Pilot Study". Novato, California. p. 11. Available online: http://www.wrapair2.org/documents/2011-07_P3%20Study%20Report%20(Final%20July-2011).pdf. Accessed: 04/12/2012.

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Table 5-5: On-Road Vehicles Used During Hydraulic Fracturing and Completion from Previous Studies

Vehicle Type	Para-meter	Purpose	Cornell University Marcellus	San Juan Public Lands Center, Colorado	ENVIRON Colorado	ENVIRON Southern Ute	Jonah Infill, Wyoming	Pinedale Anticline Project, Wyoming	Buys & Assoc-iates, Utah	National Park Service, Marcellus	New York City, Marcellus	All Consulting Marcellus	NCTCOG, Barnett	TxDOT, Barnett
HDDV	Number/ well	Completion Eq.	5	15	148.6	5	400	300	238	5	10	5	440	**4**
		Fracture Eq.	150			94				100-150	40	220		**94**
		Water/Sand Truck	440			21				100-1,000	350-1,000	523		**685**
		Chemical Truck	5			1				10-20	5-50	20		**-**
		Flowback Trucks	190			-				-	350-1,000	100		**24**
	Distance (miles)	Completion Eq.	200	12.5	40.2	10	9.5	10	168	-	-	-	-	-
		Fracture Eq.	200			10								
		Water/Sand Truck	125			10								
		Chemical Truck	125			10								
		Flowback Trucks	125			10								
	Speed (mph)	Completion Eq.	-	20 (road)	16.85	20	20 (road)	35	-	-	-	-	-	-
		Fracture Eq.				20								
		Water/Sand Truck				20								
		Chemical Truck				20								
		Flowback Trucks				20								
	Idling Hours/trip	Completion Eq.	-	-	**1.1**	-	-	-	-	-	-	-	-	-
		Fracture Eq.												
		Water/Sand Truck												
		Chemical Truck												
		Flowback Trucks												
LDT	Number/ well	Eq./Supplies	-	30	**41**	16	170	450	134	-	-	376	-	-
		Employee			**86.7**	113						85		
	Distance (miles)	Eq./Supplies	-	12.5	100.0	10	9.5	10	168	-	-	-	-	-
		Employee			118.85	10								
	Speed (mph)	Eq./Supplies	-	30 (road)	20.0	30	30 (road)	35	-	-	-	-	-	-
		Employee			18.425	30								
	Idling Hours/trip	Eq./Supplies	-	-	**2.0**	-	-	-	-	-	-	-	-	-
		Employee			**2.1**									

Equation 5-4, Ozone season day on-road emissions during hydraulic fracturing

$E_{Onroad.ABC}$ = NUM_{BC} x $TRIPS_A$ x ($DIST_B$ x 2) x OEF_A / 907,184.74 grams per ton / 365 days/year

Where,

- $E_{Onroad.ABC}$ = Ozone season day NO_X, VOC, or CO emissions from on-road vehicles in county B for Eagle Ford development well type C (Gas or Oil)
- NUM_{BC} = Number of production wells drilled in county B for Eagle Ford development well type C, in Table 4-1 (from Schlumberger Limited)
- $TRIPS_A$ = Number of trips for vehicle type A, 807 for heavy duty trucks (from TxDOT in the Barnett), 41 for light duty trucks for equipment/supplies, and 86.7 light duty trucks for employees in Table 5-5 (from ENVIRON's Colorado report)
- $DIST_B$ = Distance to the nearest town for county B, Table 3-2 (from Railroad Commission of Texas)
- OEF_A = NO_X, VOC, or CO on-road emission factor for vehicle type A in Table 3-5 (from MOVES Model)

Equation 5-5, Ozone season day idling emissions during hydraulic fracturing

$E_{Idling.ABC}$ = NUM_{BC} x $TRIPS_A$ x $IDLE_A$ x IEF_A / 907,184.74 grams per ton / 365 days/year

Where,

- $E_{Idling.ABC}$ = Ozone season day NO_X, VOC, or CO emissions from idling vehicles in county B for Eagle Ford development well type C (Gas or Oil)
- NUM_{BC} = Number of production wells drilled in county B for Eagle Ford development well type C, in Table 4-1 (from Schlumberger Limited)
- $TRIPS_A$ = Number of trips for vehicle type A, 807 for heavy duty trucks (from TxDOT in the Barnett), 41 for light duty trucks for equipment/supplies, and 86.7 light duty trucks for employees in Table 5-5 (from ENVIRON's Colorado report)
- $IDLE_A$ = Number of Idling Hours/Trip for vehicle type A, 1.1 hours for heavy duty trucks, 2.0 for light duty trucks for equipment/supplies, and 2.1 light duty trucks for employees in Table 5-5 (from ENVIRON's Colorado report)
- IEF_A = NO_X, VOC, or CO idling emission factor for vehicle type A in Table 3-5 (from EPA based on the MOVES model)

5.6 Completion Venting

As stated by ENVIRON, "once drilling and other well construction activities are finished, a well must be completed in order to begin producing. The completion process requires venting of the well for a sustained period of time to remove mud and other solid debris in the well, to remove any inert gas used to stimulate the well (such as CO_2 and/or N_2) and to bring the gas composition to pipeline grade".[250] "Unless companies bring special equipment to the well site to capture the natural gas and liquids that are produced during well completions, these gases will be vented to the atmosphere or flared".[251]

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[250] Amnon Bar-Ilan, Rajashi Parikh, John Grant, Tejas Shah, Alison K. Pollack, ENVIRON International Corporation. Nov. 13, 2008. "Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories". Novato, CA. p. 48. Available online: http://www.wrapair.org/forums/ogwg/documents/2008-11_CENRAP_O&G_Report_11-13.pdf. Accessed: 04/30/2012.

[251] Al Armendariz. Jan. 26, 2009. "Emissions from Natural Gas Production in the Barnett Shale Area and Opportunities for Cost-Effective Improvements". Prepared for Environmental Defense Fund. Austin, Texas. p. 18. Available Online: http://www.edf.org/sites/default/files/9235_Barnett_Shale_Report.pdf. Accessed: 04/19/2012.

ENVIRON[252] and ERG[253] estimated the amount of gas vented, molecular weight of VOC, and the Mass fraction of VOC for both oil and gas wells in the Western Gulf Basin (Table 5-6). Armendariz, in his calculation of emissions from natural gas completion, found that green completions and control by flaring was used for 25 percent of the gas released during well completion.[254] Interviews with local companies operating in the Eagle Ford found that 100% of the completions are now flared. The amount of gas vented, 1,200 Mcf per well from ERG's report, will be reduced by 100% to account for flaring.

Table 5-6: Completion Venting Parameters from Previous Studies

Parameters	ENVIRON, Haynesville Shale	ENVIRON's CENRAP EI (Western Gulf Basin)	ERG's Texas EI (Western Gulf)		Armendariz, Barnett Shale
			Oil Wells	Gas Wells	
Amount of Gas Vented (MCF)	2,417	1,200	**1,200**	**1,200**	5,000
Fraction controlled by flares	0%	0%	0%	0%	25%
Fraction controlled by green completion	0%	0%	0%	0%	
Atmospheric Pressure	**1 atm**	1 atm	1 atm	1 atm	
Universal Gas Consent	**0.082 L-atm/mol-K**	0.082 L-atm/mol-K	0.082 L-atm/mol-K	0.082 L-atm/mol-K	
Molecular weight of VOC	58.9		**27**	**20**	
Atmospheric temperature	**298 K**	298 K	298 K	298 K	
Mass fraction of VOC in the venting gas	0.43		**0.141**	**0.036**	

The following equation, based on ENVIRON's CENRAP methodology, will be used for calculate VOC emissions from completion venting.

Equation 5-6, Ozone season day completion venting emissions

$$E_{Completion.BC} = NUM_{BC} \times \{ (P \times V_{vented}) / [(R / MW_{gas}) \times T \times 3.5 \times 10^{-5}] \} \times F_{VOC} \times (1 - PER) / 907{,}184.74 \text{ grams/ton} / 365 \text{ days/year}$$

Where,

[252] Amnon Bar-Ilan, Rajashi Parikh, John Grant, Tejas Shah, Alison K. Pollack, ENVIRON International Corporation. Nov. 13, 2008. "Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories". Novato, CA. p. 49. Available online: http://www.wrapair.org/forums/ogwg/documents/2008-11_CENRAP_O&G_Report_11-13.pdf. Accessed: 04/30/2012.

[253] Mike Pring, Daryl Hudson, Jason Renzaglia, Brandon Smith, and Stephen Treimel, Eastern Research Group, Inc. Nov. 24, 2010. "Characterization of Oil and Gas Production Equipment and Develop a Methodology to Estimate Statewide Emissions". Prepared for: Texas Commission on Environmental Quality Air Quality Division. Austin, Texas. p. 4-36. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820784003FY1026-20101124-ergi-oilGasEmissionsInventory.pdf. Accessed: 04/10/2012.

[254] Al Armendariz. Jan. 26, 2009. "Emissions from Natural Gas Production in the Barnett Shale Area and Opportunities for Cost-Effective Improvements". Prepared for Environmental Defense Fund. Austin, Texas. p. 19. Available Online: http://www.edf.org/sites/default/files/9235_Barnett_Shale_Report.pdf. Accessed: 04/19/2012.

$E_{Completion.BC}$ = Ozone season day VOC emissions from completion venting in county B for Eagle Ford development well type C (Gas or Oil)
NUM_{BC} = Number of production wells drilled in county B for Eagle Ford development well type C, in Table 4-1 (from Schlumberger Limited)
P = Atmospheric pressure, 1 atm in Table 5-6 (from ENVIRON's CENRAP emission inventory)
V_{vented} = Volume of vented gas per completion, 1,200 Mcf/event in Table 5-6 (from ENVIRON's CENRAP emission inventory for the Western Gulf Basin)
R = Universal gas constant, 0.082 L-atm/mol-K in Table 5-6 (from ENVIRON's CENRAP emission inventory)
MW_{gas} = Molecular weight of the gas, 27 g/mol of oil wells and 20 g/mol for gas wells in Table 5-6 (from ERG's Texas emission inventory - Western Gulf Basin)
T = Atmospheric temperature, 298 K in Table 5-6 (from ENVIRON's CENRAP emission inventory)
F_{VOC} = Mass fraction of VOC in the completion venting gas, 0.141 for oil wells and 0.036 for gas wells in Table 5-6 (from ERG's Texas emission inventory for the Western Gulf Basin)
PER = Percentage of wells controlled by flares, 1.00 (local industry data)

5.7 Completion Flares

According to local industry representatives, all the completion activity in the Eagle Ford is controlled by flares. The amount of gas vented per completion, 1,200 MCF/event, from ERG's Texas emissions inventory[255] and the average heat content, 1,209 BTU/scf, from ENVIRON's CENRAP emission inventory[256] will be used to calculate emissions (Table 5-7). Other studies that included flaring emissions from well completion are ENVIRON study in Southern Ute,[257] San Juan Public Lands Center in Colorado,[258] Tumble-weed II in Utah[259], and Buys & Associates in Utah[260]

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[255] Mike Pring, Daryl Hudson, Jason Renzaglia, Brandon Smith, and Stephen Treimel, Eastern Research Group, Inc. Nov. 24, 2010. “Characterization of Oil and Gas Production Equipment and Develop a Methodology to Estimate Statewide Emissions”. Prepared for: Texas Commission on Environmental Quality Air Quality Division. Austin, Texas. p. 4-36. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820784003FY1026-20101124-ergi-oilGasEmissionsInventory.pdf. Accessed: 04/10/2012.

[256] Amnon Bar-Ilan, Rajashi Parikh, John Grant, Tejas Shah, Alison K. Pollack, ENVIRON International Corporation. Nov. 13, 2008. “Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories”. Novato, CA. p. 49. Available online: http://www.wrapair.org/forums/ogwg/documents/2008-11_CENRAP_O&G_Report_11-13.pdf. Accessed: 04/30/2012.

[257] ENVIRON, August 2009. “Programmatic Environmental Assessment for 80 Acre Infill Oil and Gas Development on the Southern Ute Indian Reservation”. Novato, California. Appendix A, p. 70. Available online: http://www.suitdoe.com/Documents/Appendix_G_AirQualityTSD.pdf. Accessed: 04/25/2012.

[258] BLM National Operations Center, Division of Resource Services, December, 2007. “San Juan Public Lands Center Draft Land Management Plan & Draft Environmental Impact Statement: Air Quality Impact Assessment Technical Support Document”. Bureau of Land Management, San Juan Public Lands Center, Durango, Colorado. Available online: http://ocs.fortlewis.edu/forestplan/DEIS/pdf/120507_TSD&App%20A.pdf. Accessed: 04/03/2012.

[259] U.S. Department of the Interior, Bureau of Land Management. June 2010. “Tumbleweed II Exploratory Natural Gas Drilling Project”. East City, Utah. DOI-BLM-UTG010-2009-0090-EA. p. 16 of 29. Available online: http://www.blm.gov/pgdata/etc/medialib/blm/ut/lands_and_minerals/oil_and_gas/november_2011.Par.24530.File.dat/. Accessed: 04/12/2012.

[260] Buys & Associates, Inc., Sept. 2008. “APPENDIX J: Near-Field Air Quality Technical Support Document for the West Tavaputs Plateau Oil and Gas Producing Region Environmental Impact

Table 5-7: Completion Flares Parameters for Wells from Previous Studies

Parameters	ENVIRON's CENRAP EI (Western Gulf Basin)	ENVIRON Southern Ute	San Juan Public Lands Center, Colorado	Buys & Associates, Utah	Tumbleweed II, Utah
Average Heat Content	**1,209 BTU/scf**	-	1,093 BTU/scf	1,066 BTU/scf	1,028 BTU/scf
Total Volume of Gas Flared	13.4 Mscf	5,000 MMbtu	1,000 Mscf	5 MMscf	2.5 MMscf
Count per Site	-	1	1	1	1
Flaring Duration/well	-	168 hours	24 hours	48 hours	24 hours

Emission factors from EPA's AP42 will be used to calculate emission from flaring during completion. According to the EPA, 0.068 lbs of NO_X/MMBtu and 0.37 lbs of VOC/MMBtu are emitted during industrial flaring. [261] Since oil wells in the Eagle Ford vent casinghead natural gas, the same emission parameters will be used for both natural gas and oil wells. As shown in Table 5-8, ENVIRON's CENRAP EI (Western Gulf Basin)[262], ENVIRON Southern Ute[263], and San Juan Public Lands Center in Colorado[264] used the same NO_X and CO emission factors reported in AP42. Only All Consulting inventory in the Marcellus[265] used a different emission factor for NO_X. No VOC emissions will be calculated for completion flaring in the Eagle Ford.

Statement". Prepared for: Bureau of Land Management Price Field Office Littleton, Colorado. Available online: http://www.blm.gov/ut/st/en/fo/price/energy/Oil_Gas/wtp_final_eis.html. Accessed: 04/20/2012.

[261] EPA, Sept. 1991. "AP 42: Section 13.5 Industrial Flares". Available online: http://www.epa.gov/ttnchie1/ap42/ch13/final/c13s05.pdf. Accessed 05/20/2012.

[262] Amnon Bar-Ilan, Rajashi Parikh, John Grant, Tejas Shah, Alison K. Pollack, ENVIRON International Corporation. Nov. 13, 2008. "Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories". Novato, CA. p. 43. Available online: http://www.wrapair.org/forums/ogwg/documents/2008-11_CENRAP_O&G_Report_11-13.pdf. Accessed: 04/30/2012.

[263] ENVIRON, August 2009. "Programmatic Environmental Assessment for 80 Acre Infill Oil and Gas Development on the Southern Ute Indian Reservation". Novato, California. Appendix A, p. 70. Available online: http://www.suitdoe.com/Documents/Appendix_G_AirQualityTSD.pdf. Accessed: 04/25/2012.

[264] BLM National Operations Center, Division of Resource Services, December, 2007. "San Juan Public Lands Center Draft Land Management Plan & Draft Environmental Impact Statement: Air Quality Impact Assessment Technical Support Document". Bureau of Land Management, San Juan Public Lands Center, Durango, Colorado. Available online: http://ocs.fortlewis.edu/forestplan/DEIS/pdf/120507_TSD&App%20A.pdf. Accessed: 04/03/2012.

[265] All Consulting, Sept. 16, 2010. "NY DEC SGEIS Information Requests". Prepared for Independent Oil & Gas Association, Project no.: 1284. Available online: http://catskillcitizens.org/learnmore/20100916IOGAResponsetoDECChesapeake_IOGAResponsetoDEC.pdf. p. 10. Accessed: 04/16/2012.

Table 5-8: Completion Flares Emission Factors from Previous Studies

Pollutant	AP-42 Section 13.5	ENVIRON, Haynesville Shale	ENVIRON's CENRAP EI (Western Gulf Basin)	ENVIRON Southern Ute	All Consulting Marcellus	San Juan Public Lands Center, Colorado	Buys & Associates, Utah	Tumble-weed II, Utah
NO_X	**0.068 lbs/MMBtu**	0.068 lbs/MMBtu	0.068 lbs/MMBtu	0.068 lbs/MMBtu	2,448 lb/well	0.068 lbs/MMBtu	0.068 lbs/MMBtu	0.068 lbs/MMBtu
VOC	**-**	-	-	0.0063 lbs/MMBtu	-	2.35 lbs/MMBtu	390 lbs/well	1.4 lbs/well
CO	**0.37 lbs/MMBtu**	0.37 lbs/MMBtu	0.37 lbs/MMBtu	0.37 lbs/MMBtu	-	0.37 lbs/MMBtu	0.37 lbs/MMBtu	0.37 lbs/MMBtu

Equation 5-7, Ozone season day completion flares emissions

$E_{Comp.Vent.BC}$ = NUM_{BC} x V_{vented} / 1000 Mcf/MMscf x HEAT x FEF x PER / 2,000 lbs/ton / 365 days/year

Where,

- $E_{Comp.Vent.BC}$ = Ozone season day NO_X and CO emissions from completion venting in county B for Eagle Ford development well type C (Gas or Oil)
- NUM_{BC} = Number of production wells drilled in county B for Eagle Ford development well type C, in Table 4-1 (from Schlumberger Limited)
- V_{vented} = Volume of vented gas per completion, 1,200 Mcf/event in Table 5-6 (from ENVIRON's CENRAP emission inventory for the Western Gulf Basin)
- HEAT = Heat content of the gas, 1,209 BTU/scf in Table 5-7 (from ENVIRON's CENRAP emission inventory)
- FEF = Flare emission factor, 0.068 lbs of NO_X/MMBtu and 0.37 lbs of CO/MMBtu in Table 5-8 (from AP42)
- PER = Percentage of wells controlled by flares, 1.00 (local industry data)

6 PRODUCTION

"Production is the process of extracting petroleum from the underground reservoir and bringing it to the surface to be separated into gases and fluids that can be sold to refineries. Production begins with a high level of output from the well that decreases as the well ages until the well is ultimately plugged and abandoned. This decrease in production is a natural result of the inevitable decline in original pressure within the reservoir".[266] The methodology to calculate emissions from production will be based on data produced from TCEQ's Barnett Shale special inventory. Draft results for the Barnett survey are presented in this section for the proposed production emission calculation methodologies. When the final results are available from TCEQ, they will be incorporated into the Eagle Ford emission inventory. Other data sources include TexN Model, ERG's Fort Worth Natural Gas Study in the Barnett, and ENVIRON's CENRAP emission inventory.

Schlumberger Limited provided data on the number of production wells drilled in the Eagle Ford[267] by year and production in barrels of oil equivalent (BOE) is provided by the railroad commission[268] in Table 6-1 with a detailed breakdown in Appendix E. Production of natural gas, oil, or condensate in each county will be calculated using Equation 6-1.

Table 6-1: Number of Wells Drilled and Production in the Eagle Ford, 2008-2011

Year	Number of Wells Drilled		Production			
	Liquid	Gas	Oil (MMbbl)	Condensate (MMbbl)	Gas (BCF)	BOE (MMbbl)
2008	92	113	0.1	0.1	1	0.4
2009	63	150	0.3	0.8	19	4.3
2010	338	559	4.4	7.0	108	28.9
2011	1,081	1,259	36.6	20.9	287	104.1

Equation 6-1, Production of Natural Gas, Oil, or Condensate in each County

$$P_{BC} = PROD_C \times W_{County \cdot B} / W_{Total}$$

Where,

P_{BC} = Production of substance C for county B

$PROD_C$ = Eagle Ford natural gas, oil, or condensate production for substance C, 287 BCF, 36,626 MMbbl of Oil, or 20,876 MMbbl of condensate in 2011 (from Railroad Commission)

$W_{County \cdot B}$ = Number natural gas or liquid wells drilled in County B in Appendix E (from Schlumberger Limited)

W_{Total} = Total Number natural gas or liquid wells drilled in the Eagle Ford Shale, Table 6-1 (from Schlumberger Limited)

Calculated production estimates per county will be compared to production data published by the Texas Railroad Commission for each field.[269] This section does not contain

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[266] Lone Star Securities, Inc, 2009. "Understanding and Investing in Oil and Natural Gas Drilling and Production Projects ". p. 15. Available online: http://lonestarsecurities.com/Book-CH-IV.htm. Accessed: 04/20/2012.

[267] Schlumberger Limited. "STATS Rig Count History". Available online: http://stats.smith.com/new/history/statshistory.htm. Accessed: 04/21/2012.

[268] Railroad Commission of Texas, April 3, 2012. "Eagle Ford Information". Available online: http://www.rrc.state.tx.us/eagleford/index.php. Accessed: 06/15/2012.

[269] *Ibid*.

equipment and fugitives from large central facilities including compressor stations and processing facilities.

6.1 Wellhead Compressor

Wellhead compressor engines "are used to boost produced gas pressure from downhole pressure to the required pressure for delivery to a transmission pipeline. "[270] This section only calculates emissions from wellhead compressors at the well pad and does not include compressor stations. Compressor stations will be included in the midstream calculation methodology in the following chapter. Figure 6-1 shows a photo of a wellhead compressor, while Table 6-2 lists wellhead compressors parameters from previous studies. There was an average of 0.33 compressor from the Barnett Shale special inventory survey with average horsepower of 159.

Figure 6-1: Photo of a Wellhead Compressor[271]

The number of compressors per site was similar to ERG's Fort Worth natural gas study result of 0.40 per well site[272] and ENVIRON's CENWRAP result of 0.45 compressors per

[270] Amnon Bar-Ilan, Rajashi Parikh, John Grant, Tejas Shah, Alison K. Pollack, ENVIRON International Corporation. Nov. 13, 2008. "Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories". Novato, CA. p. 23. Available online: http://www.wrapair.org/forums/ogwg/documents/2008-11_CENRAP_O&G_Report_11-13.pdf. Accessed: 04/30/2012.

[271] Energyindustryphotos.com. "Natural Gas Pipeline Equipment Photos". Available online: http://www.energyindustryphotos.com/photos_of_pipeline_equipment_for.htm. Accessed: 05/01/2012.

[272] Eastern Research Group Inc. July 13, 2011. "Fort Worth Natural Gas Air Quality Study Final Report". Prepared for: City of Fort Worth, Fort Worth, Texas. Available online: http://fortworthtexas.gov/gaswells/?id=87074. Accessed: 04/09/2012.

site in the Western Gulf Basin[273]. Barnett Shale Special inventory found wellhead compressors ran for an average of 7,729, while ENVIRON's Haynesville Shale[274] report and San Juan Public Lands Center study in Colorado[275] used 8,760 hours.

Table 6-2: Wellhead Compressor Parameters from Previous Studies

Compressor Parameters	TexN Model, Eagle Ford Counties	Barnett Shale Special Inventory	ERG's Fort Worth Natural Gas Study, Barnett	ENVIRON, Haynesville Shale	ENVIRON's CENRAP EI (Western Gulf Basin)	San Juan Public Lands Center, Colorado
Count per Site		**0.33**	0.40	0.02	0.45	1
Horsepower	269	**159**	264	242	207	50
Gas Consumption Rate		233.2 MMscf/yr				10,000 Btu/hp-hr
Compressor Requirements			3.21 hp-hr/Mscf			
Hours	6,000	**7,729**		8,760	8,760	8,760
Load Factor	0.43			0.85	0.80	

Majority of the engines surveyed in the Barnett Special Inventory are natural gas 4-cycle rich engines, 45.8%, and natural gas 4-cycle rich engines with Non Selective Catalytic Reduction (NSCR), 44.3%. As shown in Table 6-3, most of the rest of the engines, 5.2 percent, were natural gas 4-cycle rich engines with Catalytic Oxidation. Although data on engine type is only used to calculate CO emissions, data from the Barnett Shale Special Inventory combined with local data can be used to refine the emission inventory in the future.

[273] Amnon Bar-Ilan, Rajashi Parikh, John Grant, Tejas Shah, Alison K. Pollack, ENVIRON International Corporation. Nov. 13, 2008. "Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories". Novato, CA. p. 25. Available online: http://www.wrapair.org/forums/ogwg/documents/2008-11_CENRAP_O&G_Report_11-13.pdf. Accessed: 04/30/2012.

[274] John Grant, Lynsey Parker, Amnon Bar-Ilan, Sue Kemball-Cook, and Greg Yarwood, ENVIRON International Corporation. August 31, 2009. "Development of an Emission Inventory for Natural Gas Exploration and Production in the Haynesville Shale and Evaluation of Ozone Impacts". Novato, CA. p. 49. Available online: http://www.netac.org/UserFiles/File/NETAC/9_29_09/Enclosure_2b.pdf. Accessed: 04/19/2012.

[275] BLM National Operations Center, Division of Resource Services, December, 2007. "San Juan Public Lands Center Draft Land Management Plan & Draft Environmental Impact Statement: Air Quality Impact Assessment Technical Support Document". Bureau of Land Management, San Juan Public Lands Center, Durango, Colorado. Available online: http://ocs.fortlewis.edu/forestplan/DEIS/pdf/120507_TSD&App%20A.pdf. Accessed: 04/03/2012.

Table 6-3: Compressor Engine Types from Previous Studies

<table>
<tr><th>Engine Type</th><th>TexN Model, Eagle Ford Counties</th><th>Barnett Shale Special Inventory</th><th>ERG's Fort Worth Natural Gas Study, Barnett</th><th>ENVIRON, Haynesville Shale EI</th></tr>
<tr><td>Electric</td><td>0.0%</td><td>-</td><td>0.7%</td><td rowspan="5">-</td></tr>
<tr><td>Diesel, Lean - 4 Cycle</td><td rowspan="2">0.0%</td><td>0.1%</td><td>-</td></tr>
<tr><td>Diesel, Rich - 4 Cycle</td><td>0.1%</td><td>-</td></tr>
<tr><td>NG, Lean - 2 Cycle</td><td rowspan="13">100.0%</td><td>0.6%</td><td rowspan="11">93.4%</td></tr>
<tr><td>NG, Lean - 2 Cycle w/ NSCR</td><td>0.2%</td></tr>
<tr><td>NG, Lean - 4 Cycle</td><td>1.6%</td><td>3%</td></tr>
<tr><td>NG, Lean - 4 Cycle w/ NSCR</td><td>0.1%</td><td rowspan="4">-</td></tr>
<tr><td>NG, Lean - 4 Cycle w/ other controls</td><td>0.5%</td></tr>
<tr><td>NG, Rich - 2 Cycle</td><td>0.4%</td></tr>
<tr><td>NG, Rich - 2 Cycle w/ NSCR</td><td>0.5%</td></tr>
<tr><td>NG, Rich - 4 Cycle</td><td>45.8%</td><td>97%</td></tr>
<tr><td>NG, Rich - 4 Cycle w/ NSCR</td><td>44.3%</td><td rowspan="5">-</td></tr>
<tr><td>NG, Rich - 4 Cycle w/ SCR</td><td>0.1%</td></tr>
<tr><td>NG, Rich - 4 Cycle w/ Other Controls</td><td>0.2%</td></tr>
<tr><td>NG, Lean - 4 Cycle w/ Catalytic Oxidation</td><td>0.2%</td><td rowspan="2">5.9%</td></tr>
<tr><td>NG, Rich - 4 Cycle w/ Catalytic Oxidation</td><td>5.2%</td></tr>
</table>

The types of control on compressor engines include:

"Nonselective Catalytic Reduction (NSCR):

This technique uses the residual hydrocarbons and CO in the rich-burn engine exhaust as a reducing agent for NO_X. In an NSCR, hydrocarbons and CO are oxidized by O_2 and NO_X. The excess hydrocarbons, CO, and NO_X pass over a catalyst (usually a noble metal such as platinum, rhodium, or palladium) that oxidizes the excess hydrocarbons and CO to H_2O and CO_2, while reducing NO_X to N_2. NO_X reduction efficiencies are usually greater than 90 percent, while CO reduction efficiencies are approximately 90 percent. Engines operating with NSCR require tight air-to-fuel control to maintain high reduction effectiveness without high hydrocarbon emissions.

Catalytic Oxidation:

Catalytic oxidation is a postcombustion technology that has been applied, in limited cases, to oxidize CO in engine exhaust, typically from lean-burn engines. The application of catalytic oxidation has been shown to be effective in reducing CO emissions from lean-burn engines. In a catalytic oxidation system, CO passes over a catalyst, usually a noble metal, which oxidizes the CO to CO_2.

Selective Catalytic Reduction:

Selective catalytic reduction is a postcombustion technology that has been shown to be effective in reducing NO_X in exhaust from lean-burn engines. An SCR system consists of an ammonia storage, feed, and injection system, and a catalyst and catalyst housing. Selective catalytic reduction systems selectively reduce NO_X emissions by injecting ammonia (either in the form of liquid anhydrous ammonia or aqueous ammonium hydroxide) into the exhaust gas stream upstream of the catalyst. Nitrogen oxides, NH_3, and O_2 react on the surface of the catalyst to form N_2 and H_2O. For the SCR system to operate properly, the exhaust gas must be within a particular temperature range (typically between 450 and 850EF). The temperature range is dictated by the catalyst (typically made from noble metals, base metal

> oxides such as vanadium and titanium, and zeolite-based material). Exhaust gas temperatures greater than the upper limit (850EF) will pass the NO_X and ammonia unreacted through the catalyst. SCR is most suitable for lean-burn engines operated at constant loads, and can achieve efficiencies as high as 90 percent."[276]

NO_X and VOC emission factors in Table 6-4 from the Barnett Shale special inventory and CO emission factor from ENVIRON's CENRAP emission inventory for the Western Gulf Basin[277] will be used to calculate emissions from wellhead compressors. Percentage of compressor by engine type will also be based on results from Barnett Shale special inventory. Only half of the natural gas wells drilled in 2011 are predicted to be in production by the end of the year. The following equations will be used for calculate emissions from wellhead compressors.

Equation 6-2, Ozone season day wellhead compressors NO_X and VOC emissions

$$E_{Compresor.BE} = NUM_B \times PER \times EF / 365 \text{ days/year}$$

Where,

- $E_{Compresor.BE}$ = Ozone season day NO_X or VOC emissions from wellhead compressors in county B
- NUM_B = Number of gas wells drilled in county B in Table 6-1 (from Schlumberger Limited)
- PER = Percentage of natural gas wells serviced by wellhead compressors, 0.33 in Table 6-2 (from Barnett Shale Area Special Inventory)
- EF = NO_X or VOC emission factor for compressors, 10.584 tons/year or 0.412 tons/year in Table 6-4 (from Barnett Shale Area Special Inventory)

[276] EPA, Aug. 2000. "AP 42, Fifth Edition, Volume I Chapter 3: Stationary Internal Combustion Sources, 3.2 Natural Gas-fired Reciprocating Engines". Research Triangle Park, NC. p. 3.2-5 – 3.2-6. Available online: http://www.epa.gov/ttnchie1/ap42/ch03/final/c03s02.pdf. Accessed: 04/01/2012.

[277] Amnon Bar-Ilan, Rajashi Parikh, John Grant, Tejas Shah, Alison K. Pollack, ENVIRON International Corporation. Nov. 13, 2008. "Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories". Novato, CA. p. 26. Available online: http://www.wrapair.org/forums/ogwg/documents/2008-11_CENRAP_O&G_Report_11-13.pdf. Accessed: 04/30/2012.

Table 6-4: Wellhead Compressor Emission Factors from Previous Studies

Pollutant	Barnett Shale Special Inventory (2009)	ERG's Fort Worth Natural Gas Study	ENVIRON, Haynesville Shale[278]	ENVIRON's CENRAP EI (Western Gulf Basin)		ERG's Texas EI (attainment counties)[279]	AP-42[280] (uncontrolled, 90 - 105% Load)		San Juan Public Lands Center, Colorado[281]	EPA Region 8, Oil and Gas Production[282]	
				Rich-Burn	Lean-Burn		Rich-Burn	Lean-Burn		Rich-Burn	Lean-Burn
NO_X EF	**10.584 tons/year**	0.55 g/hp-hr	2.00 g/hp-hr	14.28 g/hp-hr	3.10 g/hp-hr	7.57 g/hp-hr	2.21 lbs/MMBtu	4.08 lbs/MMBtu	2.21 lbs/MMBtu	2,254 lbs/MMscf	4,162 lbs/MMscf
VOC EF	**0.412 tons/year**	0.82 g/hp-hr	1.00 g/hp-hr	0.84 g/hp-hr	1.51 g/hp-hr	0.35 g/hp-hr	0.030 lbs/MMBtu	0.118 lbs/MMBtu	0.030 lbs/MMBtu	30.2 lbs/MMscf	120.4 lbs/MMscf
CO EF		4.77 g/hp-hr	4.00 g/hp-hr	**4.63 g/hp-hr**	**2.29 g/hp-hr**	3.85 g/hp-hr	3.720 lbs/MMBtu	0.317 lbs/MMBtu	3.720 lbs/MMBtu	3,794 lbs/MMscf	568 lbs/MMscf

278 John Grant, Lynsey Parker, Amnon Bar-Ilan, Sue Kemball-Cook, and Greg Yarwood, ENVIRON International Corporation. August 31, 2009. "Development of an Emission Inventory for Natural Gas Exploration and Production in the Haynesville Shale and Evaluation of Ozone Impacts". Novato, CA. p. 49. Available online: http://www.netac.org/UserFiles/File/NETAC/9_29_09/Enclosure_2b.pdf. Accessed: 04/19/2012.

279 Mike Pring, Daryl Hudson, Jason Renzaglia, Brandon Smith, and Stephen Treimel, Eastern Research Group, Inc. Nov. 24, 2010. "Characterization of Oil and Gas Production Equipment and Develop a Methodology to Estimate Statewide Emissions". Prepared for: Texas Commission on Environmental Quality Air Quality Division. Austin, Texas. p. 4-7. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820784003FY1026-20101124-ergi-oilGasEmissionsInventory.pdf. Accessed: 04/10/2012.

280 EPA. Available online: http://www.epa.gov/ttn/chief/ap42/ch03/final/c03s02.pdf. Accessed 05/11/2012.

281 BLM National Operations Center, Division of Resource Services, December, 2007. "San Juan Public Lands Center Draft Land Management Plan & Draft Environmental Impact Statement: Air Quality Impact Assessment Technical Support Document". Bureau of Land Management, San Juan Public Lands Center, Durango, Colorado. Available online: http://ocs.fortlewis.edu/forestplan/DEIS/pdf/120507_TSD&App%20A.pdf. Accessed: 04/03/2012.

282 EPA Region 8, Sept. 2008. "An Assessment of the Environmental Implications of Oil and Gas Production: A Regional Case Study" Working Draft. p. B-5. Available online: http://www.epa.gov/sectors/pdf/oil-gas-report.pdf. Accessed: 05/02/2012.

Equation 6-3, Ozone season day wellhead compressors CO emissions

$E_{Compresor.BE} = NUM_B \times PER_{Comp} \times HP \times HRS \times PER_E \times EF$ / 907,184.74 grams per ton / 365 days/year

Where,

$E_{Compresor.BE}$ = Ozone season day CO emissions from wellhead compressors in county B for engine type E

NUM_B = Number of gas wells drilled in county B from Equation 6-1 and Appendix E (based on data from Schlumberger Limited)

PER_{Comp} = Percentage of natural gas wells serviced by wellhead compressors, 0.33 in Table 6-2 (from Barnett Shale Area Special Inventory)

HP = Average horsepower for wellhead compressors, 159 hp in Table 6-2 (from Barnett Shale Area Special Inventory)

HRS = Hours per year, 7,729 hours in Table 6-3 (from Barnett Shale Area Special Inventory)

PER_E = Percent of Engine type E, 96.5% for Rich Burn, 3.3% for Lean Burn, and 0.2% for Diesel in Table 6-2 (from Barnett Shale Area Special Inventory)

EF = CO emission factor for compressors, 4.63 g/hp-hr for Rich-Burn, 2.29 g/hp-hr for Lean Burn, and g/hp-hr for Diesel in Table 6-4 (from ENVIRON's CENRAP emission inventory in the Western Gulf Basin and TexN model)

6.2 Heaters

Heaters are generally natural gas-fired external combustors at gas and oil wells. "They are typically used as either separator heaters (to provide heat input to the separators), or as tank heaters (to maintain tank temperatures). It should be noted that this source category considers only tank and separator heaters, not heaters or boilers used in dehydrators."[283] Emissions from dehydrators are included in section 6.4. The Barnett Shale special inventory estimated that there were 0.05 heaters per natural gas well pad (Table 6-5) and each heater emits 0.142 tons/year of NO_X and 0.008 tons/year of VOC annually (Table 6-6).

Table 6-5: Heater Parameters for Gas Wells from Previous Studies

Parameters	Barnett Shale Special Inventory	ENVIRON, Haynesville Shale	ENVIRON's CENRAP EI (Western Gulf Basin)	ERG's Texas EI		San Juan Public Lands Center, Colorado
				Gas Wells	Oil Wells	
Heater MMBtu Rating		0.64 MMBtu/hr	0.46 MMBtu/hr	**0.64 MMBtu/hr**	**0.64 MMBtu/hr**	0.25 MMBtu/hr
Count per Site	**0.05**	0.95	1.1	0.91	**0.91**	1
Hours	**5,346**	2,982	4,297	4,076	4,076	876
Heater Cycling		1	**1**	1	1	
Local Heating Value		950 Btu/scf	**1,209 Btu/scf**	1,209 Btu/scf	**1,655 Btu/scf**	1,000 Btu/scf
Volume of Natural Gas Combusted						0.22 MMscf/yr

283 Amnon Bar-Ilan, Rajashi Parikh, John Grant, Tejas Shah, Alison K. Pollack, ENVIRON International Corporation. Nov. 13, 2008. "Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories". Novato, CA. p. 36. Available online: http://www.wrapair.org/forums/ogwg/documents/2008-11_CENRAP_O&G_Report_11-13.pdf. Accessed: 04/30/2012.

Table 6-6: Heater Emission Factors from Previous Studies

Pollutant	Barnett Shale Special Inventory (2009)	ENVIRON, Haynesville Shale	ENVIRON's CENRAP EI (Western Gulf Basin)	ERG's Texas EI	AP-42[284] (uncontrolled, 90 - 105% Load)		San Juan Public Lands Center, Colorado	EPA Region 8. Oil and Gas Production
					Rich-Burn	Lean-Burn		
NO_X EF	**0.142 tons/year**	100 lbs/MMscf	**100 lbs/MMscf**	100 lbs/MMscf	2.21 lbs/MMBtu	4.08 lbs/MMBtu	0.034 lbs/hr	140 lbs/MMscf
VOC EF	**0.008 tons/year**	5.50 lbs/MMscf	**5.50 lbs/MMscf**	5.50 lbs/MMscf	0.030 lbs/MMBtu	0.118 lbs/MMBtu	8.0 lbs/MMscf	2.80 lbs/MMscf
CO EF		84 lbs/MMscf	**84 lbs/MMscf**	84 lbs/MMscf	3.720 lbs/MMBtu	0.317 lbs/MMBtu	0.291 lbs/hr	35.0 lbs/MMscf

[284] EPA. July, 2000. "AP42: 3.2 Natural Gas-fired Reciprocating Engines". Available online: http://www.epa.gov/ttn/chief/ap42/ch03/final/c03s02.pdf. Accessed 05/11/2012.

For oil wells, ERG's report provided data including heater rating of 0.64 MMBtu/hr, 0.91 heaters per oil well, and annual operation of 4,076 hours per year.[285] This data, combine with ENVIRON's CENRAP emission inventory methodology[286], will be used to calculate heater emissions for oil wells and CO emissions from natural gas wells in the Eagle Ford. Other studies included San Juan Public Lands Center in Colorado[287], EPA Region 8 study on Oil and Gas Production[288], and ENVIRON's Haynesville Shale emission inventory.[289]

The following equations will be used for calculate emissions from wellhead heaters for natural gas and oil wells. Only half of the wells drilled in 2011 are predicted to be in production by the end of the year.

Equation 6-4, Ozone season day natural gas wellhead heaters NO_X and VOC emissions

$E_{Gas.Heaters.B} = NUM_B \times PER_{Heat} \times EF$ / 365 days/year

Where,

$E_{Gas.Heaters.B}$ = Ozone season day NO_X or VOC emissions from natural gas wellhead heaters in county B

NUM_B = Number of gas wells drilled in county B for Eagle Ford development in Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)

PER_{Heat} = Percentage of natural gas wells serviced by wellhead heaters, 0.05 in Table 6-5 (from Barnett Shale Area Special Inventory)

EF = NO_X or VOC emission factor for compressors, 0.142 tons/year for NO_X or 0.008 tons/year for VOC in Table 6-6 (from Barnett Shale Area Special Inventory)

Equation 6-5, Ozone season day natural gas wellhead heaters CO emissions

$E_{Gas.Heaters.B} = NUM_B \times PER_{Heat} \times (Q_{Heater} \times HRS \times hc \times EF) / HV$ / 2,000 lbs/ton / 365 days/year

[285] Mike Pring, Daryl Hudson, Jason Renzaglia, Brandon Smith, and Stephen Treimel, Eastern Research Group, Inc. Nov. 24, 2010. "Characterization of Oil and Gas Production Equipment and Develop a Methodology to Estimate Statewide Emissions". Prepared for: Texas Commission on Environmental Quality Air Quality Division. Austin, Texas. p. 4-55. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820784003FY1026-20101124-ergi-oilGasEmissionsInventory.pdf. Accessed: 04/10/2012.

[286] John Grant, Lynsey Parker, Amnon Bar-Ilan, Sue Kemball-Cook, and Greg Yarwood, ENVIRON International Corporation. August 31, 2009. "Development of an Emission Inventory for Natural Gas Exploration and Production in the Haynesville Shale and Evaluation of Ozone Impacts". Novato, CA. p. 45. Available online: http://www.netac.org/UserFiles/File/NETAC/9_29_09/Enclosure_2b.pdf. Accessed: 04/19/2012.

[287] BLM National Operations Center, Division of Resource Services, December, 2007. "San Juan Public Lands Center Draft Land Management Plan & Draft Environmental Impact Statement: Air Quality Impact Assessment Technical Support Document". Bureau of Land Management, San Juan Public Lands Center, Durango, Colorado. Available online: http://ocs.fortlewis.edu/forestplan/DEIS/pdf/120507_TSD&App%20A.pdf. Accessed: 04/03/2012.

[288] EPA Region 8, Sept. 2008. "An Assessment of the Environmental Implications of Oil and Gas Production: A Regional Case Study" Working Draft. p. B-5. Available online: http://www.epa.gov/sectors/pdf/oil-gas-report.pdf. Accessed: 05/02/2012.

[289] John Grant, Lynsey Parker, Amnon Bar-Ilan, Sue Kemball-Cook, and Greg Yarwood, ENVIRON International Corporation. August 31, 2009. "Development of an Emission Inventory for Natural Gas Exploration and Production in the Haynesville Shale and Evaluation of Ozone Impacts". Novato, CA. p. 53. Available online: http://www.netac.org/UserFiles/File/NETAC/9_29_09/Enclosure_2b.pdf. Accessed: 04/19/2012.

Where,

$E_{Gas.Heaters.B}$ = Ozone season day CO emissions from natural gas wellhead heaters in county B
NUM_B = Number of gas wells drilled in county B for Eagle Ford development in Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)
PER_{Heat} = Percentage of natural gas wells serviced by wellhead heaters, 0.05 in Table 6-5 (from Barnett Shale Area Special Inventory)
Q_{Heater} = Heater rating, 0.64 MMBtu/hr in Table 6-5 (from ERG's Texas Emission inventory)
HV = Natural Gas heating Value, 1,209 MMBtu/MMscf in Table 6-5 (from ENVIRON's CENRAP emission inventory in the Western Gulf Basin)
HRS = Annual hours of operation, 5,346 in Table 6-5 (from Barnett Shale Area Special Inventory)
hc = Heater cycle, 1 in Table 6-5 (from ENVIRON's CENRAP emission inventory in the Western Gulf Basin)
EF = CO emission factor for compressors, 84 lbs/MMscf in Table 6-6 (from ENVIRON's CENRAP emission inventory in the Western Gulf Basin)

Equation 6-6, Ozone season day oil wellhead heaters NO_X, VOC, and CO emissions

$E_{Oil.Heaters.B}$ = NUM_B x PER_{Heat} x (Q_{Heater} x HRS x hc x EF) / HV / 2,000 lbs/ton / 365 days/year

Where,

$E_{Oil.Heaters.B}$ = Ozone season day NO_X, VOC, or CO emissions from oil wellhead heaters in county B
NUM_B = Number of oil wells drilled in county B for Eagle Ford development in Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)
PER_{Heat} = Percentage of oil wells serviced by wellhead heaters, 0.91 in Table 6-5 (from ERG's Texas Emission inventory)
Q_{Heater} = Heater rating, 0.64 MMBtu/hr in Table 6-5 (from ERG's Texas Emission inventory)
HV = Natural Gas heating Value, 1,655 MMBtu/MMscf in Table 6-5 (from ERG's Texas Emission inventory)
HRS = Annual hours of operation, 4,076 in Table 6-5 (from ERG's Texas Emission inventory)
hc = Heater cycle, 1 in Table 6-5 (from ENVIRON's CENRAP emission inventory in the Western Gulf Basin)
EF = NO_X, VOC, and CO emission factor for compressors, 100 lbs/MMscf for NO_X, 5.5 lbs/MMscf for VOC and 84 lbs/MMscf for CO in Table 6-6 (from ENVIRON's CENRAP emission inventory in the Western Gulf Basin)

6.3 Flares

Flaring is used as a control process on natural gas dehydration, oil storage tanks, and condensate storage tanks. Although the Barnett Special Inventory surveyed flares activity and emissions, the results cannot be applied to the Eagle Ford because the play has a significant liquid production. Operators in the Eagle Ford often use flares to burn off natural gas in liquid production wells to obtain the oil and condensate. Visual inspections of Eagle Ford wells show a significant number of flares operating in the region. Figure 6-2, from the San Antonio Express News, shows an example of a flare near a petroleum and gas storage tanks in McMullen County.

ENVIRON's CENRAP emission inventory provided data on the volume of natural gas flared and heat value of the gas for the Western Gulf Basin in Table 6-7.[290] Emission factors, 0.068 lbs of NO_X/MMBtu and 0.37 lbs of CO/MMBtu, from AP42 will be used to calculate emissions from wellhead flares (Table 6-8).[291] These emission factors are used in most oil and gas production emission inventories including ERG's Texas emission inventory for attainment counties[292] and ENVIRON study in the Haynesville Shale[293].

Figure 6-2: Flares Near a Petroleum and Gas Storage Tanks in McMullen County, Texas[294]

[290] Amnon Bar-Ilan, Rajashi Parikh, John Grant, Tejas Shah, Alison K. Pollack, ENVIRON International Corporation. Nov. 13, 2008. "Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories". Novato, CA. p. 42-43. Available online: http://www.wrapair.org/forums/ogwg/documents/2008-11_CENRAP_O&G_Report_11-13.pdf. Accessed: 04/30/2012.

[291] EPA, Sept. 1991. "AP42: 13.5 Industrial Flares". p. 13.5-4. Available online: http://www.epa.gov/ttn/chief/ap42/ch13/final/c13s05.pdf. Accessed 05/16/2012.

[292] Mike Pring, Daryl Hudson, Jason Renzaglia, Brandon Smith, and Stephen Treimel, Eastern Research Group, Inc. Nov. 24, 2010. "Characterization of Oil and Gas Production Equipment and Develop a Methodology to Estimate Statewide Emissions". Prepared for: Texas Commission on Environmental Quality Air Quality Division. Austin, Texas. p. 4-25. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820784003FY1026-20101124-ergi-oilGasEmissionsInventory.pdf. Accessed: 04/10/2012.

[293] John Grant, Lynsey Parker, Amnon Bar-Ilan, Sue Kemball-Cook, and Greg Yarwood, ENVIRON International Corporation. August 31, 2009. "Development of an Emission Inventory for Natural Gas Exploration and Production in the Haynesville Shale and Evaluation of Ozone Impacts". Novato, CA. p. 47. Available online: http://www.netac.org/UserFiles/File/NETAC/9_29_09/Enclosure_2b.pdf. Accessed: 04/19/2012.

[294] Vicki Vaughan, San Antonio Express News, Feb 8, 2012. "Risk and stealth paid off in Eagle Ford shale". San Antonio, Texas. Available online: http://fuelfix.com/blog/2012/02/08/risk-and-stealth-paid-off-in-eagle-ford-shale/#2971-14. Accessed: 04/01/2012.

Table 6-7: Flares Parameters for Wells from Previous Studies

Parameters	Barnett Shale Special Inventory	ENVIRON, Haynesville Shale	ENVIRON's CENRAP EI (Western Gulf Basin)		ERG's Texas EI (attainment counties)	Tumbleweed II, Utah
			Gas	Oil and Condensate		
Flow Rate (Stock Tank)	2.92 MMscf/yr	8.84 MCF Flared / BCF produced	**8.84 MCF Flared / BCF produced**	**0.836 MCF Flared / 1,000 bbl**	297.15 MCF Flared / BCF produced	60.9 scf/hr
Flow Rate (Pilot Light)						50 scf/hr
Fuel Rate (Stock Tank)						0.081 MMBtu/hr
Fuel Rate (Pilot Light)						0.051 MMBtu/hr
Total Volume of Gas Flared						2.5 MMscf
Count per Site	0.008					2
Flaring Duration	5,548					8,760
Heat Value (Stock Tank)		950 BTU/SCF	**1,209 BTU/SCF**	**1,655 BTU/SCF**	1,209 BTU/SCF	1,334 btu/scf
Heat Value (Pilot Light)						1,028 btu/scf

Table 6-8: Flares Emission Factors from Previous Studies

Parameters	Barnett Shale Special Inventory	AP-42 Section 13.5	ENVIRON, Haynesville Shale	ENVIRON's CENRAP EI (Western Gulf Basin)	ERG's Texas EI	Tumbleweed II, Utah
NO_X EF	0.437 tons/year	**0.068 lbs/MMBtu**	0.068 lbs/MMBtu	0.068 lbs/MMBtu	0.068 lbs/MMBtu	0.068 lbs/MMBtu
VOC EF	0.650 tons/year	0.14 lbs/MMBtu	-	-	-	0.14 lbs/MMBtu
CO EF		**0.37 lbs/MMBtu**	0.37 lbs/MMBtu	0.37 lbs/MMBtu	0.37 lbs/MMBtu	0.37 lbs/MMBtu

The following formula, with data from the Railroad commissions, ENVIRON's CENRAP Emission Inventory, and EPA's AP42, will be used to calculate flare emissions in the Eagle Ford.

Equation 6-7, Ozone season day wellhead flaring emissions

$$E_{Flare.BC} = Q_{Flare,C} \times HV_C \times PROD_C \times PERW_B \times EF / 365 \text{ days/year} / 2{,}000 \text{ lbs/ton}$$

Where,

$E_{Flare.BC}$ = Ozone season day NO_X or CO emissions from wellhead flaring in county B for substance C

HV_C = Heating value for substance C, 1,209 BTU/SCF for natural gas and 1,655 BTU/SCF for oil/condensate in Table 6-7 (from ENVIRON's CENRAP Emission Inventory for the Western Gulf Basin)

$PROD_C$ = Eagle Ford production for substance C, 287 BCF, 36,626 Mbbl of Oil, or 20,876 Mbbl of condensate in 2011 (from Railroad Commission)

$Q_{Flare,C}$ = Volume of gas flared for substance C, 8.84 MCF Flared/BCF produced or 0.836 MCF Flared/1,000 bbl produced in Table 6-7 (from ENVIRON's CENRAP Emission Inventory for the Western Gulf Basin)

$PERW_B$ = Percent of natural gas or liquid wells in County B in Table 6-1 (from Schlumberger Limited)

EF = NO_X or CO flaring emission factors, 0.068 lbs of NO_X/MMBtu and 0.37 lbs of CO/MMBtu in Table 6-8 (from AP42)

6.4 Dehydrators Flash Vessels and Regenerator Vents

"Dehydrators are devices used to remove excess water from produced natural gas prior to transmission into a pipeline or to a gas processing facility. These wellhead devices are normally only used in regions where there are significant concentrations of water in the gas that cannot be removed by separators. Thus their usage is highly localized depending on the composition of the gas."[295] A photograph, Figure 6-3, from Energyindustryphotos.com shows an dehydrator and separator in Karnes County[296]

"ERG derived estimates of the amount of gas flared for each unit of gas produced from the emissions data submitted to TCEQ by operators of dehydrators in use at point sources in

[295] Amnon Bar-Ilan, Rajashi Parikh, John Grant, Tejas Shah, Alison K. Pollack, ENVIRON International Corporation. Nov. 13, 2008. "Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories". Novato, CA. p. 46. Available online: http://www.wrapair.org/forums/ogwg/documents/2008-11_CENRAP_O&G_Report_11-13.pdf. Accessed: 04/30/2012.

[296] Energyindustryphotos.com. "Eagle Ford Shale Play Photos". Available online: http://eaglefordshaleblog.com/2012/04/09/eagle-ford-shale-play-photos/. Accessed: 05/01/2012.

Texas."[297] This approach is not suitable for production in the Eagle Ford because wells have different characteristics and production cycles compared to production facilities in the point source database. TCEQ's Barnett Shale Special Inventory offers excellent survey results of emissions from dehydrators in the Barnett; however the results could not be applied to the Eagle Ford because additional dehydrators are needed in the Eagle Ford to remove excess water from produced natural gas.

Figure 6-3: Dehydrator and Separator in Karnes County

Methodology and emission factors from ENVIRON's CENRAP emission inventory for the Western Gulf Basin[298] will be used to calculate VOC emissions from dehydrators flash vessels and regenerator vents in the Eagle Ford (Table 6-9). This methodology is similar to the one used in by ENVIRON in the Haynesville Shale.[299]

[297] Mike Pring, Daryl Hudson, Jason Renzaglia, Brandon Smith, and Stephen Treimel, Eastern Research Group, Inc. Nov. 24, 2010. "Characterization of Oil and Gas Production Equipment and Develop a Methodology to Estimate Statewide Emissions". Prepared for: Texas Commission on Environmental Quality Air Quality Division. Austin, Texas. p. 4-25. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820784003FY1026-20101124-ergi-oilGasEmissionsInventory.pdf. Accessed: 04/10/2012.

[298] Amnon Bar-Ilan, Rajashi Parikh, John Grant, Tejas Shah, Alison K. Pollack, ENVIRON International Corporation. Nov. 13, 2008. "Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories". Novato, CA. p. 47. Available online: http://www.wrapair.org/forums/ogwg/documents/2008-11_CENRAP_O&G_Report_11-13.pdf. Accessed: 04/30/2012.

[299] John Grant, Lynsey Parker, Amnon Bar-Ilan, Sue Kemball-Cook, and Greg Yarwood, ENVIRON International Corporation. August 31, 2009. "Development of an Emission Inventory for Natural Gas Exploration and Production in the Haynesville Shale and Evaluation of Ozone Impacts". Novato, CA.

Table 6-9: Dehydrators VOC Emission Factors from Previous Studies

Barnett Shale Special Inventory	ENVIRON, Haynesville Shale	ENVIRON's CENRAP EI (Western Gulf Basin)	ERG's Texas EI	San Juan Public Lands Center, Colorado[300]
14.17 lbs per year/well	2.622 lbs/MMscf	2.622 lbs/MMscf	**1.632 lbs/MMscf**	8.0 lbs/MMscf

Equation 6-8, Ozone season day wellhead dehydrators emissions

$E_{Dehydrators.B}$ = PROD x $PERW_B$ x EF / 365 days/year / 2,000 lbs/ton

Where,

$E_{Dehydrators.B}$ = Ozone season day NO_X, VOC, or CO emissions from wellhead dehydrators in county B

PROD = Eagle Ford natural gas production, 287,000 MMscf of natural gas (from Railroad Commission)

$PERW_B$ = Percent of natural gas wells in County B in Table 6-1 (from Schlumberger Limited)

EF = NO_X, VOC, or CO dehydrator emission factors, 1.632 lbs of VOC/MMscf in Table 6-9 (from ERG's Texas Emission Inventory)

6.5 Storage Tanks

"Oil and condensate tanks are used to store produced liquid at individual well sites and there may be many thousands of such storage tanks throughout a basin. Two primary processes create emissions of gas from oil and condensate tanks: (1) flashing, whereby condensate brought from downhole pressure to atmospheric pressure may experience a sudden volatilization of some of the condensate; and (2) working and breathing losses, whereby some volatilization of stored product occurs through valves and other openings in the tank battery over time. Note that flashing emissions are associated with condensate tanks, whereas working and breathing losses are associated with both oil and condensate tanks."[301] The picture provided in Figure 6-4 shows a separator and storage tanks at a site near Kennedy in the Eagle Ford[302]

p. 46. Available online: http://www.netac.org/UserFiles/File/NETAC/9_29_09/Enclosure_2b.pdf. Accessed: 04/19/2012.

[300] BLM National Operations Center, Division of Resource Services, December, 2007. "San Juan Public Lands Center Draft Land Management Plan & Draft Environmental Impact Statement: Air Quality Impact Assessment Technical Support Document". Bureau of Land Management, San Juan Public Lands Center, Durango, Colorado. Available online: http://ocs.fortlewis.edu/forestplan/DEIS/pdf/120507_TSD&App%20A.pdf. Accessed: 04/03/2012.

[301] Amnon Bar-Ilan, Rajashi Parikh, John Grant, Tejas Shah, Alison K. Pollack, ENVIRON International Corporation. Nov. 13, 2008. "Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories". Novato, CA. p. 44. Available online: http://www.wrapair.org/forums/ogwg/documents/2008-11_CENRAP_O&G_Report_11-13.pdf. Accessed: 04/30/2012.

[302] Deon Daugherty, .Houston Business Journal, October 28, 2011. "A Look Inside an Eagle Ford Boomtown — and its Traffic". Available online: http://www.bizjournals.com/houston/blog/2011/10/a-look-inside-an-eagle-ford-boomtown--.html?s=image_gallery. Accessed: 04/04/2012.

Figure 6-4: Separator and Storage Tanks at a Site near Kennedy in the Eagle Ford

The natural gas well survey performed by ERG in Fort Worth found the average number of oil and condensate tanks per well pad was 3.02.[303] The Barnett Shale special Inventory had a total of 20,663 storage tanks[304] from over 4,933 survey locations or 4.19 tanks per site.

Emission factors from the Barnett Shale Special Inventory for oil and condensate tanks will be used to calculate emissions: 183 g/hr/oil tank and 429 g/hr/condensate tank in Table 6-10. ENVIRON's Upstream Oil and Gas Tank survey in Texas[305] found that emissions were between 2,345.07 - 2,830.42 g/hr/tank battery and Hy-Bon Engineering study on upstream oil and gas sites in Texas average 75.1 tons/yr for each oil/condensate storage tank.[306] Almost all the other studies had significantly higher emission factors for storage tanks at well sites including San Juan Public Lands Center emission inventory in

303 Eastern Research Group Inc. July 13, 2011. "Fort Worth Natural Gas Air Quality Study Final Report". Prepared for: City of Fort Worth, Fort Worth, Texas. Available online: http://fortworthtexas.gov/gaswells/?id=87074. Accessed: 04/09/2012.

304 Miles T Whitten, TCEQ, Oct 16, 2010. "Emissions Inventory Processes, Recent Research and Improvements, and The Barnett Shale Special Inventory". Presented at The Barnett Shale Open House at the North Central Texas Council of Governments. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/ie/pseiforms/10162010arlington.pdf. Accessed: 04/18/2012.

305 ENVIRON International Corporation, August 2010. "Upstream Oil and Gas Tank Emission Measurements TCEQ Project 2010 – 39". Prepared for: Texas Commission on Environmental Quality, Austin, Texas. p. 2. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820784004FY1025-20100830-environ-Oil_Gas_Tank_Emission_Measurements.pdf. Accessed: 04/12/2012.

306 Butch Gidney and Stephen Pena, Hy-Bon Engineering Company, Inc., July 16, 2009. "Upstream Oil and Gas Storage Tank Project Flash Emissions Models Evaluation". Midland, Texas. p. 64. Available online: http://www.bdlaw.com/assets/attachments/TCEQ%20Final%20Report%20Oil%20Gas%20Storage%20Tank%20Project.pdf. Accessed: 04/25/2012.

Colorado[307], ENVIRON's CENRAP emission inventory[308], and EPA Region 8 data on oil and gas production[309]. The following formula, with data from the Barnett Shale special inventory and ERG's Fort Worth natural gas study, will be used to calculate emissions for oil and condensate storage tanks in the Eagle Ford.

Equation 6-9, Ozone season day emissions from storage tanks

$E_{Tanks.BC}$ = (NUM_B / $WPAD_B$) x TANKS x ($PROD_C$ / TPROD) x EF_C x 24 hours/day / 90,184.74 grams/ton

Where,

$E_{Tanks.BC}$ = Ozone season day VOC emissions from storage tanks in county B for substance C (oil or condensate)

NUM_B = Number of gas wells drilled in county B for Eagle Ford development in Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)

$WPAD_B$ = Number of Wells per Pad for county B, Table 3-2 (calculated from data provided by the Railroad Commission of Texas)

TANKS = Average number of oil or condensate tanks per well pad, 3.02 (from ERG's Fort Worth Natural Gas Study)

$PROD_C$ = Eagle Ford oil or condensate production for substance C, 36,626 Mbbl of Oil or 20,876 Mbbl of condensate in 2011, Table 6-1 (from Railroad Commission)

TPROD = Total Eagle Ford production of oil and condensate, 57,502 Mbbl in 2011, Table 6-1 (from Railroad Commission)

EF_C = VOC emission factor for substance C, 183 g/hr/tank for oil and 429 g/hr/tank for condensate in Table 6-8 (from Barnett Shale special inventory)

Remote sensing and canister sampling of tanks in the Eagle Ford would improve emission estimates, but significant number of sites would have to be surveyed to get accurate emission estimates. "In practice, the TCEQ has informally evaluated IR camera images collected as part of a study to evaluate the upstream oil and gas flash emissions model. IR camera images were captured from 36 upstream oil and gas tank batteries at varying distances under varying conditions. On average, these tank batteries, which had source testing performed, had emissions rates that ranged from 1.5 to 408 pounds per hour."[310]

[307] BLM National Operations Center, Division of Resource Services, December, 2007. "San Juan Public Lands Center Draft Land Management Plan & Draft Environmental Impact Statement: Air Quality Impact Assessment Technical Support Document". Bureau of Land Management, San Juan Public Lands Center, Durango, Colorado. p. 19. Available online: http://ocs.fortlewis.edu/forestplan/DEIS/pdf/120507_TSD&App%20A.pdf. Accessed: 04/03/2012.

[308] Amnon Bar-Ilan, Rajashi Parikh, John Grant, Tejas Shah, Alison K. Pollack, ENVIRON International Corporation. Nov. 13, 2008. "Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories". Novato, CA. p. 45. Available online: http://www.wrapair.org/forums/ogwg/documents/2008-11_CENRAP_O&G_Report_11-13.pdf. Accessed: 04/30/2012.

[309] EPA Region 8, Sept. 2008. "An Assessment of the Environmental Implications of Oil and Gas Production: A Regional Case Study" Working Draft. p. C-9. Available online: http://www.epa.gov/sectors/pdf/oil-gas-report.pdf. Accessed: 05/02/2012.

[310] Available online: http://www.tceq.texas.gov/airquality/barnettshale/bshale-faq. Accessed: 04/07/11.

Table 6-10: Storage Tanks VOC Emission Factors from Previous Studies

<table>
<tr><th rowspan="2">Substance</th><th rowspan="2">Barnett Shale Area Special Inventory</th><th rowspan="2">ERG's Fort Worth Natural Gas Study</th><th colspan="2">Armendariz, Barnett Shale</th><th rowspan="2">ENVIRON's CENRAP EI (Western Gulf Basin)</th><th rowspan="2">ERG's Texas EI</th><th rowspan="2">ENVIRON's Upstream Oil and Gas Tank, Texas (mean)</th><th rowspan="2">EPA Region 8. Oil and Gas Production</th><th rowspan="2">San Juan Public Lands Center, Colorado</th><th rowspan="2">Upstream Oil and Gas, Hy-Bon Engineering (Texas)</th></tr>
<tr><th>Peak Summer</th><th>Annual</th></tr>
<tr><td>Oil</td><td>183 g/hr/tank</td><td rowspan="2">14.76 g/hr/well</td><td>6.1 lbs/bbl</td><td>1.3 lbs/bbl</td><td>1.60 lbs/bbl</td><td>1.60 lbs/bbl</td><td></td><td>36 lbs/kgal-yr-crude oil</td><td rowspan="2">2,069.82 g/hr</td><td rowspan="2">Average of 191.5 tons/yr tank battery or 75.1 tons/yr tank</td></tr>
<tr><td>Condensate</td><td>429 g/hr/tank</td><td>48 lbs/bbl</td><td>10 lbs/bbl</td><td>33.30 bbs/bbl</td><td>33.30 lbs/bbl</td><td rowspan="2">2,345.07 – 2,830.42 g/hr/tank battery</td><td rowspan="2"></td></tr>
<tr><td>Production Water Tank</td><td>30 g/hr/tank</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

6.6 Fugitives (Leaks)

Components used on natural gas and oil wells can leak and emit VOC emissions into the atmosphere. Valves, connectors, flanges, open ended lines, and pump seals are all potential sources of emissions and are included in the proposed emission inventory of the Eagle Ford. Emission factors for natural gas well fugitives are based on TCEQ's Barnett Shall special inventory results. Other studies, including ENVIRON's Haynesville Shale emission inventory[311], Armendariz study on the Barnett[312], and ERG's Fort Worth Natural Gas Study [313], calculated fugitive emissions from wells in Texas.

Fugitive VOC emissions for oil wells are based on ERG methodology for Texas[314] and EPA protocol for equipment leaks.[315] ERG used EPA's emission factors for each component multiplied by the average number of components per well from ENVIRON's CENRAP emission inventory for the Western Gulf Basin.[316] The number of fugitive components per well from previous studies is provided in Table 6-11. The Barnett shale special inventory, 781 components for natural gas wells, and ERG's Fort Worth Natural Gas study, 603 components per well, had significantly more components per well compared to other studies. Calculated natural gas and oil well fugitive emission factors from other studies are provided in Table 6-12.

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311 John Grant, Lynsey Parker, Amnon Bar-Ilan, Sue Kemball-Cook, and Greg Yarwood, ENVIRON International Corporation. August 31, 2009. "Development of an Emission Inventory for Natural Gas Exploration and Production in the Haynesville Shale and Evaluation of Ozone Impacts". Novato, CA. p. 38. Available online: http://www.netac.org/UserFiles/File/NETAC/9_29_09/Enclosure_2b.pdf. Accessed: 04/19/2012.

312 Al Armendariz. Jan. 26, 2009. "Emissions from Natural Gas Production in the Barnett Shale Area and Opportunities for Cost-Effective Improvements". Prepared for Environmental Defense Fund. Austin, Texas. Available Online: http://www.edf.org/sites/default/files/9235_Barnett_Shale_Report.pdf. Accessed: 04/19/2012.

313 Eastern Research Group Inc. July 13, 2011. "Fort Worth Natural Gas Air Quality Study Final Report". Prepared for: City of Fort Worth, Fort Worth, Texas. Available online: http://fortworthtexas.gov/gaswells/?id=87074. Accessed: 04/09/2012.

314 Mike Pring, Daryl Hudson, Jason Renzaglia, Brandon Smith, and Stephen Treimel, Eastern Research Group, Inc. Nov. 24, 2010. "Characterization of Oil and Gas Production Equipment and Develop a Methodology to Estimate Statewide Emissions". Prepared for: Texas Commission on Environmental Quality Air Quality Division. Austin, Texas. p. 4-49. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820784003FY1026-20101124-ergi-oilGasEmissionsInventory.pdf. Accessed: 04/10/2012.

315 EPA, Nov. 1995. "Protocol for Equipment Leak Emission Estimates". EPA-453/R-95-017. Research Triangle Park, NC. p. 2-15. Available online: http://www.epa.gov/ttnchie1/efdocs/equiplks.pdf. Accessed 04/30/2012.

316 Amnon Bar-Ilan, Rajashi Parikh, John Grant, Tejas Shah, Alison K. Pollack, ENVIRON International Corporation. Nov. 13, 2008. "Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories". Novato, CA. p. 53-54. Available online: http://www.wrapair.org/forums/ogwg/documents/2008-11_CENRAP_O&G_Report_11-13.pdf. Accessed: 04/30/2012.

Table 6-11: Number of Fugitive Components per Well

<table>
<tr><th rowspan="2">Source</th><th rowspan="2">Barnett Shale Special Inventory</th><th rowspan="2">ERG's Fort Worth Natural Gas Study</th><th rowspan="2">ENVIRON, Haynesville Shale</th><th colspan="2">ENVIRON’s CENRAP EI (Western Gulf Basin)</th><th colspan="2">ERG’s Texas EI</th></tr>
<tr><th>Gas</th><th>Light Oil</th><th>Gas</th><th>Oil</th></tr>
<tr><td>Valves</td><td>70</td><td>71</td><td>12</td><td>24</td><td>18</td><td>24</td><td>18</td></tr>
<tr><td>Connectors</td><td>185</td><td rowspan="5">532</td><td>35</td><td>118</td><td>95</td><td>118</td><td>95</td></tr>
<tr><td>Flanges</td><td>97</td><td>18</td><td>59</td><td>25</td><td>59</td><td>25</td></tr>
<tr><td>Open Ended Lines</td><td>16</td><td>6</td><td>3</td><td>2</td><td>3</td><td>2</td></tr>
<tr><td>Other</td><td>3</td><td>0</td><td>0</td><td>0</td><td>10</td><td>10</td></tr>
<tr><td>Pump Seals</td><td>411</td><td>0</td><td>0</td><td>0</td><td>2</td><td>2</td></tr>
<tr><td>Total</td><td>781</td><td>603</td><td>71</td><td>204</td><td>140</td><td>216</td><td>152</td></tr>
</table>

The formula listed below will be used to calculate fugitive emissions from natural gas wells, while Equation 6-10 will be used to calculate fugitive emissions from oil wells.

Equation 6-10, Ozone season day VOC fugitive emissions from natural gas wells

$$E_{Gas.Fugitive.B} = NUM_B \times EF_{Gas.Fugitive} \times 24 \text{ hours/day} / 907{,}184.74 \text{ grams/ton}$$

Where,

$E_{Gas.Fugitive.B}$ = Ozone season day VOC fugitive emissions from natural gas wells in county B

NUM_B = Number of gas wells drilled in county B from Equation 6-1 and Appendix E (based on data from Schlumberger Limited)

$EF_{Gas.Fugitive}$ = VOC emission factor for fugitives from natural gas wells, 104.89 grams/hour/well in Table 6-12 (from Barnett Shale Special Inventory)

Equation 6-11, Ozone season day VOC fugitive emissions from oil wells

$$E_{Oil.Fugitive.B} = NUM_B \times EF_{Oil.Fugitive} / 2{,}000 \text{ lbs/ton} / 365 \text{ days/year}$$

Where,

$E_{Oil.Fugitive.B}$ = Ozone season day VOC fugitive emissions from oil wells in county B

NUM_B = Number of oil wells drilled in county B from Equation 6-1 and Appendix E (based on data from Schlumberger Limited)

$EF_{Oil.Fugitive}$ = VOC emission factor for fugitives from oil wells, 368.27 lbs/year/well in Table 6-12 (from ERG’s Texas emission inventory)

Table 6-12: Fugitive Emission Factors for Gas and Oil Wells from Previous Studies

Barnett Shale Area Special Inventory*	ERG's Fort Worth Natural Gas Study	ENVIRON's Haynesville Shale EI	ENVIRON's CENRAP EI (Western Gulf Basin)		ERG's Texas EI		Armendariz Barnett Shale	EPA Region 8. Oil and Gas Production
			Gas	Light Oil	Gas	Oil		
104.89 g/hr/well	7.51 g/hr/well	34.3 kg-TOC/hr	68.9 kg-TOC/hr	30.23 kg-TOC/hr	433.31 lbs/ year/well	**368.27 lbs/ year/well**	11 lbs/MMscf	14.4 lb/each-yr valve

*includes process vents, piping fugitives, acid gas removal vents, and separators

6.7 Loading fugitives

"Oil and condensate stored in field storage tanks is transferred to trucks and railcars and shipped to refineries for further processing. Fugitive VOC emissions are released from these loading processes as the vapors in the receiving vessel are displaced by the liquids from the storage tanks".[317] The formulas used to calculate loading loss emission factors for crude oil and condensate loading are based on ERG Texas statewide emission inventory and EPA's AP 42 methodology.[318] To calculate loading emission factors for each specific county, average temperature data from 1980 to 2010 was calculated using ArcGIS software[319] and data from NOAA[320] for the following 12 stations in Texas:

- USW00012912 - Victoria
- USW00012919 - Brownsville INTL
- USW00012921 - San Antonio INTL
- USW00012924 - Corpus Christi
- USW00012960 - Houston Bush INTL
- USW00013904 - Austin Bergstrom
- USW00013959 - Waco
- USW00013962 - Abilene
- USW00022010 - Del Rio
- USW00023034 - San Angelo
- USW00012917 - Port Arthur
- USW00013960 - Dallas

Using ERG methodology, the Reid vapor pressure (RVP) of crude oil is 5 while condensate is 7. According to AP42[321] and the methodology used by ERG, the molecular weight of oil vapor is 50 lb/lb-mole and condensate vapor is 68 lb/lb-mole. It is estimated that all operators used submerged loading with dedicated vapor balance service. Emissions will be calculated based on all venting emissions being uncontrolled by flares or vapor recovery units. Annual and ozone season VOC emission factors for loading loss are presented in Table 6-13 and Table 6-14.

To calculate emission factors for loading loss for each county, true vapor pressure is required. Equation 6-12 and Equation 6-13, from ERG's Texas emission inventory, will be used to calculate the true vapor pressure for crude oil and condensate in each county.

Equation 6-12, True vapor pressure for crude oil

$$P_{Crude.oil} = (0.057 \times T_B) - 0.58$$

Where,

$P_{Crude.oil}$ = True vapor pressure for County B for crude oil

T_B = Atmospheric temperature in degrees Fahrenheit for County B in Table 6-13 (based on data from NOAA)

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317 Mike Pring, Daryl Hudson, Jason Renzaglia, Brandon Smith, and Stephen Treimel, Eastern Research Group, Inc. Nov. 24, 2010. "Characterization of Oil and Gas Production Equipment and Develop a Methodology to Estimate Statewide Emissions". Prepared for: Texas Commission on Environmental Quality Air Quality Division. Austin, Texas. p. 4-30. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820784003FY1026-20101124-ergi-oilGasEmissionsInventory.pdf. Accessed: 04/10/2012.

318 EPA, June 2008. "AP42 - 5.2 Transportation And Marketing Of Petroleum Liquids". Available online: http://www.epa.gov/ttn/chief/ap42/ch05/final/c05s02.pdf. Accessed: 05/12/2012.

319 ESRI. "ArcGIS". Available online: http://www.esri.com/software/arcgis/index.html. Accessed 06/19/2012.

320 National Oceanic and Atmospheric Administration (NOAA), National Climatic Data Center. July 1, 2011. "NOAA's 1981-2010 Climate Normals". Available online: http://www.ncdc.noaa.gov/oa/climate/normals/usnormals.html. Accessed: 04/30/2012.

321 EPA , Nov. 11, 2006. "AP42: 7.1 Organic Liquid Storage Tanks". p. 7.1-63. Available online: http://www.epa.gov/ttn/chief/ap42/ch07/final/c07s01.pdf. Accessed: 04/30/2012.

Table 6-13: Crude Oil Loading Fugitive Parameters and Emission Factors

County	Saturation Factor	Annual Avg. Temperature	Ozone Season Avg. Temperature	Molecular Weight of Vapor @ 60F (lb/lb-mole)	Annual True Vapor Pressure (psi)	Ozone Season True Vapor Pressure (psi)	Annual Loading Loss (lb/1000 gal)	Ozone Season Loading Loss (lb/1000 gal)
Atascosa	1.00	69.1	76.3	50	3.36	3.77	3.95	4.38
Bee	1.00	70.2	77.8	50	3.42	3.86	4.02	4.47
Brazos	1.00	68.2	77.0	50	3.31	3.81	3.91	4.42
Burleson	1.00	68.2	77.0	50	3.31	3.81	3.91	4.42
DeWitt	1.00	69.4	77.4	50	3.38	3.83	3.98	4.44
Dimmit	1.00	68.7	76.6	50	3.34	3.78	3.93	4.40
Fayette	1.00	68.6	77.1	50	3.33	3.81	3.93	4.43
Frio	1.00	68.8	76.3	50	3.34	3.77	3.94	4.38
Gonzales	1.00	68.9	77.0	50	3.34	3.81	3.94	4.42
Grimes	1.00	68.5	77.1	50	3.33	3.81	3.92	4.43
Houston	1.00	68.2	77.0	50	3.31	3.81	3.90	4.42
Karnes	1.00	69.3	77.0	50	3.37	3.81	3.97	4.42
La Salle	1.00	69.2	76.8	50	3.36	3.80	3.96	4.41
Lavaca	1.00	69.2	77.4	50	3.37	3.83	3.97	4.44
Lee	1.00	68.3	77.0	50	3.31	3.81	3.91	4.42
Leon	1.00	67.9	76.9	50	3.29	3.81	3.89	4.42
Live Oak	1.00	70.0	77.6	50	3.41	3.84	4.01	4.45
Madison	1.00	68.2	77.0	50	3.31	3.81	3.90	4.42
McMullen	1.00	69.5	77.1	50	3.38	3.81	3.98	4.43
Maverick	1.00	68.3	76.3	50	3.31	3.77	3.91	4.38
Milam	1.00	67.8	76.9	50	3.29	3.80	3.88	4.42
Washington	1.00	68.5	77.1	50	3.33	3.81	3.92	4.43
Webb	1.00	69.4	77.2	50	3.38	3.82	3.98	4.43
Wilson	1.00	69.0	76.3	50	3.35	3.77	3.95	4.38
Zavala	1.00	68.5	76.3	50	3.32	3.77	3.92	4.38

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Table 6-14: Condensate Loading Fugitive Parameters and Emission Factors

County	Saturation Factor	Annual Avg. Temperature	Ozone Season Avg. Temperature	Molecular Weight of Vapor @ 60F (lb/lb-mole)	Annual True Vapor Pressure (psi)	Ozone Season True Vapor Pressure (psi)	Annual Loading Loss (lb/1000 gal)	Ozone Season Loading Loss (lb/1000 gal)
Atascosa	1.00	69.1	76.3	68	4.29	4.84	6.87	7.66
Bee	1.00	70.2	77.8	68	4.38	4.96	7.00	7.82
Brazos	1.00	68.2	77.0	68	4.22	4.90	6.78	7.73
Burleson	1.00	68.2	77.0	68	4.22	4.90	6.78	7.73
DeWitt	1.00	69.4	77.4	68	4.31	4.93	6.91	7.77
Dimmit	1.00	68.7	76.6	68	4.26	4.87	6.83	7.69
Fayette	1.00	68.6	77.1	68	4.25	4.91	6.82	7.74
Frio	1.00	68.8	76.3	68	4.27	4.85	6.85	7.66
Gonzales	1.00	68.9	77.0	68	4.27	4.90	6.85	7.73
Grimes	1.00	68.5	77.1	68	4.25	4.90	6.81	7.74
Houston	1.00	68.2	77.0	68	4.22	4.90	6.78	7.73
Karnes	1.00	69.3	77.0	68	4.31	4.90	6.90	7.73
La Salle	1.00	69.2	76.8	68	4.29	4.89	6.88	7.72
Lavaca	1.00	69.2	77.4	68	4.30	4.93	6.89	7.77
Lee	1.00	68.3	77.0	68	4.23	4.90	6.78	7.73
Leon	1.00	67.9	76.9	68	4.20	4.89	6.74	7.73
Live Oak	1.00	70.0	77.6	68	4.36	4.94	6.97	7.79
Madison	1.00	68.2	77.0	68	4.22	4.90	6.78	7.73
McMullen	1.00	69.5	77.1	68	4.32	4.91	6.92	7.74
Maverick	1.00	68.3	76.3	68	4.23	4.84	6.78	7.66
Milam	1.00	67.8	76.9	68	4.19	4.89	6.73	7.72
Washington	1.00	68.5	77.1	68	4.25	4.90	6.81	7.74
Webb	1.00	69.4	77.2	68	4.32	4.91	6.91	7.75
Wilson	1.00	69.0	76.3	68	4.28	4.84	6.86	7.65
Zavala	1.00	68.5	76.3	68	4.24	4.85	6.81	7.66

Equation 6-13, True vapor pressure for condensate

$P_{Condensate} = (0.077 \times T_B) - 1.03$

Where,

$P_{Condensate}$ = True vapor pressure for County B for condensate
T_B = Atmospheric temperature in degrees Fahrenheit for County B in Table 6-13 (based on data from NOAA)

The following formula was used to calculate loading loss VOC emission factors for each county in Texas. To convert from Fahrenheit to the Rankine (R) temperature scale required by the formula, 459.67 was added to average Fahrenheit temperature.

Equation 6-14, VOC emission factor for loading loss

$EF_{Loading.BC} = 12.46 \times [S \times P_{BC} \times M_C / (T_B + 459.67)]$

Where,

$EF_{Loading.BC}$ = VOC emission factor for loading loss for County B for substance C
S = Saturation factor for loading, 1.00 in Table 6-13 (from EPA's AP42)
P_{BC} = True vapor pressure for County B for substance C in Table 6-13 and Table 6-14 (from Equation 6-12 and Equation 6-13)
M_C = Molecular weight of tank vapors for substance C, 50 lb/lb-mole for oil and 68 lb/lb-mole for condensate in Table 6-13 (from EPA's AP42)
T_B = Atmospheric temperature in degrees Fahrenheit for County B in Table 6-13 and Table 6-14 (based on data from NOAA)

By using loading loss emission factors calculated in the above formulas, ozone season daily VOC emissions will be calculated using the following formula.

Equation 6-15, Ozone season day VOC emissions from loading loss

$E_{Loading.BC} = PROD_C \times PERW_B \times EF_{Loading.BC}$ / 42 gallons/barrel / 365 days/year / 2,000 lbs/ton

Where,

$E_{Loading.BC}$ = Ozone season day VOC emissions from loading loss in county B
$PROD_C$ = Eagle Ford production for substance C, 36,626 Mbbl of Oil or 20,876 Mbbl of condensate in 2011 (from Railroad Commission)
$PERW_B$ = Percent of liquid wells in County B in Table 6-1 (from Schlumberger Limited)
$EF_{Loading.BC}$ = VOC emission factor for loading loss for County B and Substance C in Table 6-13 and Table 6-14 (from Equation 6-14)

6.8 Well Blowdowns

"Well blowdowns refer to the practice of venting gas from wells that have developed some kind of cap or obstruction before any additional intervention work can be done on the wells. Typically well blowdowns are conducted on wells that have been shut in for a period of time and the operator desires to bring the well back into production. Well blowdowns are also sometimes conducted to remove fluid caps that have built up in producing gas wells. Because gas is directly vented from the blowdown event, blowdowns can be a source of VOC emissions."[322]

[322] Amnon Bar-Ilan, Rajashi Parikh, John Grant, Tejas Shah, Alison K. Pollack, ENVIRON International Corporation. Nov. 13, 2008. "Recommendations for Improvements to the CENRAP

To calculate blowdowns, data on the molecular weight of VOC, mass fraction of VOC, blowdown frequency, and the volume of gas vented per blowdown (MCF) in the Eagle Ford are needed. ERG estimates that the molecular weight of VOC for gas wells is 20 and for oil wells is 27 (Table 6-15).[323] The mass fraction of VOC in each event was 0.036 for gas wells and 0.141 for oil wells. There was an average of 0.71 blowdowns a year per well in the Western Gulf Basin and there was 173.9 MCF of gas release during each blowdown.

Table 6-15: Well Blowdowns Venting Emission Estimation Inputs from Previous Studies

Property	ENVIRON's Haynesville Shale EI	ENVIRON's CENRAP EI (Western Gulf Basin)	ERG's Texas EI (Karnes County)	
			Gas	Oil
Molecular Weight of VOC	17.2	17.2	**20**	**27**
Mass Fraction of VOC	0.036	0.036	**0.036**	**0.141**
Blowdown Frequency	1.00	**0.71**	0.71	0.71
Volume of Gas Vented Per Blowdown (MCF)	32	**173.9**	173.9	173.9
Fraction of Blowdowns Controlled by Flares	0%	**0%**	0%	0%
Flaring Control Efficiency for VOC Emissions	95%	**98%**		
Fraction of Blowdowns Controlled by Green Completion	0%	**0%**	0%	0%

VOC emission factors listed in Table 6-16, from ERG's Texas emission inventory, will be used to calculate emissions from blowdowns. "Flaring and/or green practices may be used to control emissions from the blowdown process."[324] Although emission reductions due to flaring and green completions are not calculated, flaring has a control efficiency of 98 percent and green completion has a control efficiency of 100%.[325]

States' Oil and Gas Emissions Inventories". Novato, CA. p. 50. Available online: http://www.wrapair.org/forums/ogwg/documents/2008-11_CENRAP_O&G_Report_11-13.pdf. Accessed: 04/30/2012.

[323] Mike Pring, Daryl Hudson, Jason Renzaglia, Brandon Smith, and Stephen Treimel, Eastern Research Group, Inc. Nov. 24, 2010. "Characterization of Oil and Gas Production Equipment and Develop a Methodology to Estimate Statewide Emissions". Prepared for: Texas Commission on Environmental Quality Air Quality Division. Austin, Texas. p. 4-7. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820784003FY1026-20101124-ergi-oilGasEmissionsInventory.pdf. Accessed: 04/10/2012.

[324] Amnon Bar-Ilan, Rajashi Parikh, John Grant, Tejas Shah, Alison K. Pollack, ENVIRON International Corporation. Nov. 13, 2008. "Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories". Novato, CA. p. 50. Available online: http://www.wrapair.org/forums/ogwg/documents/2008-11_CENRAP_O&G_Report_11-13.pdf. Accessed: 04/30/2012.

[325] *Ibid*.

Table 6-16: Well Blowdowns VOC Emission Factors from Previous Studies

ENVIRON's Haynesville Shale EI	ENVIRON's CENRAP EI (Western Gulf Basin)	ERG's Texas EI (Karnes County)[326]	
		Gas	Oil
0.026 tons/ year/well	0.099 tons/year/well	**0.16 tons/blowdown**	**0.85 tons/blowdown**

The following equation was used by ERG to calculate VOC emissions from blowdowns at each well in the Texas Gulf Basin.

Equation 6-16, Blowdowns VOC emissions from each well

$EF_{Blowdown,C} = (P \times V_{vented}) / [(R / MW_{gas.C}) \times T \times 0.00003531 \text{ Mscf/liter})] \times (F_{VOC.C} / 907{,}184.74 \text{ grams/ton})$

Where,

$EF_{Blowdown.C}$ = Blowdowns VOC emission factor for substance C
P = Atmospheric pressure, 1 atm
V_{vented} = Volume of vented gas per blowdown, 173.9 MCF/event (from ENVIRON's CENRAP emission inventory)
R = Universal gas constant, 0.082 L-atm/mol-K
$MW_{gas.C}$ = Molecular weight of the gas for substance C, 20 g/mol for natural gas and 27 g/mol for oil (from ERG's Texas emission inventory)
T = Atmospheric temperature, 298 K
$F_{VOC.C}$ = Mass fraction of VOC in the vented gas for substance C, 0.036 for natural gas and 0.141 for oil (from ERG's Texas emission inventory)

Once emission factors for blowdowns at a single well are calculated, ozone season daily VOC emissions from natural gas or oil wells will be calculated using the following formula.

Equation 6-17, Ozone season day VOC emissions from blowdowns

$E_{Blowdowns.BC} = NUM_{BC} \times N_{Blowdown} \times [1 - (C_{flare} \times CE_{flare}) - C_{green}] \times EF_{Blowdown.C} / 365 \text{ days/year} / 2{,}000 \text{ lbs/ton}$

Where,

$E_{Blowdowns.BC}$ = Ozone season day VOC emissions from blowdowns in county B for substance C (natural gas or oil)
NUM_{BC} = Number of gas wells drilled in county B for Eagle Ford development in Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)
$N_{Blowdown}$ = Number of blowdowns per well, 0.71 blowdowns/year (from ENVIRON's CENRAP emission inventory)
C_{flare} = Fraction of blowdowns in the basin that were controlled by flares, 0% (from ENVIRON's CENRAP emission inventory)
CE_{flare} = Control efficiency of Flaring during blowdowns, 98% (from ENVIRON's CENRAP emission inventory)
C_{green} = Faction of blowdowns in the basin that were controlled by green techniques, 0% (from ENVIRON's CENRAP emission inventory)

[326] Mike Pring, Daryl Hudson, Jason Renzaglia, Brandon Smith, and Stephen Treimel, Eastern Research Group, Inc. Nov. 24, 2010. "Characterization of Oil and Gas Production Equipment and Develop a Methodology to Estimate Statewide Emissions". Prepared for: Texas Commission on Environmental Quality Air Quality Division. Austin, Texas. p. 4-7. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820784003FY1026-20101124-ergi-oilGasEmissionsInventory.pdf. Accessed: 04/10/2012.

$EF_{Blowdown.C}$ = VOC emission factor for blowdowns for substance C, 0.16 tons/blowdown for oil wells and 0.85 tons/blowdown for gas wells (from Equation 6-16 and ERG's Texas Emission Inventory)

6.9 Pneumatic Devices

"Pneumatic devices are those devices used for a variety of wellhead processes which are powered mechanically by high-pressure produced gas as the working fluid – i.e. pneumatically-powered devices. This is necessary for many remote well sites where electrical grid power is not available to power these devices. Typical pneumatic devices include pressure transducers, liquid level controllers, pressure controllers and positioners. These devices are typically in operation continuously throughout the year."[327]

Pneumatic devices emission factors from ENVIRON's CENRAP emission inventory and ERG's Texas emission inventory[328] are based on EPA's natural gas star program[329] (Table 6-17). There was a few pneumatic devices recorded in the Barnett Shale special Inventory, but many of the wells are located in areas with electric grid power. Many wells in the Eagle Ford are in rural areas were the electric grid power is not available and these devices usually run off natural gas. If further data becomes available from the Barnett Shale special inventory, the data will be included in the emission calculations.

Table 6-17: Pneumatic Devices VOC Emission Factors for Natural Gas Wells from Previous Studies

Barnett Shale Area Special Inventory	ENVIRON's Haynesville Shale EI	ENVIRON's CENRAP EI (Western Gulf Basin)	ERG's Texas EI
0.18 g/hr/well (for Pneumatic and other Pumps)	13,160 lbs/year/well	13,160 lbs/year/well	**3,689 lbs/year/well**

According to ERG's Texas emission inventory, the molecular weight of the gas is 19.68 g/mol and the volumetric bleed rate from liquid level controllers is 31 scf/hr/device and for pressure controllers is 16.8 scf/hr/device. There are 2 liquid level controller and 1 pressure controller in each pneumatic device that emit 31 scf of gas/hr/device for liquid level controllers and 16.8 scf of gas/hr/device for pressure controllers. The following equation was used by ERG to calculate VOC emissions from pneumatic devices at each natural gas well in the Texas Gulf Basin.

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[327] John Grant, Lynsey Parker, Amnon Bar-Ilan, Sue Kemball-Cook, and Greg Yarwood, ENVIRON International Corporation. August 31, 2009. "Development of an Emission Inventory for Natural Gas Exploration and Production in the Haynesville Shale and Evaluation of Ozone Impacts". Novato, CA. p. 42. Available online: http://www.netac.org/UserFiles/File/NETAC/9_29_09/Enclosure_2b.pdf. Accessed: 04/19/2012.

[328] Mike Pring, Daryl Hudson, Jason Renzaglia, Brandon Smith, and Stephen Treimel, Eastern Research Group, Inc. Nov. 24, 2010. "Characterization of Oil and Gas Production Equipment and Develop a Methodology to Estimate Statewide Emissions". Prepared for: Texas Commission on Environmental Quality Air Quality Division. Austin, Texas. p. 4-7. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820784003FY1026-20101124-ergi-oilGasEmissionsInventory.pdf. Accessed: 04/10/2012.

[329] EPA, Natural Gas Star Program, Feb. 2004. "Convert Gas Pneumatic Controls to Instrument Air". EPA-430-B-04-003. Available online: http://nepis.epa.gov/Adobe/PDF/P1004FJ1.pdf. Accessed 04/23/2012.

Equation 6-18, VOC emissions from pneumatic devices at each well

$EF_{Pneumatic}$ = [(F_{VOC} / 907,184.74 grams/ton) x (ΣV_i x N_i x HRS_{annual})] x [P / (R / MW_{gas} x T x 0.00003531 Mscf/liter)]

Where,

$EF_{Pneumatic}$ = VOC emission factor for pneumatic devices
F_{VOC} = Mass fraction of VOC in the vented gas, 0.1054 (from ERG's Texas emission inventory)
V_i = Volumetric bleed rate from device i, 31 scf/hr/device for liquid level controller and 16.8 scf/hr/device for pressure controller (from ERG's Texas emission inventory)
N_i = Total number of device i, 2 liquid level controller and 1 pressure controller (from ENVIRON's CENRAP emission inventory)
HRS_{annual} = Number of operating hours per year, 8760 hours/year (from ENVIRON's CENRAP emission inventory)
P = Atmospheric pressure, 1 atm
R = Universal gas constant, 0.082 L-atm/mol-K
MW_{gas} = Molecular weight of the gas, 19.68 g/mol (from ERG's Texas emission inventory)
T = Atmospheric temperature, 298 K

Once the emission factor for pneumatic devices at a single well is calculated, ozone season daily VOC emissions from natural gas wells will be calculated using the following formula.

Equation 6-19, Ozone season day VOC emissions from pneumatic devices

$E_{Pneumatic.B}$ = NUM_B x $EF_{Pneumatic}$ / 365 days/year / 2,000 lbs/ton

Where,

$E_{Pneumatic.B}$ = Ozone season day VOC emissions from pneumatic devices in county B
NUM_B = Number of gas wells drilled in county B from Equation 6-1 and Appendix E (based on data from Schlumberger Limited)
$EF_{Pneumatic}$ = VOC emission factor for pneumatic devices, 3,656 lbs/year/well in Table 6-17 (from Equation 6-18 and ERG's Texas Emission Inventory)

6.10 Production On-Road Emissions

There is a wide variety of truck traffic estimation for each pad per year during production; from 2 - 3 trucks per year from New York City study in the Marcellus[330] to 365 trucks in Pinedale Anticline Project, Wyoming survey.[331] Cornell University only estimated 15 trucks per well pad in the Marcellus,[332] while San Juan Public Lands Center had a higher

[330] Haxen and Sawyer, Environmental Engineers & Scientists, Sept. 2009. "Impact Assessment of Natural Gas Production in the New York City Water Supply Watershed Rapid Impact Assessment Report" New York City Department of Environmental Protection. p. 47. Available online: http://www.nyc.gov/html/dep/pdf/natural_gas_drilling/rapid_impact_assessment_091609.pdf. Accessed: 04/20/2012.

[331] U.S. Department of the Interior, Bureau of Land Management, Sept. 2008. "Final Supplemental Environmental Impact Statement for the Pinedale Anticline Oil and Gas Exploration and Development Project: Pinedale Anticline Project Area Supplemental Environmental Impact Statement". Sheyenne, Wyoming. pp. F51-52. Available online: http://www.blm.gov/pgdata/etc/medialib/blm/wy/information/NEPA/pfodocs/anticline/rd-seis/tsd.Par.13395.File.dat/07appF.pdf. Accessed: 04/12/2012.

[332] Santoro, R.L.; R.W. Howarth; A.R. Ingraffea. 2011. Indirect Emissions of Carbon Dioxide from Marcellus Shale Gas Development. A Technical Report from the Agriculture, Energy, & Environment

estimation of 158 trucks in Colorado.[333] TxDOT estimation of 353 trucks per year for each well will be used to calculate heavy duty truck emissions from production.[334] The number of trucks provided by TxDOT match very closely to Chesapeake Energy statement that there is one truck per well pad per day during production.[335]

For light duty vehicles, Tumble-weed II study in Utah report 365 vehicles annually[336], while Jonah Infill in Wyoming stated that there was 122 light duty vehicles during production[337] Data from ENVIRON report in Colorado, 73.2 light duty vehicles, will be used to estimate emissions. Data on idling rates from the ENVIRON report will also be used to estimate idling emissions. In the report, ENVIRON estimated that heavy duty trucks idle between 0.9 hours to 3 hours, while light duty vehicles idle approximately 2.5 hours.[338] An analysis of 66 wells in the Eagle Ford found that almost all oil and condensate was transported by truck. Only three wells transported condensate by pipeline and no oil was transported by pipeline.[339]

On-road VOC, NO_X, and CO emissions during production for heavy duty trucks and light duty trucks will be calculated in Equation 6-20 and Equation 6-21. The inputs into the formula will be based on local data, MOVES output emission factors, TxDOT, and data from ENVIRON's survey in Colorado.

Equation 6-20, Ozone season day on-road emissions during production

$$E_{Onroad.ABC} = NUM_{BC} \times TRIPS_A \times (DIST_B \times 2) \times OEF_A / WPAD_B / 907{,}184.74 \text{ grams per ton} / 365 \text{ days/year}$$

Program at Cornell University. June 30, 2011. Available online: http://www.eeb.cornell.edu/howarth/IndirectEmissionsofCarbonDioxidefromMarcellusShaleGasDevelopment_June302011%20.pdf Accessed: 04/02/2012.

333 BLM National Operations Center, Division of Resource Services, December, 2007. "San Juan Public Lands Center Draft Land Management Plan & Draft Environmental Impact Statement: Air Quality Impact Assessment Technical Support Document". Bureau of Land Management, San Juan Public Lands Center, Durango, Colorado. p. A-16. Available online: http://ocs.fortlewis.edu/forestplan/DEIS/pdf/120507_TSD&App%20A.pdf. Accessed: 04/03/2012.

334 Richard Schiller, P.E. Fort, Worth District. Aug. 5, 2010. "Barnett Shale Gas Exploration Impact on TxDOT Roadways". TxDOT, Forth Worth. Slide 18.

335 Chesapeake Energy Corporation, 2012. "Part 1 – Drilling". Available online: http://www.askchesapeake.com/Barnett-Shale/Multimedia/Educational-Videos/Pages/Information.aspx. Accessed: 04/22/2012.

336 U.S. Department of the Interior, Bureau of Land Management. June 2010. "Tumbleweed II Exploratory Natural Gas Drilling Project". East City, Utah. DOI-BLM-UTG010-2009-0090-EA. p. 24 of 29. Available online: http://www.blm.gov/pgdata/etc/medialib/blm/ut/lands_and_minerals/oil_and_gas/november_2011.Par.24530.File.dat/. Accessed: 04/12/2012.

337 Amnon Bar-Ilan, ENVIRON Corporation, June 2010. "Oil and Gas Mobile Source Emissions Pilot Study: Background Research Report". UNC-EMAQ (3-12)-006.v1. Novato, CA. p. 18. Available online: http://www.wrapair2.org/documents/2010-06y_WRAP%20P3%20Background%20Literature%20Review%20(06-06%20REV).pdf. Accessed: 04/03/2012.

338 Amnon Bar-Ilan, John Grant, Rajashi Parikh, Ralph Morris, ENVIRON International Corporation, July 2011. "Oil and Gas Mobile Sources Pilot Study". Novato, California. pp. 11-12. Available online: http://www.wrapair2.org/documents/2011-07_P3%20Study%20Report%20(Final%20July-2011).pdf. Accessed: 04/12/2012.

339 Railroad Commission of Texas. "Specific Lease Query". Austin, Texas. Available online: http://webapps.rrc.state.tx.us/PDQ/quickLeaseReportBuilderAction.do. Accessed 06/01/2012.

Where,

$E_{Onroad.ABC}$ = Ozone season day NO_X, VOC, or CO emissions from on-road vehicles in county B for Eagle Ford development well type C (Gas or Oil)

NUM_{BC} = Number of wells drilled in county B from Equation 6-1 and Appendix E (based on data from Schlumberger Limited)

$TRIPS_A$ = Number of trips for vehicle type A, 353 for heavy duty trucks (from TxDOT in the Barnett), 68.5 for light duty trucks for production, and 4.7 light duty trucks for maintenance in Table 6-18 (from ENVIRON's Colorado report)

$DIST_B$ = Distance to the nearest town for county B, Table 3-2 (from Railroad Commission of Texas)

OEF_A = NO_X, VOC, or CO on-road emission factor for vehicle type A in Table 3-5 (from MOVES Model)

$WPAD_B$ = Number of Wells per Pad for county B, Table 3-2 (calculated from data provided by the Railroad Commission of Texas)

Equation 6-21, Ozone season day idling emissions during production

$E_{Idling.ABC}$ = NUM_{BC} x $TRIPS_A$ x $IDLE_A$ x IEF_A / $WPAD_B$ / 907,184.74 grams per ton / 365 days/year

Where,

$E_{Idling.ABC}$ = Ozone season day NO_X, VOC, or CO emissions from idling vehicles in county B for Eagle Ford development well type C (Gas or Oil)

NUM_{BC} = Number of gas wells drilled in county B from Equation 6-1 and Appendix E (based on data from Schlumberger Limited)

$TRIPS_A$ = Number of trips for vehicle type A, 353 for heavy duty trucks (from TxDOT in the Barnett), 68.5 for light duty trucks for production, and 4.7 light duty trucks for maintenance in Table 6-18 (from ENVIRON's Colorado report)

$IDLE_A$ = Number of Idling Hours/Trip for vehicle type A, 0.9 hours for heavy duty trucks, 2.5 for light duty trucks for production, and 2.55 light duty trucks for maintenance in Table 6-18 (from ENVIRON's Colorado report)

IEF_A = NO_X, VOC, or CO idling emission factor for vehicle type A in Table 3-5 (from EPA based on the MOVES model)

$WPAD_B$ = Number of Wells per Pad for county B, Table 3-2 (calculated from data provided by the Railroad Commission of Texas)

Over time, the number of trips by trucks will decrease during production as the number of pipelines to haul product increases in the Eagle Ford. However, many of the wells will not be directly connected to the pipelines. Also, the number of truck trips will decrease over time due to steep liquid decline curves at wells in the Eagle Ford. As the well ages, production will significantly decline and fewer truck visits will be needed for each well. Emissions from truck activity at saltwater disposal sites are not included in the proposed emission inventory. If data on truck traffic at disposal wells becomes available, their emissions will be incorporated into the inventory.

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Table 6-18: On-Road Vehicles used during Production from Previous Studies

Vehicle Type	Para-meter	Purpose	Cornell University Marcellus Study	San Juan Public Lands Center, Colorado	Tumble-weed II, Utah	ENVIRON Colorado	Jonah Infill, Wyoming	National Park Service, Marcellus	New York City, Marcellus	Pinedale Anticline Project, Wyoming	NCTCOG, Barnett (after 90 days)[340]	TxDOT, Barnett
HDDV	Annual Number/Well	Water Truck	15	158	1	3.3	35	5 - 13.3	2-3	365	< 1 trip per day	**353**
		Product Truck			80							
		Maintenance			-	0.9						
	Distance (miles)	Water Truck	62.5	12.5	80	37.8	9.5	-	-	10	-	-
		Product Truck			80							
		Maintenance			-	100.0						
	Speed (mph)	Water Truck	-	20 (road)	-	21.15	20 (road)	-	-	35	-	-
		Product Truck										
		Maintenance				20.0						
	Idling Hours/Trip	Water Truck	-	-	-	**0.9**	-	-	-	-	-	-
		Product Truck										
		Maintenance				3.0						
LDT	Annual Number/well	Production	-	10	365	**68.5**	122	-	-	365	-	-
		Maintenance				**4.7**						
	Distance (miles)	Production	-	12.5	43	100.0	9.5	-	-	10	-	-
		Maintenance				117.75						
	Speed (mph)	Production	-	30 (road)	-	20	30 (road)	-	-	35	-	-
		Maintenance				20						
	Idling Hours/Trip	Production	-	-	-	**2.5**	-	-	-	-	-	-
		Maintenance				**2.55**						

340 North Central Texas Council of Governments. "Barnett Shale Truck Traffic Survey". Dallas, Texas. Slide 9. Available online: http://www.nctcog.org/trans/air/barnettshale.asp. Accessed 05/04/2012.

7 COMPRESSOR STATIONS AND MIDSTREAM SOURCES

7.1 Midstream Facilities

Midstream sources are facilities that transport, handle, process, and distribute products or waste from oil and gas production. After the initial production from the well, midstream sources handle and process the product. Examples of midstream sources include:

- Compressor stations
- Processing facilities
- Cryogenic plants
- Tank Batteries
- Saltwater disposal sites
- Pipelines
- Other facilities

Large emission sources at midstream facilities include heater/boilers, glycol dehydration, compressor engine, storage tanks, loading, flare/combustor, and fugitives. Detailed information on equipment counts, equipment characteristics, and permitted emission allowances can be collected from TCEQ permit database.[341]

Mid Stream source in the Eagle Ford are also used to process traditional oil and natural gas supplies, but only facilities with new permits or modification to existing permits after 2007 are included in the analysis. These new facilities will primary be used for Eagle Ford production and product from other sources will be insignificant. Some of Eagle Ford product may be transported outside of the region to midstream sources for processing, but these sources are not included in the emission inventory.

7.1.1 Compressor Stations

Compressors "can either be used at the wellhead or at a central location along a pipeline, where several compressors or pumps are usually grouped together at a facility called a compressor or pump station. The number of compressors or pumps at a station or stations will vary based on the amount of production from nearby wells, the size of the pipeline and the distance the product has to travel to the next station or pipeline market. Other treating equipment, such as separators and dehydrators, may also be located at these stations to remove impurities and entrained water vapors from the oil or gas."[342] There are two areas were compressor stations are located:

1. Compressor stations located at well site
2. Compressor stations located along pipelines

A picture of Natural Gas Compressor Station under Construction in the Eagle Ford Shale is provided in Figure 7-1. [343]

"Compressor stations contain one or more large (generally 250 horsepower (hp) or greater) line compressors which provide the necessary pressure to move the natural gas through many miles of transmission lines. The most significant emissions from compressors stations are usually from combustion at the compressor engines or turbines. Other emissions sources may include equipment leaks, storage tanks, glycol dehydrators, flares, and condensate and/or wastewater loading."[344]

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[341] TCEQ. "TCEQ Document Search". Available online: https://webmail.tceq.state.tx.us/gw/webpub. Accessed 06/08/2012.
[342] Chesapeake Energy, 2012. "Compressor Stations". Available online: http://www.askchesapeake.com/Eagle-Ford-Shale/Pipelines-and-Facilities/Pages/Compressor-Stations.aspx. Accessed: 03/27/2012.
[343] The Eagle Ford Shale Blog. June 30, 2010. "Photos Of Eagle Ford Shale Oil Wells". Available online: http://eaglefordshaleblog.com/photos-of-eagle-ford-shale-oil-wells/. Accessed: 04/02/2012.
[344] Eastern Research Group Inc. July 13, 2011. "Fort Worth Natural Gas Air Quality Study Final Report". Prepared for: City of Fort Worth, Fort Worth, Texas. p. 3-2. Available online: http://fortworthtexas.gov/gaswells/?id=87074. Accessed: 04/09/2012.

Figure 7-1: Natural Gas Compressor Station under Construction in the Eagle Ford Shale

7.1.2 Processing Facilities

"Processing facilities generally remove impurities from the natural gas, such as carbon dioxide, water, and hydrogen sulfide. These facilities may also be designed to remove ethane, propane, and butane fractions from the natural gas for downstream marketing. Processing facilities are usually the largest emitting natural gas-related point sources including multiple emission sources such as, but not limited to equipment leaks, storage tanks, separator vents, glycol dehydrators, flares, condensate and wastewater loading, compressors, amine treatment and sulfur recovery units.[345]

"Natural gas collected at the wellhead has a variety of components that typically render it unsuitable for long-haul pipeline transportation. Produced natural gas can be saturated with water, which must be extracted." Water can "cause corrosion when combined with carbon dioxide (CO_2) or hydrogen sulfide (H_2S) in natural gas. In addition, condensed water in a pipeline can raise pipeline pressure. To meet downstream pipeline and end-user gas quality standards, natural gas is dehydrated to remove the saturated water."[346]

"Once water and other impurities are removed from natural gas, the gas must then be separated into its components. Natural gas processing involves the separation of natural gas into pipeline quality natural gas and a mixed stream of natural gas liquids (NGLs). The primary component of natural gas is methane (CH_4), but most gas also contains varying degrees of liquids including ethane (C_2H_6), propane (C_3H_8), normal butane (C_4H_{10}), isobutane (C_4H_{10}), and natural gasoline. NGLs are used as heating fuels and as feedstock in the petrochemical and oil refining industries. Natural gas pipelines have specifications as to the maximum NGL content of the gas to be shipped. In order to meet quality standards for pipelines, natural gas that does not meet these specifications must be processed to separate liquids that can have higher values as distinct NGLs than they would by being kept in the natural gas stream."[347]

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[345] Eastern Research Group Inc. July 13, 2011. "Fort Worth Natural Gas Air Quality Study Final Report". Prepared for: City of Fort Worth, Fort Worth, Texas. p. 3-2. Available online: http://fortworthtexas.gov/gaswells/?id=87074. Accessed: 04/09/2012.
[346] SteelPath Fund Advisors. "What is a Midstream Asset?". p. 5. Available online: http://www.steelpath.com/wp-content/uploads/Whats-a-Midstream-Asset.pdf. Accessed 06/08/2012.
[347] *Ibid*.

"In addition to water, natural gas collected through a gathering system may also contain impurities such as carbon dioxide and hydrogen sulfide, depending on the reservoir from which it is derived. Natural gas with elevated amounts of carbon dioxide or hydrogen sulfide can be damaging to pipelines and fail to meet end-user specifications. As a result, gas with impurities higher than what is permitted by pipeline quality standards is treated with liquid chemicals called amines at a separate plant prior to processing. The treating process involves a continuous circulation of amine, which has a chemical affinity for carbon dioxide and hydrogen sulfide that allows it to absorb the impurities from the gas. After mixing, gas and amine are separated and the impurities are removed from the amine by heating."[348]

Fugitive emissions from processing will vary by processing plant depending on the chemical composition of the product being processed, the processing capacity of the plants, and other factors.[349] Figure 7-2 shows a facility for processing gas liquid under construction in the Eagle Ford Shale.[350] These facilities can be large and contain a significant number of emission sources.

Figure 7-2: Processing Facility for Processing Gas Liquid under Construction in the Eagle Ford Shale

7.1.3 Cryogenic Processing Plants

"A cryogenic processing plant (aka striping plant) is a facility where natural gas flowing from wells is cooled to sub-zero temperatures in order to condense liquids or NGLs (natural gas liquids). These can include butane, ethane and propane. NGLs are shipped to market and

[348] *Ibid*.

[349] Al Armendariz. Jan. 26, 2009. "Emissions from Natural Gas Production in the Barnett Shale Area and Opportunities for Cost-Effective Improvements". Prepared for Environmental Defense Fund. Austin, Texas. p. 19. Available Online: http://www.edf.org/sites/default/files/9235_Barnett_Shale_Report.pdf. Accessed: 04/19/11.

[350] The Quarterly Newsletter of Koch Companies. Oct. 2011. "Eagle Ford Takes Flight". Available online: http://www.republicreport.org/wp-content/uploads/2012/03/kochfracking.pdf. Accessed: 04/02/2012.

often used in refineries and petrochemical plants for fuel or feedstock. The methane gas that remains after removing liquids is transported via pipeline to where it is needed."[351]

Cryogenic plants are being built in the Eagle Ford by oil and gas companies, including 11 built by Thomas Russell Co.[352], to process natural gas. Cryogenic plants built by Thomas Russell Co alone can handle 2,200 MMscfd, or 800 BCF per year, of natural gas.

7.1.4 Tank Batteries

"Oil and condensate tanks are used to store produced liquid at individual well sites and there may be many thousands of such storage tanks throughout a basin. Two primary processes create emissions of gas from oil and condensate tanks: (1) flashing, whereby condensate brought from downhole pressure to atmospheric pressure may experience a sudden volatilization of some of the condensate; and (2) working and breathing losses, whereby some volatilization of stored product occurs through valves and other openings in the tank battery over time."[353]

Tank batteries are at centralized locations to handle oil or condensate from multiple wells. The product is shipped from each well to the tank battery using pipelines before the product can be sent to be process. The centralized tank battery in Gonzales County, pictured in Figure 7-3, serves multiple wells in the surrounding region.

7.1.5 Saltwater Disposal Sites

Oil and gas reservoirs in the Eagle Ford are located in porous rocks, which also contain saltwater. When the well is hydraulic fractured, completed, and production starts, significant amounts of flowback and produce water is returned to the surface. "Flowback is a mixture of the water used in the hydraulic fracturing process, chemicals and water returning from the geological formation being drilled. Typically, the volume of flowback water is greater during the first week after completion and through the first month. It also has a lower salinity of up to 80,000 ppm when compared to produced water. Produced water is naturally occurring wastewater from the geological formation being drilled. The salinity of produced water may range from 80,000 to 180,000 ppm."[354]

[351] WikiMarcellus -- Marcellus Shale and Other Appalachian Plays. Jan. 16, 2011. "Cryogenic Processing Plant". Available online: http://waytogoto.com/wiki/index.php/Cryogenic_processing_plant. Accessed 06/08/2012.
[352] Thomas Russell Co. "Project Experience". Available online: http://www.thomasrussellco.com/projects.html. Accessed 06/08/2012.
[353] Amnon Bar-Ilan, Rajashi Parikh, John Grant, Tejas Shah, Alison K. Pollack, ENVIRON International Corporation. Nov. 13, 2008. "Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories". Novato, CA. p. 44. Available online: http://www.wrapair.org/forums/ogwg/documents/2008-11_CENRAP_O&G_Report_11-13.pdf. Accessed: 04/30/2012.
[354] City of Fort Worth, Texas. "Salt Water Disposal Terms and Data". p. 1. Available online: http://fortworthtexas.gov/uploadedFiles/Gas_Wells/SWD_questions.pdf. Accessed 06/08/2012.

Figure 7-3: Centralized Tank Battery in Gonzales County[355]

"This saltwater, which accompanies the oil and gas to the surface, can be disposed in two ways: 1) Returned by fluid injection into the reservoir where it originated for secondary or enhanced oil recovery; or 2) Injected into underground porous rock formations not productive of oil or gas, and sealed above and below by unbroken, impermeable strata. Saltwater disposal wells use this second method to manage saltwater. Operators are responsible for disposing of produced water and frac fluid."[356] An Eagle Ford saltwater disposal facility north of Tilden Texas is provided in Figure 7-4. Equipment, storage tanks, and fugitives can be sources of emissions located at saltwater disposal sites.

[355] Energyindustryphotos.com. "Eagle Ford Shale Play Photos". Available online: http://eaglefordshaleblog.com/2012/04/09/eagle-ford-shale-play-photos/. Accessed: 06/08/2012.
[356] Railroad Comission of Texas. Feb. 1, 2010. "Saltwater Disposal Wells Frequently Asked Questions (FAQs)". Austin, Texas. Available online: http://www.rrc.state.tx.us/about/faqs/saltwaterwells.php. Accessed 06/08/2012.

Figure 7-4: Saltwater Disposal Facility North of Tilden Texas[357]

7.2 Emission Calculation Methodology for Mid-stream Sources

7.2.1 TCEQ Permit Database

TCEQ's permit database provided detailed emission allowances from new oil and gas midstream facilities in the Eagle Ford.[358] When TCEQ permits were reviewed, there were 643 oil and gas facilities permitted between 2008 and April 2012 in the Eagle Ford. Dimmit county had the most new midstream facilities (89 facilities) followed by Dewitt (79), Mcmullen (72), and La Salle (71) counties. It is expected that these facilities will be used to process and distribute Eagle Ford oil and gas production.

Data on emission allowance, types of equipment, number of equipment, and equipment characteristics were gathered from the permitted database. Total annual permitted emissions from Eagle Ford oil and gas midstream facilities were 11,004 tons of VOC, 11,308 tons of NO_X, and 11,165 tons of CO (Table 7-1) in April 2012. To prevent double counting of emissions, TCEQ point source database was reviewed and 13 facilities were located. It is expected that more of the identified facilities will included in TCEQ's point source database as midstream facilities are built and start production.

[357] Energyindustryphotos.com. "Eagle Ford Shale Play Photos". Available online: http://eaglefordshaleblog.com/2012/04/09/eagle-ford-shale-play-photos/. Accessed: 05/01/2012.
[358] TCEQ, Jan. 2012. "Detailed Data from the Point Source Emissions Inventory". Austin, Texas. Available online: http://www.tceq.texas.gov/airquality/point-source-ei/psei.html. Accessed 06/01/2012.

Table 7-1: Mid-Stream Sources and Permitted Emissions in the Eagle Ford, 2008-2012

County	Point Sources							Non-Point Sources						
	Number of Facilities	Tons/Year			Tons/Day			Number of Facilities	Tons/Year			Tons/Day		
		VOC	NO_x	CO	VOC	NO_x	CO		VOC	NO_x	CO	VOC	NO_x	CO
Atascosa	1	29	58	53	0.08	0.16	0.15	15	281	136	134	0.77	0.37	0.37
Bee	-	-	-	-	-	-	-	23	219	249	278	0.60	0.68	0.76
Brazos	-	-	-	-	-	-	-	2	32	131	160	0.09	0.36	0.44
Burleson	-	-	-	-	-	-	-	6	80	79	73	0.22	0.22	0.20
Dewitt	2	10	29	42	0.03	0.08	0.11	77	1,313	1,120	1,317	3.60	3.07	3.61
Dimmit	-	-	-	-	-	-	-	89	2,059	2,031	1,687	5.64	5.56	4.62
Fayette	-	-	-	-	-	-	-	9	166	444	359	0.45	1.22	0.98
Frio	-	-	-	-	-	-	-	24	412	541	343	1.13	1.48	0.94
Gonzales	-	-	-	-	-	-	-	18	250	212	230	0.69	0.58	0.63
Grimes	2	48	99	34	0.13	0.27	0.09	6	80	193	237	0.22	0.53	0.65
Houston	-	-	-	-	-	-	-	2	52	63	30	0.14	0.17	0.08
Karnes	-	-	-	-	-	-	-	31	695	633	625	1.90	1.73	1.71
La Salle	-	-	-	-	-	-	-	71	1,385	1,148	1,056	3.80	3.14	2.89
Lavaca	3	3	10	17	0.01	0.03	0.05	16	284	556	593	0.78	1.52	1.62
Lee	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Leon	-	-	-	-	-	-	-	32	260	414	302	0.71	1.13	0.83
Live Oak	3	6	32	59	0.02	0.09	0.16	45	693	687	843	1.90	1.88	2.31
Madison	-	-	-	-	-	-	-	5	66	116	53	0.18	0.32	0.14
Maverick	-	-	-	-	-	-	-	11	168	154	156	0.46	0.42	0.43
Mcmullen	-	-	-	-	-	-	-	72	1,177	707	793	3.22	1.94	2.17
Milam	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Washington	-	-	-	-	-	-	-	6	55	203	357	0.15	0.55	0.98
Webb	2	60	186	53	0.16	0.51	0.14	49	912	1,392	1,359	2.50	3.81	3.72
Wilson	-	-	-	-	-	-	-	14	228	70	135	0.62	0.19	0.37
Zavala	-	-	-	-	-	-	-	7	138	29	45	0.38	0.08	0.12
All Counties	13	156	414	257	0.43	1.13	0.70	630	11,004	11,308	11,165	30.15	30.98	30.59

The methodologies used by TCEQ to estimate emissions from each facility can vary depending on the manufacture, production company, and reviewer. Some of the methodologies used to calculate emissions included TCEQ “Technical Guidance Package for Flares and Vapor Oxidizers” (0.138 lb/MMBtu NO_X and 0.2755 lb/MMBtu CO)[359], TCEQ technical guidance document for "Equipment Fugitive Leaks", and truck loading emission rates from AP-42 Section 5. Also, EPA document 453/R-95-017, ”Protocol for Equipment Leak Emission Estimates”, was used to calculate fugitive emissions.[360] Equipment emissions were often from AP-42 Chapter 1.4 for heaters while the Tanks model was used to calculate emissions from liquid storage tanks at midstream facilities. Emissions factors for compressor engines are based on manufacturing data or default AP-42 factors.

Overall permitted allowed emission rates were 32.06 tons of VOC, 35.50 tons of NO_X, and 34.64 tons of CO per day (Table 7-2). For some categories, permitted emission rates maybe too high compared to actual emissions. However, the permit database provides a robust equipment count, equipment type, and engine characteristics of midstream sources permitted in the Eagle Ford.

When permitted emission rates were broken down for each equipment piece, the largest emission source was compressor engines (Table 7-3). NO_X emission rates from compressor engines are higher in the permit database than actually emission rates and NO_X emissions are much higher than what is reported in other oil and gas emission inventories. Other significant sources of emissions included flares/combustors, fugitives, loading fugitives, condensate tanks, and heaters/boilers.

[359] TCEQ, Oct. 2006. “NSR Guidance for Flares and Vapor Combustors”. Austin, Texas. Available online: http://www.tceq.texas.gov/assets/public/permitting/air/Guidance/NewSourceReview/emiss_calc_flares.pdf. Accessed 06/08/2012.

[360] United States Environmental Protection Agency, Nov. 1995. “Protocol for Equipment Leak Emission Estimates”. 453/R-95-017. Research Triangle Park, NC. Available online: http://www.epa.gov/ttn/chief/efdocs/equiplks.pdf. Accessed 06/11/2012.

Table 7-2: Equipment Population and Permitted Emissions from Mid-Stream Sources in the Eagle Ford (tons/day), 2008-2012

County	Criteria	Heater/ Boiler	Glycol Dehydration	Amine Unit	Compressor Engine	Pumps	Gas Cooler Engine	Crude Storage Tanks	Produced Water Storage Tanks	Condensate Tank	Oil Loading Facility	Produced Water Loading Facility	Condensate Loading	Flare/ Combustor	Fugitives	Other	Total
Atascosa	Pop	26	8	1	22	-	-	12	25	32	3	11	11	18	16	3	166
	VOC	0.00	0.04	0.00	0.15	-	-	0.01	0.01	0.08	0.03	0.04	0.09	0.21	0.21	0.01	0.88
	NO_x	0.02	0.01	0.02	0.56	-	-	-	-	-	-	-	-	0.06	-	-	0.67
	CO	0.02	0.01	0.01	0.49	-	-	-	-	-	-	-	-	0.11	-	-	0.64
Bee	Pop	13	6	-	19	-	-	9	16	29	6	14	11	6	23	2	130
	VOC	0.01	0.08	-	0.17	-	-	0.03	0.02	0.09	0.00	0.00	0.02	0.06	0.12	0.00	0.60
	NO_x	0.02	-	-	0.62	-	-	-	-	-	-	-	-	0.04	-	-	0.68
	CO	0.02	-	-	0.58	-	-	-	-	-	-	-	-	0.16	-	-	0.76
Brazos	Pop	-	-	-	7	-	-	-	6	5	-	2	1	-	2	-	21
	VOC	-	-	-	0.06	-	-	-	0.00	0.00	-	0.00	0.00	-	0.02	-	0.09
	NO_x	-	-	-	0.36	-	-	-	-	-	-	-	-	-	-	-	0.36
	CO	-	-	-	0.44	-	-	-	-	-	-	-	-	-	-	-	0.44
Burleson	Pop	5	-	-	4	-	-	21	4	1	6	4	1	3	6	6	49
	VOC	0.00	-	-	0.07	-	-	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.22
	NO_x	0.00	-	-	0.21	-	-	-	-	-	-	-	-	0.00	-	-	0.22
	CO	0.00	-	-	0.20	-	-	-	-	-	-	-	-	0.00	-	-	0.20
Dewitt	Pop	41	14	5	100	6	-	99	111	208	22	72	50	21	76	16	759
	VOC	0.00	0.06	0.01	0.50	0.00	-	0.12	0.09	0.42	0.03	0.01	1.09	0.35	0.89	0.06	3.63
	NO_x	0.04	0.05	0.01	3.11	-	-	-	-	-	-	-	-	0.08	-	-	3.29
	CO	0.04	0.04	0.01	3.47	-	-	-	-	-	-	-	-	0.26	-	-	3.82
Dimmit	Pop	97	24	-	114	-	-	212	121	124	48	79	25	86	84	33	929
	VOC	0.03	0.20	-	0.88	-	-	0.06	0.04	1.07	0.81	0.03	0.09	1.69	0.60	0.14	5.64
	NO_x	0.22	-	-	4.85	-	-	-	-	-	-	-	-	0.49	-	0.01	5.56
	CO	0.26	0.00	-	3.55	-	-	-	-	-	-	-	-	0.76	-	0.05	4.62
Fayette	Pop	2	-	-	21	-	-	6	4	3	1	3	5	1	8	3	44
	VOC	0.00	-	-	0.31	-	-	0.03	0.00	0.00	-	0.00	0.01	0.01	0.04	0.04	0.45
	NO_x	0.02	-	-	1.18	-	-	-	-	-	-	-	-	0.01	-	0.00	1.22
	CO	0.02	-	-	0.95	-	-	-	-	-	-	-	-	0.01	-	0.00	0.98
Frio	Pop	17	3	-	22	-	-	13	26	60	4	8	17	24	24	6	217
	VOC	0.00	0.02	-	0.16	-	-	0.09	0.00	0.10	0.06	0.00	0.13	0.34	0.21	0.02	1.13
	NO_x	0.02	0.00	-	1.34	-	-	-	-	-	-	-	-	0.10	-	0.01	1.48
	CO	0.02	0.00	-	0.67	-	-	-	-	-	-	-	-	0.21	-	0.02	0.94

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County	Criteria	Heater/ Boiler	Glycol Dehydration	Amine Unit	Compressor Engine	Pumps	Gas Cooler Engine	Crude Storage Tanks	Produced Water Storage Tanks	Condensate Tank	Oil Loading Facility	Produced Water Loading Facility	Condensate Loading	Flare/ Combustor	Fugitives	Other	Total
Gonzales	Pop	34	9	-	23	-	-	45	10	9	4	9	5	14	18	-	161
	VOC	0.00	0.07	-	0.14	-	-	0.07	0.00	0.01	0.01	0.03	0.04	0.13	0.19	-	0.69
	NO_x	0.04	0.01	-	0.47	-	-	-	-	-	-	-	-	0.06	-	-	0.58
	CO	0.04	0.01	-	0.34	-	-	-	-	-	-	-	-	0.25	-	-	0.63
Grimes	Pop	7	4	-	26	-	-	2	10	17	1	3	2	4	7	1	72
	VOC	0.01	0.01	-	0.32	-	-	0.01	0.00	0.04	0.00	0.00	0.01	0.01	0.03	0.02	0.47
	NO_x	0.04	-	-	1.38	-	-	-	-	-	-	-	-	0.02	-	-	1.45
	CO	0.05	-	-	1.34	-	-	-	-	-	-	-	-	0.02	-	-	1.41
Houston	Pop	3	2	-	3	-	-	2	1	1	1	-	1	-	2	1	15
	VOC	0.00	0.01	-	0.01	-	-	0.03	0.00	0.03	0.02	-	0.01	-	0.03	0.00	0.14
	NO_x	0.00	0.00	-	0.17	-	-	-	-	-	-	-	-	-	-	-	0.17
	CO	0.00	0.00	-	0.08	-	-	-	-	-	-	-	-	-	-	-	0.08
Karnes	Pop	59	25	3	73	-	-	20	32	68	2	16	20	29	30	8	329
	VOC	0.01	0.16	0.00	0.56	-	-	0.02	0.03	0.19	0.02	0.02	0.17	0.31	0.39	0.02	1.90
	NO_x	0.10	0.01	0.00	1.52	-	-	-	-	-	-	-	-	0.07	-	0.03	1.73
	CO	0.09	0.01	0.00	1.46	-	-	-	-	-	-	-	-	0.15	-	0.01	1.71
La Salle	Pop	92	29	4	61	-	1	163	85	121	42	51	29	65	69	15	737
	VOC	0.03	0.07	0.00	0.51	-	0.00	0.12	0.07	0.13	0.47	0.11	0.18	1.40	0.64	0.05	3.80
	NO_x	0.18	0.02	-	2.66	-	0.01	-	-	-	-	-	-	0.26	-	0.02	3.14
	CO	0.15	0.02	-	2.17	-	0.02	-	-	-	-	-	-	0.53	-	0.02	2.89
Lavaca	Pop	13	5	3	32	-	2	19	25	9	9	11	6	10	18	4	144
	VOC	0.02	0.04	0.00	0.28	-	0.04	0.08	0.05	0.03	0.03	0.00	0.04	0.07	0.11	0.00	0.79
	NO_x	0.14	0.00	0.00	1.32	-	0.09	-	-	-	-	-	-	0.03	-	-	1.57
	CO	0.07	0.00	0.00	1.35	-	0.12	-	-	-	-	-	-	0.14	-	-	1.68
Leon	Pop	29	5	-	26	-	-	8	45	10	7	16	2	15	30	7	163
	VOC	0.02	0.01	-	0.15	-	-	0.09	0.11	0.04	0.02	0.01	0.00	0.10	0.12	0.04	0.71
	NO_x	0.03	-	-	1.06	-	-	-	-	-	-	-	-	0.05	-	0.00	1.13
	CO	0.04	-	-	0.72	-	-	-	-	-	-	-	-	0.07	-	0.01	0.83
Live Oak	Pop	30	15	8	44	-	-	57	62	71	19	17	13	44	47	26	371
	VOC	0.03	0.06	0.02	0.38	-	-	0.23	0.02	0.10	0.01	0.00	0.05	0.77	0.37	0.14	2.18
	NO_x	0.16	0.00	-	2.08	-	-	-	-	-	-	-	-	0.19	-	-	2.44
	CO	0.14	0.00	-	1.78	-	-	-	-	-	-	-	-	1.18	-	-	3.10

County	Criteria	Heater/ Boiler	Glycol Dehydration	Amine Unit	Compressor Engine	Pumps	Gas Cooler Engine	Crude Storage Tanks	Produced Water Storage Tanks	Condensate Tank	Oil Loading Facility	Produced Water Loading Facility	Condensate Loading	Flare/ Combustor	Fugitives	Other	Total
Madison	Pop	4	2	-	7	-	-	6	3	1	2	3	1	1	4	1	28
	VOC	0.00	0.01	-	0.03	-	-	0.00	-	0.01	0.08	0.00	0.00	0.01	0.04	0.00	0.18
	NO_x	0.00	0.00	-	0.31	-	-	-	-	-	-	-	-	0.00	-	-	0.32
	CO	0.00	0.00	-	0.14	-	-	-	-	-	-	-	-	0.00	-	-	0.14
Maverick	Pop	3	5	1	12	-	-	13	10	15	3	5	5	4	10	5	76
	VOC	-	0.14	-	0.07	-	-	0.04	0.00	0.03	0.01	0.00	0.00	0.07	0.07	0.02	0.46
	NO_x	0.00	0.02	-	0.38	-	-	-	-	-	-	-	-	0.02	-	0.00	0.42
	CO	0.00	0.04	-	0.34	-	-	-	-	-	-	-	-	0.04	-	0.00	0.43
Mcmullen	Pop	187	21	-	43	-	5	177	78	20	58	37	9	47	68	19	682
	VOC	0.01	0.04	-	0.39	-	0.01	0.31	0.03	0.06	0.42	0.01	0.02	1.02	0.77	0.13	3.22
	NO_x	0.20	0.00	-	1.43	-	0.04	-	-	-	-	-	-	0.19	-	0.08	1.94
	CO	0.17	0.00	-	1.49	-	0.06	-	-	-	-	-	-	0.37	-	0.08	2.17
Washington	Pop	1	1	-	12	-	-	17	9	-	-	4	1	-	6	4	47
	VOC	-	0.01	-	0.10	-	-	0.00	0.02	-	-	-	0.00	-	0.03	0.00	0.15
	NO_x	0.00	-	-	0.55	-	-	-	-	-	-	-	-	-	-	-	0.55
	CO	0.00	-	-	0.98	-	-	-	-	-	-	-	-	-	-	-	0.98
Webb	Pop	20	19	2	80	-	1	76	76	88	18	34	26	14	51	14	450
	VOC	0.01	0.28	0.02	0.64	-	0.00	0.08	0.07	0.35	0.24	0.01	0.25	0.24	0.36	0.09	2.66
	NO_x	0.04	0.00	0.04	4.47	-	0.02	-	-	-	-	-	-	0.06	-	0.01	4.64
	CO	0.03	0.00	0.03	4.02	-	0.00	-	-	-	-	-	-	0.11	-	0.06	4.26
Wilson	Pop	30	3	3	5	-	-	62	31	-	11	12	-	13	13	3	170
	VOC	0.00	0.01	0.00	0.02	-	-	0.07	0.01	-	0.03	0.01	-	0.24	0.17	0.06	0.62
	NO_x	0.02	0.00	0.00	0.10	-	-	-	-	-	-	-	-	0.08	-	-	0.19
	CO	0.02	0.00	0.00	0.08	-	-	-	-	-	-	-	-	0.27	-	-	0.37
Zavala	Pop	5	-	-	1	-	-	28	9	-	7	6	-	10	7	-	66
	VOC	0.03	-	-	0.00	-	-	0.01	0.04	-	0.08	0.00	-	0.18	0.03	-	0.38
	NO_x	0.00	-	-	0.01	-	-	-	-	-	-	-	-	0.07	-	-	0.08
	CO	0.00	-	-	0.01	-	-	-	-	-	-	-	-	0.11	-	-	0.12
Total	Pop	718	200	30	757	6	9	1,067	799	892	274	417	241	429	619	177	5,826
	VOC	0.21	1.31	0.06	5.90	0.00	0.05	1.53	0.61	2.79	2.37	0.29	2.20	7.25	5.50	0.90	31.00
	NO_x	1.30	0.13	0.06	30.14	-	0.16	-	-	-	-	-	-	1.86	-	0.16	33.84
	CO	1.17	0.13	0.06	26.65	-	0.20	-	-	-	-	-	-	4.75	-	0.24	33.22

Table 7-3: Average Permitted Emissions per Unit and per Facility by Equipment Type for Mid-Stream Sources

Equipment Type	Eq. Pop	Average number of Eq. per Site	VOC		NO_X		CO	
			tons/ eq./year	tons/facility/ year	tons/ eq./year	tons/facility/ year	tons/ eq./year	tons/facility/ year
Heater/ Boiler	718	1.12	0.11	0.12	0.66	0.77	0.60	0.69
Glycol Dehydration	200	0.31	2.40	0.77	0.23	0.07	0.24	0.08
Amine Unit	30	0.05	0.71	0.03	0.77	0.04	0.69	0.03
Compressor Engine	757	1.18	2.84	3.48	14.53	17.77	12.85	15.71
Pumps	6	0.01	0.19	0.00	-	-	-	-
Gas Cooler Engine	9	0.01	1.91	0.03	6.53	0.09	8.23	0.12
Crude Storage Tanks	1,067	1.66	0.52	0.90	-	-	-	-
Produced Water Storage Tanks	799	1.24	0.28	0.36	-	-	-	-
Condensate Tank	892	1.39	1.14	1.64	-	-	-	-
Oil Loading Facility	274	0.43	3.16	1.40	-	-	-	-
Produced Water Loading Facility	417	0.65	0.26	0.17	-	-	-	-
Condensate Loading	241	0.37	3.33	1.30	-	-	-	-
Flare/ Combustor	429	0.67	6.17	4.27	1.58	1.10	4.04	2.80
Fugitives	619	0.96	3.25	3.12	-	-	-	-
Other	177	0.28	1.86	0.53	0.33	0.09	0.50	0.14

7.2.2 Barnett Shale Area Special Inventory

As part of TCEQ's Barnett Shale special inventory survey, TCEQ requested air emissions data and related information for mid-stream facilities. The survey was sent to all companies that had calendar year 2009 operations included oil and gas production, transmission, processing, and related activities (such as saltwater disposal).[361] The Barnett Shale special inventory collected data on compressors, storage tanks, loading fugitives, production fugitive, heaters, and other sources. Data was collected on midstream facility comprised of names, emission rates, equipment types, engine sizes, existing controls, and control efficiency.

From the Barnett Shale special inventory database, average equipment characteristics and emissions rates can be calculated. Total emissions from the midstream sources in the Barnett were 3,372 tons of NO_X per year and 2,658 tons of VOC per year. The largest midstream equipment source was compressor engines with 3,328 tons of NO_X per year and 625 tons of VOC. Other significant sources included condensate tanks, 1,163 tons of VOC, and fugitive emissions, 379 tons of VOC. Equipment at midstream sources in the Barnett Shale can be significantly different then the Eagle Ford because the Eagle Ford also contains significant production of liquids that required different methods to process and store. When equipment types are similar, data from the Barnett Shale special inventory will be used to calculate emissions from midstream sources in the Eagle Ford.

7.2.3 Development of an Emission Inventory for Natural Gas Exploration and Production in the Haynesville Shale and Evaluation of Ozone Impacts

In the ENVIRON's report on emissions from Haynesville Shale natural gas exploration and production activities, emissions from midstream sources were included.[362] ENVIRON stated that "to incorporate midstream emissions for the Haynesville Shale formation the 2004 Haynesville Shale region midstream emissions are scaled by the ratio of Haynesville Shale formation produced natural gas to 2004 produced natural gas in the Haynesville Shale region."[363] Unfortunately, there is little local data used to estimate midstream emissions because there was no industry participation in the report

According to ENVIRON, there was 1,144 BCF of natural gas produced in 2004.[364] When using a ratio of amount of gas produced in 2004 to emissions from 2004 midstream sources there is 3.4 tons of VOC/BCF, 15.0 tons of NO_X/BCF, and 10.1 tons of CO/BCF. These factors were multiplied by the annual amount of natural gas produced per year. Since

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361 Julia Knezek, Emissions Inventory Specialist Air Quality Division, TCEQ, October 12, 2010. "Barnett Shale Phase Two, Special Inventory Workbook Overview". Presented to Assistance Workshop, Will Rogers Memorial Center. Available online: http://www.tceq.state.tx.us/assets/public/implementation/air/ie/pseiforms/workbookoverviewrevised.pdf. Accessed. 042/07/2012.

362 John Grant, Lynsey Parker, Amnon Bar-Ilan, Sue Kemball-Cook, and Greg Yarwood, ENVIRON International Corporation. August 31, 2009. "Development of an Emission Inventory for Natural Gas Exploration and Production in the Haynesville Shale and Evaluation of Ozone Impacts". Novato, CA. Available online: http://www.netac.org/UserFiles/File/NETAC/9_29_09/Enclosure_2b.pdf. Accessed: 04/19/2012.

363 John Grant, Lynsey Parker, Amnon Bar-Ilan, Sue Kemball-Cook, and Greg Yarwood, ENVIRON International Corporation. August 31, 2009. "Development of an Emission Inventory for Natural Gas Exploration and Production in the Haynesville Shale and Evaluation of Ozone Impacts". Novato, CA. p. 50. Available online: http://www.netac.org/UserFiles/File/NETAC/9_29_09/Enclosure_2b.pdf. Accessed: 04/19/2012.

364 *Ibid*. pp. 26, 50, 56.

emissions are based on a 2004 database, emission rates are outdated and compressor engine NO_X emission rates are too high.

7.2.4 City of Fort Worth Natural Gas Air Quality Study

Emission source testing was conducted by EGR "to determine how much air pollution is being released by natural gas exploration in Fort Worth, and if natural gas extraction and processing sites comply with environmental regulations." Under the point source testing program, field personnel determined the amount of air pollution released at compressor stations and other midstream facilities.[365] The sites visited included 8 compressor stations, 1 processing facility, and 1 saltwater treatment facility.[366]

"Emissions were only estimated from piping and instrumentation equipment leaks, storage tanks, and compressors, which contribute the majority of emissions from natural gas-related facilities. Other sources of emissions, including but not limited to, storage tank breathing and standing losses, glycol dehydrator reboiler vents, wastewater and/or condensate loading, and flaring, were not calculated."[367] Results from the midstream emission inventory included emissions from wells located at each midstream source. Table 7-4 shows on average, there were 639 values, 4,678 connectors, 4.4 tanks, and 3.6 compressors at each midstream sources. For each midstream source, ERG calculated average annual emissions of 21.8 tons of VOC, 24.5 tons of NO_X, and 225.3 tons of CO.

Table 7-4: Number of Emissions Sources per Mid-Stream Facility from ERG's Fort Worth Study

Source	Average Number per Processing Facilities	Average Number per Compressor Station	Average Number per Saltwater Disposal Facility	Weighted Average for All Facilities
Number of Facilities	1	8	1	
Wells	0.0	0.9	3.0	1.0
Valves	1,800.0	547.6	211.0	639.2
Connectors	12,590.0	4,088.6	1,477.0	4,677.6
Tanks	10.0	3.3	8.0	4.4
Compressors	12.0	2.9	1.0	3.6
VOC Emissions	79.9	17.2	0.7	21.8
NO_X Emissions	87.7	19.6	0.7	24.5
CO Emissions	1,038.9	151.5	2.0	225.3

Although the survey did provided detailed information on equipment counts, equipment types, and fugitive emission rates from midstream sources, the results are not statistically significant because only 1 processing facility and 1 saltwater facility was visited during the survey. Also, several potential sources of emissions at the midstream facilities were not included in the survey and emissions from compressor engines were not measured. Equipment at midstream sources in the Barnett Shale formation in Fort Worth can be significantly different then the Eagle Ford because the Eagle Ford also contains significant production of liquids that required different methods to process and store.

[365] Eastern Research Group Inc. July 13, 2011. "Fort Worth Natural Gas Air Quality Study Final Report". Prepared for: City of Fort Worth, Fort Worth, Texas. p. 3-98. Available online: http://fortworthtexas.gov/gaswells/?id=87074. Accessed: 04/09/2012.
[366] *Ibid*., pp. 3-3 – 3-4.
[367] *Ibid*., p. 3-23.

7.3 Emission from Mid-stream Sources

Ozone precursor emissions from midstream sources will be calculated based on the number of equipment and types of equipment at each facility. Table 7-5 compares the number of equipment per facility from the Barnett Shale special inventory survey, the results from TCEQ permit database for Eagle Ford midstream facilities, and EGR's survey in Fort Worth. There was significant more equipment listed at mid-stream facilities in the Eagle Ford, 10.3 per facility, compared to what was reported on survey returns from the Barnett, 4.5 per facility.

As expected, there were significantly more condensate and oil tanks at midstream sources in the Eagle Ford because the Eagle Ford has significant liquid deposits. Likewise, there are more loading facilities at Eagle Ford midstream facilities to handle condensate and crude oil production. There are a large numbers of flares/combustors at Eagle Ford midstream facilities because the industry often flares off natural gas that cannot use at the facility. Midstream sources in the Eagle Ford also had more heater and boilers than midstream sources in the Barnett.

Compressor engines counts per facility was almost the same in the Eagle Ford permit database and TCEQ Barnett Shale special inventory, however Eagle Ford compressors may have a lower horsepower than the ones located in the Barnett. A sampling of 135 compressors at midstream sources in the Eagle Ford had an average horsepower of 975 compared to Barnett Shale Special inventory average of 1,203 hp for 370 compressor engines. Further research needs to be completed on compressor engines size and usage at Eagle Ford midstream sources to determine the applicability of the Barnett Shale special inventory compressor engine's emission factors. ERG survey of midstream sources in Fort Worth found significantly more compressor engines per site, but the survey is not statistically significant. The number of glycol dehydration units per facility is similar between the Barnett midstream sources and Eagle Ford midstream sources.

Table 7-5: Comparison between Equipment Counts in TCEQ Permit Database, Barnett Shale Special Inventory, and ERG Fort Worth Survey

Equipment Type	Barnett		Eagle Ford		ERG - Fort Worth	
	Number	Number/ Facility	Number	Number/ Facility	Number	Number/ Facility
Heater/Boilers	80	0.24	718	1.12		
Glycol Dehydration Units	81	0.25	200	0.31		
Amine Units	3	0.01	30	0.05		
Compressor Engines	370	1.13	757	1.18	36	3.60
Pumps	11	0.03	6	0.01		
Gas Cooler Engines	0	0.00	9	0.01		
Crude Storage Tanks	29	0.09	1,067	1.66		
Produced Water Storage Tanks	204	0.62	799	1.24	44	4.40
Condensate Tanks	181	0.55	892	1.39		
Loading Facilities	177	0.54	932	1.45		
Flares/Combustors	6	0.02	429	0.67		
Fugitives	259	0.79	620	0.96	10	1.00
Other	83	0.25	177	0.28		
Total Number of Facilities	1,484	4.54	643	10.32	10	9.00

When emissions per unit are compared between TCEQ permit database and Barnett Shale special inventory, VOC emissions were similar but NO_X emissions per facility was significantly lower (Table 7-6). Annual NO_X emission factor for compressors are much lower in the Barnett Shale special inventory, 8.99 tons/unit, compared to TCEQ database, 14.53 tons/unit. Emissions factors for compressor engines from TCEQ permit database were too high and the Barnett Shale special inventory provides an improved emission factor for NO_X and VOC emissions. The emission factors for heater/boilers, flares/combustors, and fugitives were also significantly higher in TCEQ permit database.

The prefer methodology available to estimate emission for each piece of equipment would be to use the results from TCEQ Barnett Shale special inventory. Emission factors for the Barnett Shale special inventory will be used for the following categories: heaters/boilers, compressor engines, and fugitive emissions. There were not enough amine units, pumps, gas cooler engines, and flares/combustors reported in the Barnett Shale special inventory to have statistically significant result. Emission factors based on TCEQ permits will be used instead for these categories.

Although emission factors for crude storage tanks, condensate tanks, and produced water storage tanks were higher in the Barnett Shale special inventory compared to TCEQ permit database, they will be used to calculate midstream emissions from the Eagle Ford. Having an accurate emission factors for storage tanks is required for a representative emission inventory. TCEQ permit database emissions for loading facilities will be used instead of the Barnett Shale special inventory because there is not enough data for condensate and crude oil loading from the Barnett survey. For ERG Fort Worth Gas Study, there were 32.59 tons of NO_X per facility, 24.55 tons of VOC, and 225.26 tons of CO. The CO emission factors were significantly higher because ERG used CO emission factors for compressor engines that were much higher than actual emission rates. ERG's emission factors per facility are higher than the two other methodologies and will not be used to calculate emissions.

A list of which proposed emission factor will be used for each midstream equipment type is listed in the right hand column of Table 7-6. By using the most accurate emission factors available, a robust emission inventory of midstream sources can be created. CO emissions will be based on TCEQ point source database because CO emission data was not available from the Barnett Shale special inventory and the ERG's Fort Worth CO emission factor was too high. To calculate emissions from midstream sources, it is estimated that there is a 9 month delay from when a midstream source is permitted and the facility starts to operate. The following formula is used to calculate emissions for each piece of equipment using average emission factors from Barnett Shale special inventory and TCEQ permit database.

Equation 7-1, Ozone season day emissions from midstream facilities

$$E_{Midstream.AB} = NUM_{AB} \times MFEF_A / 365 \text{ days/year}$$

Where,

$E_{Midstream.AB}$ = Ozone season day NO_X, VOC, or CO emissions from midstream facilities for Equipment type A in county B (Gas or Oil)

NUM_{AB} = Number of Equipment type A in county B from midstream sources in Table 7-2 (from TCEQ permit database)

$MFEF_A$ = NO_X, VOC, or CO emission factor for equipment type A at midstream facilities in Table 7-6 (from Barnett Shale special inventory and TCEQ permit database)

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Table 7-6: Comparison between TCEQ Permit Database, Barnett Special Inventory, and ERG's Survey Emissions per Unit (tons/day)

Equipment Type	Barnett Shale Special Inventory Emission Factors (Tons/Unit/Year)		TCEQ Permit Database Emission Factors (Tons/Unit/Year)		ERG Fort Worth Natural Gas Study		Emission Factors Used for Eagle Ford Midstream Sources
	VOC	NO_x	VOC	NO_x	VOC	NO_x	
Heater/Boiler	0.03	0.37	0.11	0.66			Barnett EI
Glycol Dehydration	2.15	-	2.40	0.23			Barnett EI
Amine Unit	1.19	-	0.71	0.77			TCEQ Permit Database
Compressor Engine	1.70	8.99	2.84	14.53			Barnett EI*
Pump	0.33	-	0.19	-			TCEQ Permit Database
Gas Cooler Engine	2.12	1.29	1.91	6.53			TCEQ Permit Database
Crude Storage Tank	2.42	-	0.52	-			Barnett EI
Produced Water Storage Tank	0.39	-	0.28	-	32.59	24.55	Barnett EI
Condensate Tank	6.43	-	1.14	-			Barnett EI
Oil Loading Facility			3.16	-			TCEQ Permit Database
Produced Water Loading Facility	0.28	-	0.26	-			TCEQ Permit Database
Condensate Loading			3.33	-			TCEQ Permit Database
Flare/Combustor	0.08	0.34	6.17	1.58			TCEQ Permit Database
Fugitives	0.84	-	3.25	-			Barnett EI
Other	2.12	1.29	1.86	0.33			TCEQ Permit Database
All Equipment (Tons/Facility/Year)	18.21	11.29	17.60	19.21	32.59	24.55	

*Horsepower of Eagle Ford compressors maybe lower than the compressors reported in the Barnett Shale special Inventory

The difference between the results from TCEQ permit database, ENVIRON's methodology, Barnett Shale Special Inventory, and ERG Fort Worth study emission factors are presented in Table 7-7. When using emission factors from the Barnett Special shale inventory, VOC emissions were only 0.9 tons/day lower, but NO_X emissions where 13.9 tons/day lower. Using ENVIRON's methodology, VOC emissions were 18.3 tons/year lower in 2012, while NO_X emissions where 16.6 tons/year higher. There are a large number of crude storage tanks, produced water storage tanks, and condensate tanks in the Eagle Ford compared to other shale plays because of the considerable liquids deposits in the Eagle Ford.

Table 7-7: Difference between TCEQ Permit Database, ENVIRON's Methodology, Barnett Special Inventory, and ERG's Survey for Mid-Stream Sources (tons/day)

Year	Number of Sites	Methodology	Total VOC	Total NO_X	Total CO
2011	253	TCEQ Permit Database	9.7	14.3	14.7
		ENVIRON's Methodology	5.9	25.5	17.3
		Barnett Shale Special Inventory	10.1	7.3	
		ERG's Fort Worth Survey	15.1	17.0	156.1
		Eagle Ford Midstream EI	12.4	8.8	13.6
2012	621	TCEQ Permit Database	29.5	32.2	31.6
		ENVIRON's Methodology	11.2	48.8	33.1
		Barnett Shale Special Inventory	28.6	18.3	
		ERG's Fort Worth Survey	36.9	41.5	380.8
		Eagle Ford Midstream EI	39.3	21.0	29.7

*Based on an weighted average for all midstream sources surveyed

7.4 Construction of Mid-stream Facilities and Pipelines

Emissions are emitted from construction equipment used to build compressor stations, processing facilities, tank batteries, and other midstream sources. The Pinedale Anticline Project in Wyoming found that compressor stations covered an average of 10 acres.[368] The construction of larger midstream sources, such as production facilities, can take up even more land area and involve significant amounts of heavy equipment.

Likewise, construction of pipelines involves heavy machinery to dig trenches, move materials, and lay pipes. There can also be significant on-road vehicles emissions from midstream sources as trucks deliver product, supplies, and other equipment to facilities. Emissions from these sources will not be included in the Eagle Ford emission inventory because the data is not available.

[368] U.S. Department of the Interior, Bureau of Land Management, Sept. 2008. "Final Supplemental Environmental Impact Statement for the Pinedale Anticline Oil and Gas Exploration and Development Project: Pinedale Anticline Project Area Supplemental Environmental Impact Statement". Sheyenne, Wyoming. pp. F37. Available online: http://www.blm.gov/pgdata/etc/medialib/blm/wy/information/NEPA/pfodocs/anticline/rd-seis/tsd.Par.13395.File.dat/07appF.pdf. Accessed: 04/12/2012.

8 PROJECTIONS

Emissions from Eagle Ford production are projected to continue to grow as oil and gas development increases over the next few years. According to Bentek Energy, as production ramps up quickly "Eagle Ford producers will find themselves with a large number of important advantages over other U.S. suppliers. In the Eagle Ford there is substantial existing infrastructure, much of which has been underutilized in recent years. Production costs are much lower than costs in many other basins and plays. There also are numerous local and regional markets."[369]

"Available markets also will play a role in Eagle Ford development – the Eagle Ford is next door to the nation's largest refining markets. Eagle Ford natural gas also has pipeline space to move east, north, west or south across the Mexican border. Mexico already is becoming an important destination. Eagle Ford NGLs are being produced in close proximity to the nation's benchmark NGL market at Mt. Belvieu. Gas production from this play has among the highest liquids content of any major unconventional play today in North America, and its proximity to these important markets will ensure an aggressive growth trajectory."[370] According to Manuj Nikhanj, managing director and head of energy research at ITG, "by mid-2013, pipeline expansions will relieve most of the bottlenecks in the Eagle Ford, and more crews are being hired to complete wells. There's still a shortage of water for hydraulic fracturing, a procedure used to extract oil and gas from the shale, but some operators are treating brackish water". [371]

VOC, NO_X and CO emissions will be projected to 2018 using the latest available information from other studies, local data, and regional data. After 2018, it is expected that the number of drill rigs in the Eagle Ford will decrease, but this study will not project emissions past this year. Projections of activity in the Eagle Ford will use a methodology similar to ENVIRON's Haynesville Shale emission inventory which was based on three scenarios: low development, medium development, and aggressive development. [372] The scenarios cover a range of potential growth in the Eagle Ford based on best available information including local data, industrial projections, and projected price of petroleum products. Projected emissions are derived by the drilling activity in the region and production estimations for each well. Since hydraulic fracturing of oil reserves on a wide scale is relatively new occurrence, activity and emission projections will have a high uncertain factor.

The International Association of Drilling Contractors states "as the pricing differential between oil and natural gas has widened, operators are increasingly applying the technologies that were initially developed for horizontal wells in unconventional dry gas plays to the more liquids-rich formations, such as the Bakken, Eagle Ford and Niobrara

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[369] Bentek Energy LLC, April 18, 2011. "Eagle Ford Shale – Deep in the Heart of Texas". p. 24. Evergreen, CO.

[370] April 18, 2011. "BENTEK: Eagle Ford Crude Oil Production Expected to Grow Fivefold in Five Years; Both Gas and NGLS Will Jump 1.5X". Available online: http://www.bentekenergy.com/InTheNewsArticleM.aspx?ID=Bentek_InTheNews_Article_151. Accessed: 04/16/2012.

[371] Vicki Vaughan, San Antonio Express News, May 17, 2012. "Eagle Ford Oil Levels Expected to Sore". Available online: http://www.mysanantonio.com/news/local_news/article/Eagle-Ford-oil-levels-expected-to-soar-3564103.php. Accessed 06/05/2012.

[372] John Grant, Lynsey Parker, Amnon Bar-Ilan, Sue Kemball-Cook, and Greg Yarwood, ENVIRON International Corporation. August 31, 2009. "Development of an Emission Inventory for Natural Gas Exploration and Production in the Haynesville Shale and Evaluation of Ozone Impacts". Novato, CA. p. 13. Available online: http://www.netac.org/UserFiles/File/NETAC/9_29_09/Enclosure_2b.pdf. Accessed: 04/19/2012.

plays.[373] "After years of explosive growth, natural gas producers are retrenching. The workers and rigs aren't just being sent home. They are instead being put to work drilling for oil."[374] The Eagle Ford is expected to be a larger play than the Barnett shale because there is "a larger field area, and production of oil and condensate in much larger amounts than the Barnett."[375] In addition, the "Eagle Ford shale in the dry gas portion of the play has more technically recoverable resources than the Barnett shale."[376]

With global price for oil and the price for South Texas Sweet oil above eighty dollars a barrel for the last two years, there is significant demand to keep drilling in the Eagle Ford.[377] Price for Eagle Ford crude oil and condensate has increase dramatically from 47 dollars per barrel to over 117 dollars per barrel from 2009 to April 2012 (Figure 8-1). There was a similar increase in the price paid by Plains Marketing for Eagle Ford light crude and Eagle Ford Condensate[378], while U.S. wellhead price for natural gas has decreased rapidly since January 2010[379].

Price per barrel for crude oil has decreased in the last few months, but a barrel of Eagle Ford crude still remains above 80 dollars. According Amy Myers Jaffe, a fellow in energy studies at the Baker Institute at Rice University states that "with increasing oil production in this nation, the price of oil might come down somewhat but it isn't likely to go below $70 a barrel. That's because of jitters over the uprisings and unrest in the Arab world. In addition, hostilities between Israel and Iran aren't going away."[380] Karr Ingham, from the Texas Alliance of Energy Producers, "said a retreat from higher crude prices that prevailed earlier in 2012 wasn't unexpected, but the rate of the decline caught producers by surprise. Repercussions of European debt woes and economic slowdown in Asia that could affect the U.S. economy in the year's second half are weighing heavily on crude oil markets, he said. It's possible, Ingham said, that the state is on the cusp of a slowdown in drilling and production."[381]

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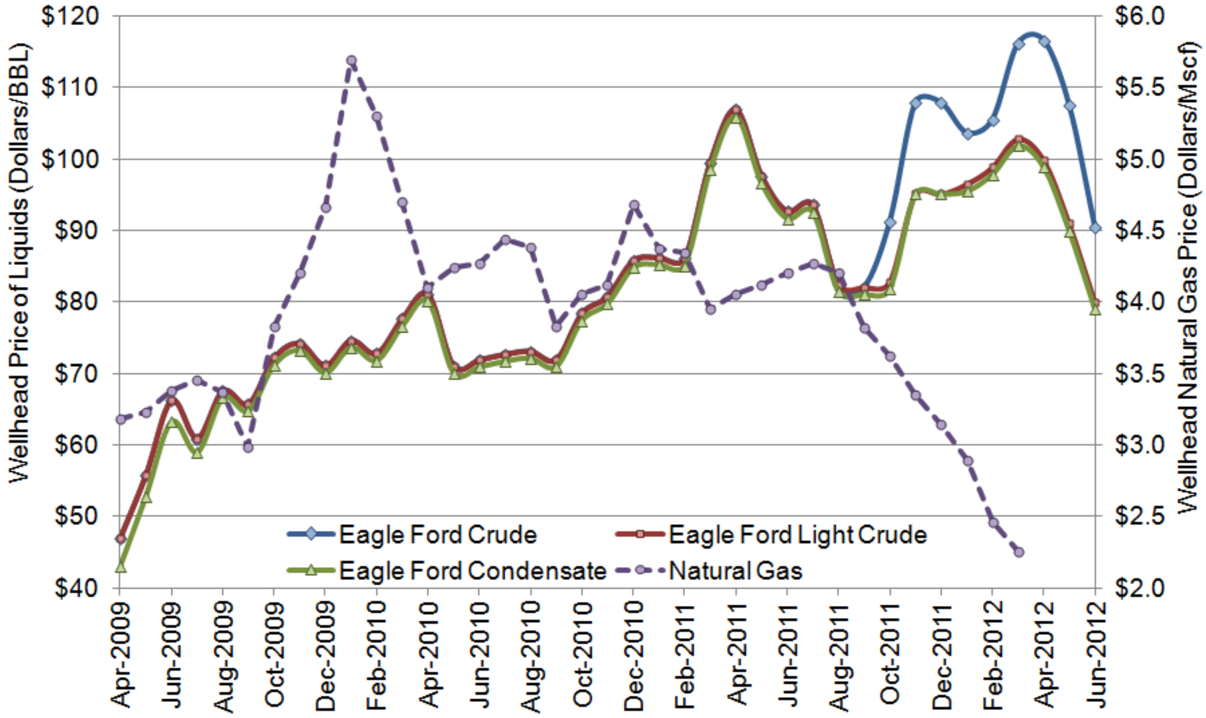
373 Katie Mazerov, Dec. 13, 2011. "Unconventional liquids-rich plays feature unique characteristics, challenges". Drilling Contractor. Available online: http://www.drillingcontractor.org/unconventional-liquids-rich-plays-feature-unique-characteristics-challenges-12280. Accessed: 04/14/2012.
374 The Associated Press, April 9, 2012. "Natural Gas Surplus Threatens to Slow Drilling Boom". Available online: http://www.cnbc.com/id/46991964. Accessed 05/21/2012.
375 Feb. 2, 2012. "Railroad Commission of Texas". Slide 36. Available online: http://baysfoundation.com/wp-content/uploads/2012/02/February-2012-AO-Eagle-Ford-Master-02-12-2012.pdf. Accessed: 04/05/2012.
376 Z. Dong, SPE, S. A. Holditch, SPE, D.A. McVay, SPE, Texas A&M University. Feb. 2012. "Resource Evaluation for Shale Gas Reservoirs". Presented at Hydraulic Fracturing Technology. Society of Petroleum Engineers
377 Texas Alliance of Energy Producers, April, 2012. "Market Information: Oil & Natural Gas". Available online: http://www.texasalliance.org/marketinformation.php. Accessed 04/30/2012.
378 Plains Marketing, L.P. "Crude Oil Price Bulletin - Recap". Houston, Texas. Available online: http://www.paalp.com/_filelib/FileCabinet/Crude%20Oil%20Price%20Bulletins/Monthly/2012/March_2012_Recap.pdf. Accessed: 05/02/2012.
379 U.S. Energy Information Administration, April 30, 2012. "U.S. Natural Gas Wellhead Price". Available online: http://www.eia.gov/dnav/ng/hist/n9190us3m.htm. Accessed 05/04/2012.
380 Vicki Vaughan, San Antonio Express News, May 17, 2012. "Eagle Ford Oil Levels Expected to Sore". Available online: http://www.mysanantonio.com/news/local_news/article/Eagle-Ford-oil-levels-expected-to-soar-3564103.php. Accessed 06/05/2012.
381 Vicki Vaughan, San Antonio Express News, June 7, 2012. "Drilling Activity Down". Available online: http://www.mysanantonio.com/business/article/Drilling-activity-trending-down-3617753.php. Accessed 06/11/2012.

Figure 8-1: Monthly Price for Eagle Ford Crude Oil and Condensate by Plains Marketing, 2009-2012



*note: Before September 2010, North Texas Sweet price was used for Eagle Ford crude and East Texas condensate price was used for Eagle Ford condensate

"There is no guarantee that new supplies will inevitably lead to lower gasoline prices, as proponents of unfettered domestic drilling argue. Oil is a global commodity with a price set on the global market. With rising demand around the world, particularly in emerging economies, and instability in many oil-producing countries, many analysts predict global oil prices will remain volatile - and high - for many years to come."[382] "Liquids rich shales will continue to be hot. New technologies (long-reach horizontal drilling, fracing, enhanced seismic imaging) combined with bullish oil price creates a very favorable future US oil supply environment. Worldwide demand expected to remain high, driven by China and India demand, hence oil price is expected to be attractive for further investments."[383]

The increase in drilling activity in the Eagle Ford has brought significant employment to the region and long term investment by large service companies. "The Eagle Ford Shale already has brought 5,000 jobs to San Antonio" and "oil and gas development likely will bring a total of 10,000 jobs to the city within three years".[384] "Oil-field-services giant Halliburton Co. began work Thursday on a $50 million base of operations in San Antonio, for

[382] Jad Mouawad, The New York Times, April 10, 2012. "Fuel to Burn: Now What". Available online: http://www.nytimes.com/2012/04/11/business/energy-environment/energy-boom-in-us-upends-expectations.html?_r=1. Accessed: 05/19/2012.
[383] William Marko, Managing Director, Jefferies & Company, Inc. Nov. 2, 2011 "Facts About The Shales SPEE Houston Chapter". Available online: http://www.spee.org/images/PDFs/Houston/Houston_NOV_2_2011.pdf. Accessed: 04/20/2012.
[384] Vicki Vaughan, San Antonio Express News, Dec. 6, 2011. "Shale linked to 10,000 jobs". San Antonio, Texas. Available online: http://www.sanantonioedf.com/news/articles/146-shale-linked-to-10000-jobs. Accessed: 05/19/2012.

which it will need 1,500 workers to support its operations in the Eagle Ford shale."[385] There is anticipation that drilling activities will significantly increase in 2012 "by the main players in the Eagle Ford shale, once a network of new pipelines is completed in 2012".[386] "Overall, the outlook for the Eagle Ford remains strong", the play is expected "to rival the Bakken by 2015 for position as North America's leading tight-oil producer".[387]

8.1 Historical Production

Number of wells drilled and production has increase dramatically in the last 4 years from almost nothing in 2008 to significant production 2011. As shown in Table 8-1, the number of oil wells drilled had grown from 89 in 2008 to 1,259 in 2011, while the number of gas wells drilled has increased from 109 in 2008 to 1,081 in 2011.[388] Production has increased from only 0.1 MMbbl of oil produced in 2008 to 36.6 MMbbl of oil produced in 2011. There was also a significant increase in natural gas and condensate production: 1 BCF in 2008 to 287 BCF in 2011 and 0.1 MMbbl to 20.9 MMbbl.[389]

Table 8-1: Permit issued for each Shale Development

Year	Number of Wells Drilled		Production		
	Oil Wells	Gas Wells	Gas (BCF)	Oil (BBL)	Condensate (BBL)
2008	89	109	1	130,802	83,744
2009	63	150	19	308,139	839,490
2010	337	558	108	4,374,792	6,956,224
2011	1,259	1,081	287	36,626,438	20,876,118

Production estimates from the Railroad Commission of Texas are often undercounting actual production from oil and gas wells in Texas. As posted on the Railroad Commission website, "the Commission may need to resolve problems in data collection, format, or processing that again result in subsequent upward revisions to monthly production totals. Company mergers and acquisitions may also delay timely producer filings. This ongoing process of reconciling operator data typically pushes the actual production totals higher."

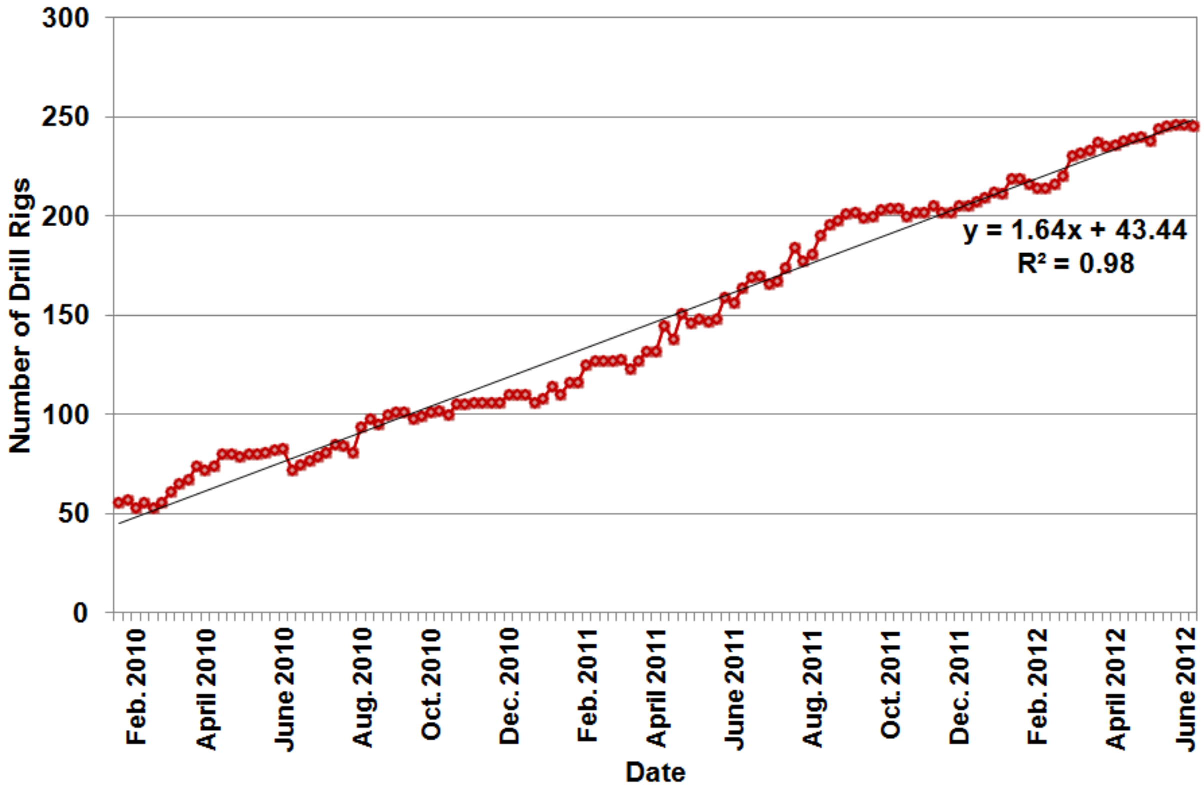
"In an effort to estimate actual monthly production more accurately, the Commission will calculate a supplemental production adjustment factor each month to be applied to the preliminary, reported statewide total of oil and gas well gas. The production adjustment factor, multiplied by the preliminary production total, is the Commission's estimate of the expected, final statewide production for a given month." "Because the Commission reports production in various ways (for example, by county and RRC district), it would be impractical to apply any adjustment factor to individual districts, leases, or wells." The Railroad Commission of Texas May 2012 adjustment factors of 1.1436 for oil wells and 1.1417 for

[385] Vicki Vaughan, San Antonio Express News, Nov. 18, 2011. "1,500 Oil Jobs Coming to City: Halliburton plans to hire 75 Percent Locally for its New Operations Base". San Antonio, Texas. Available online: http://www.mysanantonio.com/news/local_news/articleComments/1-500-oil-jobs-coming-to-city-2275100.php. Accessed: 05/19/2012.
[386] Nolan Hart, The Eagle Ford Shale Blog. July 28, 2012. "When Will Eagle Ford Shale Drilling Come To My Land?". http://eaglefordshaleblog.com/2011/07/28/when-will-eagle-ford-shale-drilling-come-to-my-land/. Accessed: 05/01/2012.
[387] Steve Toon February 1, 2012. "Boom Days In The Eagle Ford". The Champion Group". Available online: http://www.championgroup.com/news/boom-days-in-the-eagle-ford/. Accessed: 04/20/2012.
[388] Schlumberger Limited. "STATS Rig Count History". Available online: http://stats.smith.com/new/history/statshistory.htm. Accessed: 04/21/2012.
[389] Railroad Commission of Texas, April 3, 2012. "Eagle Ford Information". Austin, Texas. Available online http://www.rrc.state.tx.us/eagleford/index.php. Accessed: 05/01/2012.

gas well applies only to statewide totals and is not used to adjust production totals in the Eagle Ford.[390]

There was an increase in the number of drill rigs operating in Texas's Western Gulf Basin since early 2010.[391] The number of drill rigs operating in the Eagle Ford, provided in Figure 8-2, increased from 56 in January 2010 to 245 rigs in June 2012. From January 2011 to June 2012, annual increase in the number of rigs was 155 percent. The growth of drill rigs was steady over the last 2.5 years with a standard deviation of 8.0 rigs with a 95% confidence interval of 1.8 rigs weekly.

Figure 8-2: Horizontal Trajectory Rig Counts by Week in the Eagle Ford, 2010-2012



The massive increase in the number of drill rigs is due to the high price of crude oil and the depress cost of natural gas. Since natural gas production has increased rapidly due to production from unconventional shale plays, there is not enough demand and prices for natural gas have decreased. The Bakken shale in North Dakota has a similar increase in the number of drill rigs as the Eagle Ford starting in 2009 and the growth rates between the two plays have followed a similar pattern (Figure 8-3).[392]

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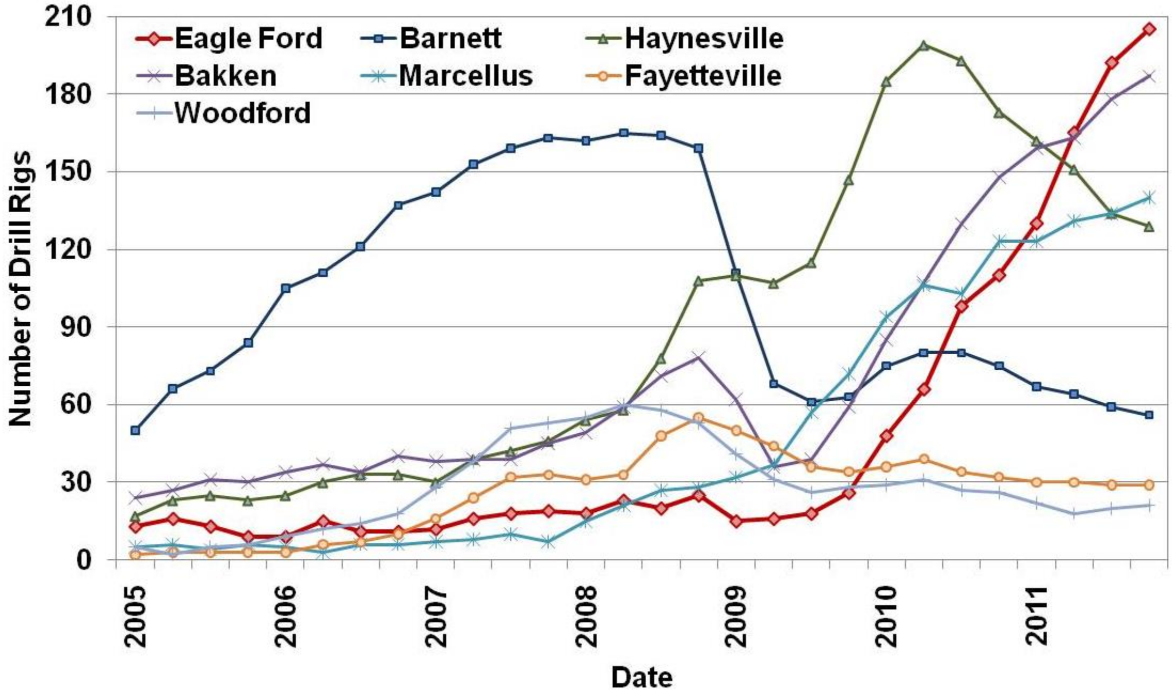
[390] The Railroad Commission of Texas May 31, 2012. "Production Adjustment Factor: An Estimate of Monthly Oil and Gas Production ". Austin, Texas. Available online: http://www.rrc.state.tx.us/data/production/adjustfactor.php. Accessed 06/15/2012.

[391] Baker Hughes Investor Relations. "Interactive Rig Counts". Available online: http://gis.bakerhughesdirect.com/Reports/RigCountsReport.aspx. Accessed: 04/20/2012.

[392] William Marko, Managing Director, Jefferies & Company, Inc. Nov. 2, 2011 "Facts About The Shales SPEE Houston Chapter". Available online: http://www.spee.org/images/PDFs/Houston/Houston_NOV_2_2011.pdf. Accessed: 04/20/2012.

Figure 8-3: Horizontal Trajectory Rig Counts by Week by Shale Play, 2005-2011



Historical growth patterns from dry gas shales cannot be used to project future growth in the Eagle Ford because the Eagle Ford has significant liquid resources. Although the number of land drill rigs has increased steadily in the U.S from April 2010 to October 2011, there was a decline in the number of drill rigs drilling for natural gas and a significant increase in the number of drill rigs searching for oil (Figure 8-4). Since October 2011, the number of land drill rigs has leveled off at just fewer than 2,000 rigs.[393]

Drill rigs operations are focusing on the Eagle Ford because it is "rated as the lowest cost play among North American shales in the liquids rich regions". [394] Since profits per well are significantly higher in the Eagle Ford and the cost for drilling is lower, drill rig operators and oil companies are attracted to south Texas. Figure 8-5 shows that Eagle Ford had the second highest well return rate of the major unconventional shale plays at 46 percent.[395] Only the Bakken, with a return rate of 50 percent, was higher than the eagle ford. Shale play dominated by natural gas had lower return rates between 5 percent for the Woodford to 41 percent for the Marcellus.

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[393] Baker Hughes Investor Relations. "Interactive Rig Counts". Available online: http://gis.bakerhughesdirect.com/Reports/RigCountsReport.aspx. Accessed: 04/20/2012.

[394] J. Michael Yeager, BHP Billiton, Nov. 14, 2011 "BHP Billiton Petroleum Onshore US Shale Briefing". Slide 38. Available online: http://www.bhpbilliton.com/home/investors/reports/Documents/2011/111114_BHPBillitonPetroleumInvestorBriefing_Presentation.pdf. Accessed 05/01/2012.

[395] William Marko, Managing Director, Jefferies & Company, Inc. Nov. 2, 2011 "Facts About The Shales SPEE Houston Chapter". Available online: http://www.spee.org/images/PDFs/Houston/Houston_NOV_2_2011.pdf. Accessed: 04/20/2012.

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Figure 8-4: Rig Counts in the U.S. drilling for Natural Gas and Oil, 2010-2012

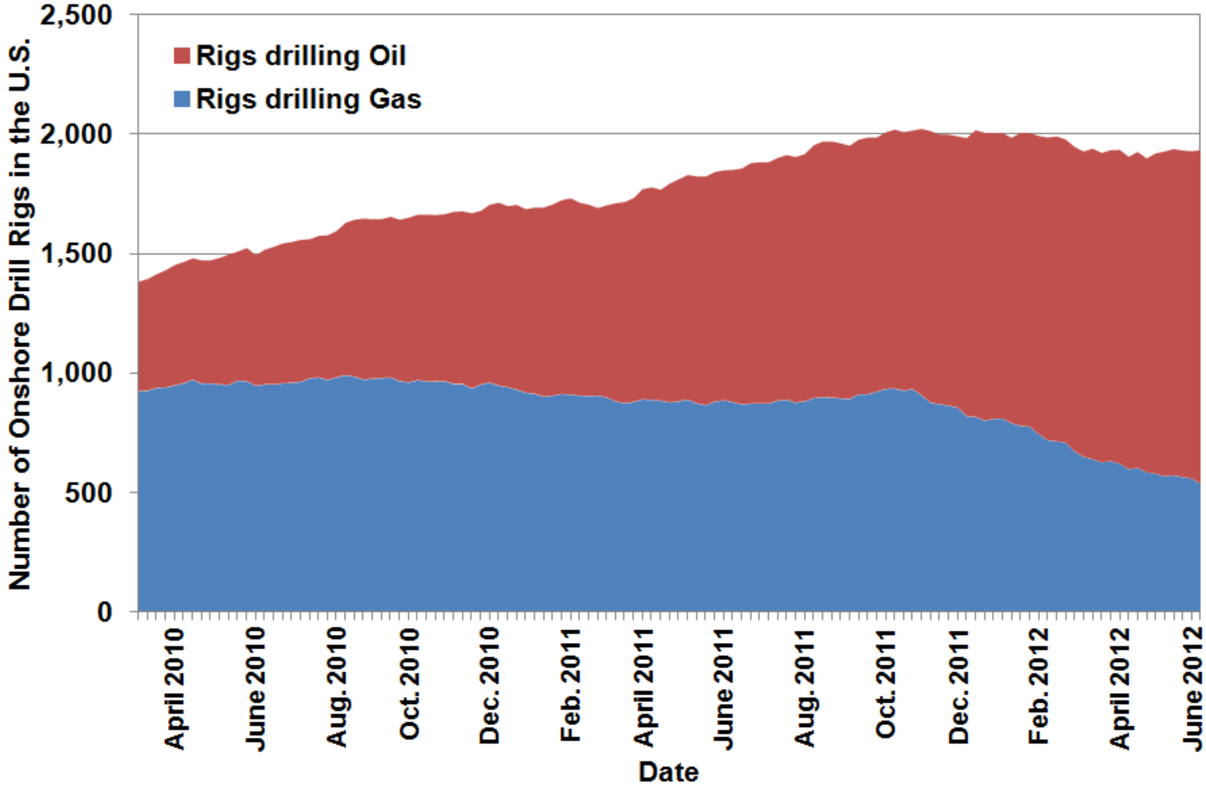
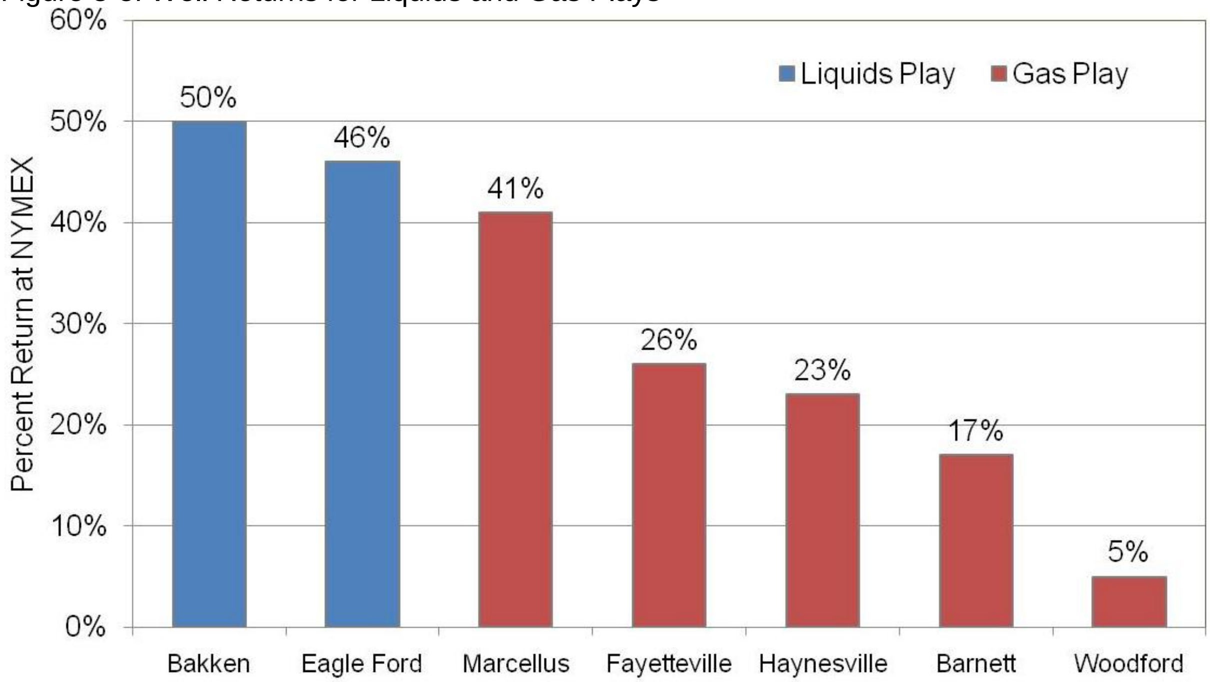


Figure 8-5: Well Returns for Liquids and Gas Plays



8.2 Previous Projections of Shale Production Activity

8.2.1 Drilling Rig Emission Inventory for the State of Texas

In ERG's "Drilling Rig Emission Inventory for the State of Texas", projection for 2009 through 2021 activity data in Texas "were developed using the 2008 base year activity data from the Railroad Commission of Texas and forecasting future activity based on Energy Information Administration (EIA) projections of oil and gas production for the Southwest and Gulf Coast regions from the Annual Energy Outlook 2009". "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."[396]

ERG projected a decrease in crude oil activity of 1.42% between 2008 and 2013, while there was an increase of 1.02% between 2008 and 2018. There was a decrease in natural gas activity for all years: 6.92% decrease between 2008 and 2015, and 8.02% decrease between 2008 and 2018. Total county-level well depth "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."[397] ERG projected that NO_X emissions will decrease from 55,238 tons/year in 2008 to 31,282 tons/year in 2018.

8.2.2 Development of an Emission Inventory for Natural Gas Exploration and Production in the Haynesville Shale and Evaluation of Ozone Impacts

ENVIRON used three sources to project future activity in the Haynesville Shale:

- Estimate total recoverable Haynesville Shale reserves from available literature
- Use historical record of activity in the nearby Barnett Shale to project future activity in the Haynesville Shale
- Use activity/equipment data from other oil and gas studies to determine emissions[398]

ENVIRON used three different scenarios to project drill rig and production activity in the Haynesville: low development, moderate development, and aggressive development. In the aggressive scenario used by ENVIRON, "development in the Haynesville begins at the current baseline 2009 rig count in the Haynesville Shale region and then grows at a rate of 25 rigs per year thereafter, at the average 2001-2008 growth rate seen in the Barnett Shale. For the low development scenario, the drill rig count was held fixed at the baseline 2009 Haynesville rig count, and for the moderate growth scenario, the drill rig count growth was modeled as 50% of the aggressive drill rig count growth rate."[399]

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[396] Eastern Research Group, Inc. July 15, 2009. "Drilling Rig Emission Inventory for the State of Texas". Prepared for: Texas Commission on Environmental Quality. Austin, Texas. p, 6-3 – 6-4. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820783985FY0901-20090715-ergi-Drilling_Rig_EI.pdf. Accessed: 04/09/2012.

[397] *Ibid*. p. 6-6.

[398] Sue Kemball-Cook, ENVIRON, April 28, 2009. "2012 Emission Inventories for Future Year Ozone Modeling". Presentation to the NETAC Technical Committee. Available online: http://etcog.sitestreet.com/UserFiles/File/NETAC/pdf/reports/air%20quality/2009/Enclosure_TC4.pdf. Accessed: 04/21/2012.

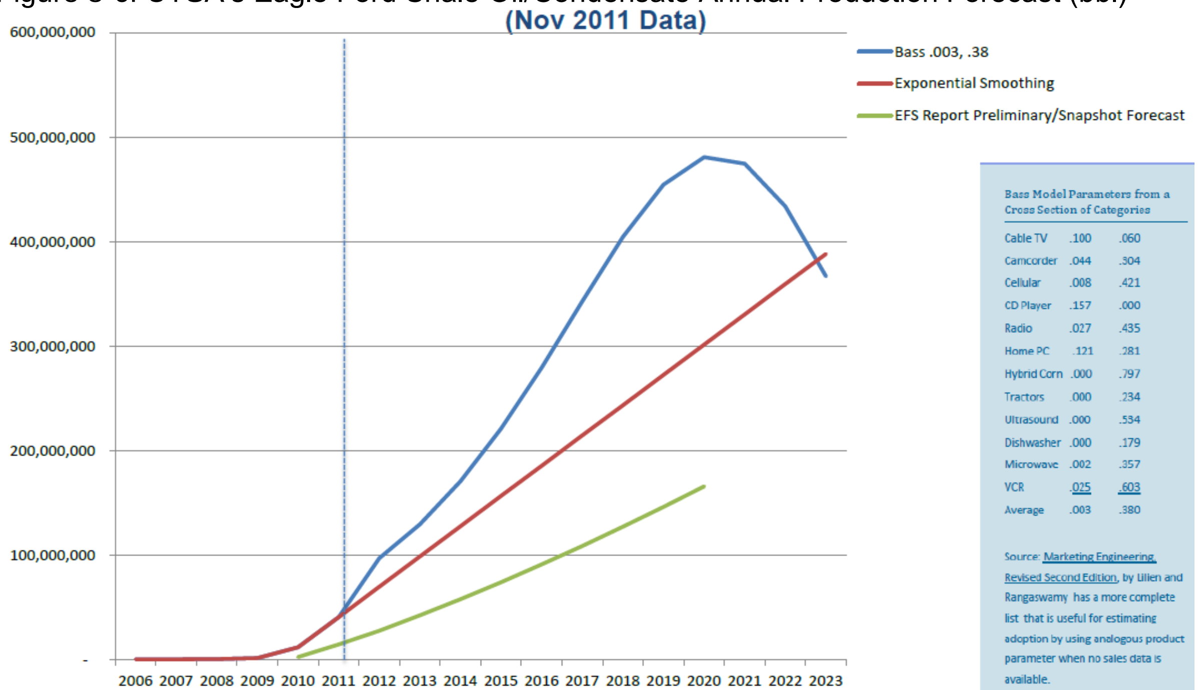
[399] John Grant, Lynsey Parker, Amnon Bar-Ilan, Sue Kemball-Cook, and Greg Yarwood, ENVIRON International Corporation. August 31, 2009. "Development of an Emission Inventory for Natural Gas Exploration and Production in the Haynesville Shale and Evaluation of Ozone Impacts". Novato, CA. p. 16. Available online: http://www.netac.org/UserFiles/File/NETAC/9_29_09/Enclosure_2b.pdf. Accessed: 04/19/2012.

When the number of drill rigs operating in the Haynesville Shale was determined, natural gas production can be estimate based on well counts and production decline curves. "Using the well development estimates for each of the three scenarios and estimates for the typical gas production of a well over its lifetime, total gas production can be calculated for the three development scenarios." The "analysis requires deriving estimates of typical well production over the time period 2009-2020, during which a well's production is expected to decline from an initial production peak. To estimate long-term production rates, eight wells with the longest production periods were identified" by ENVIRON "and the production rates analyzed for the total time period during which these wells have been active."[400] Future NO_X emissions were projected to grow from 56.69 tons/day in 2009 to 63.70 tons/day in 2020 under the low scenario. Under the high development scenario, there was an increase from 62.39 tons of NO_X in 2009 to 267.08 tons/day of NO_X in 2020.[401]

8.2.3 UTSA's Economic Impact of the Eagle Ford Shale

Thomas Tunstall, director of the Center for Community and Business Research at the University of Texas at San Antonio forecasts for activity in the Eagle Ford "to possibly peak at about 2,500 new wells drilled per year between 2014 and 2016."[402] As shown in the graph below (Figure 8-6), UTSA forecasts liquid production in the Eagle Ford will peak around 485 MMbbl in 2020 and then decline.[403]

Figure 8-6: UTSA's Eagle Ford Shale Oil/Condensate Annual Production Forecast (bbl)



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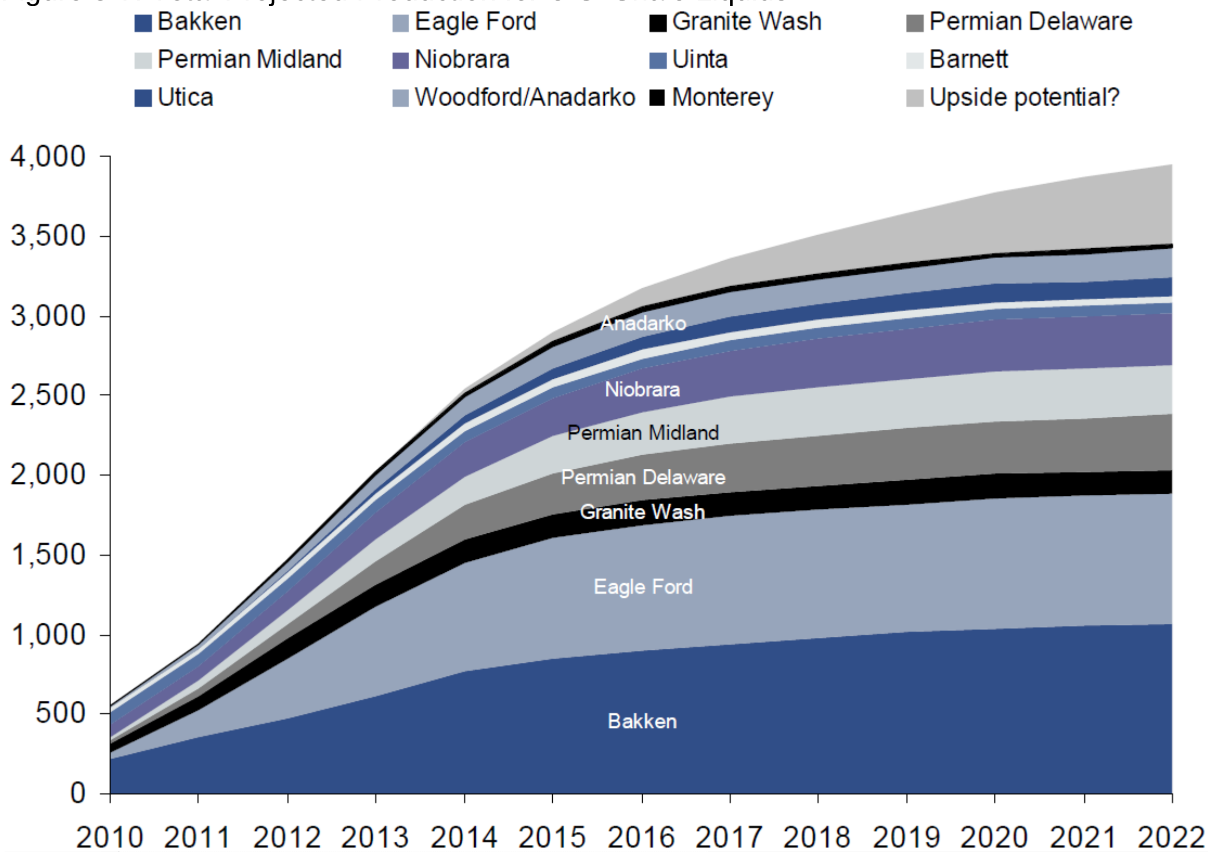
400 *Ibid*. p. 19.
401 *Ibid*. p. 60.
402 Mike D. Smith, March 2, 2012. "Eagle Ford Shale Production Surpasses Analysts' Forecasts". Corpus Christi Caller Times. Available online: http://www.caller.com/news/2012/mar/02/eagle-ford-shale-production-surpasses-analysts/. Accessed: 04/08/2012.
403 Thomas Tunstall, Ph.D., Director, Center for Community and Business Research, March 2012. "Impact of the Eagle Ford Shale on South Texas: Issues and Challenges." UTSA. San Antonio, Texas. Slide 36.

8.2.4 Eagle Ford Industry Activity and Projections

Citigroup Global Markets, states that production from new shale oil plays "(and the associated liquids from shale gas plays) is rising so fast that total US oil production is surging, even as conventional oil production in Alaska and California is continuing their structural decline, and Gulf of Mexico production is only now emerging from its post-Macondo lull." The graph, produced by the company, in Figure 8-7 shows shale oil could add over 2 MMbbl a day of oil with half of shale oil production from the Bakken and Eagle Ford. The company predicts production will grow in Eagle Ford until 2016 and for production to remaining consent from 2016 to 2022.[404]

Figure 8-7: Total Projected Production for U.S. Shale Liquids.



David Porter, Texas Railroad Commissioner, estimates that nearly three decades are needed just to "fully develop" the Eagle Ford.[405] Billiton Petroleum states that "fewer than 2,000 oil and gas wells have been drilled in the past couple of years in South Texas. The industry expects that number to climb to as many as 25,000 over the next couple of decades."[406]

[404] Citigroup Global Markets, Feb 15. 2012. "Resurging North American Oil Production and the Death of the Peak Oil Hypothesis The United States' Long March Toward Energy Independence". p. 2. Available online: https://www.citigroupgeo.com/pdf/SEUNHGJJ.pdf. Accessed: 06/13/2012.
[405] Michael Barajas, March 14, 2012. "Why the Great Shale Rush in the Eagle Ford may be over sooner than you think". Available online: http://sacurrent.com/news/why-the-great-shale-rush-in-the-eagle-ford-may-be-over-sooner-than-you-think-1.1285350. Accessed 05/28/2012.
[406] Russell Gold and Ana Campoy, Dec. 6, 2011. "Oil's Growing Thirst for Water". The Wall Street Journal. Available online: http://online.wsj.com/article/SB10001424052970204528204577009930222847246.html. Accessed: 04/04/2012.

Currently Chesapeake Energy (CHK), one of the largest producers in the Eagle Ford, is reducing the number of operating dry gas rigs to 24, from current level of 47; a decline of ~50 rigs from CHK's 2011 average. The company is planning on defer new dry gas well completions and pipeline connections whenever possible. As part of this process, the company is "redirecting capital savings from curtailing dry gas activity to liquids-rich plays". Approximately "85% of its 2012 total net operated drilling capital expenditures (capex) will be invested in liquids-rich plays" and 40% of drilling budget allocated to the Eagle Ford. Liquids are "expected to be ~30% of total production and ~60% of total revenues in 2013."[407]

ZaZa Energy predicts that they will increase the number of wells they drilled in the Eagle ford from 30 wells in 2011 to 150 wells in 2013.[408] Pioneer is expecting to increase production from 12 MBOEPD in 2011 to 47-53 MBOEPD in 2014, over 4 times increase in production by 2014.[409] On the Gates Ranch lease alone, there are 29,960 acres and Rosetta Resources "expects to drill 441 wells as infill drilling continues for years". The company estimates "that there will be over 25 years of rig time on the Gates Ranch alone".[410]

8.3 Drilling and Hydraulic Fracturing Projections

8.3.1 Drill Rigs

The number of drill rigs operating in the Eagle Ford, provided in Figure 8-2, increased from 56 in January 2010 to 245 rigs in June 2012.[411] The number of new drill rigs has increase on average 81 rigs a year since January 2010. Many oil companies have to drill significant number of wells over the next few years to meet oil and gas leases requirements before leases expire. Three different scenarios are used to estimate future rig counts:

- Low Development: Decrease of 10 rigs per year
- Moderate Development: No new rigs per year
- Aggressive Development: Increase of 20 rigs per year (one half of the annual increase)

The following equation is used to estimate the number of new rigs for each year between 2012 and 2018.

Equation 8-1, Total number of drill rigs for each projection year

$$RPROJ_B = (RCUR_A) + [RNEW \times (YEAR_B - YEAR_A)]$$

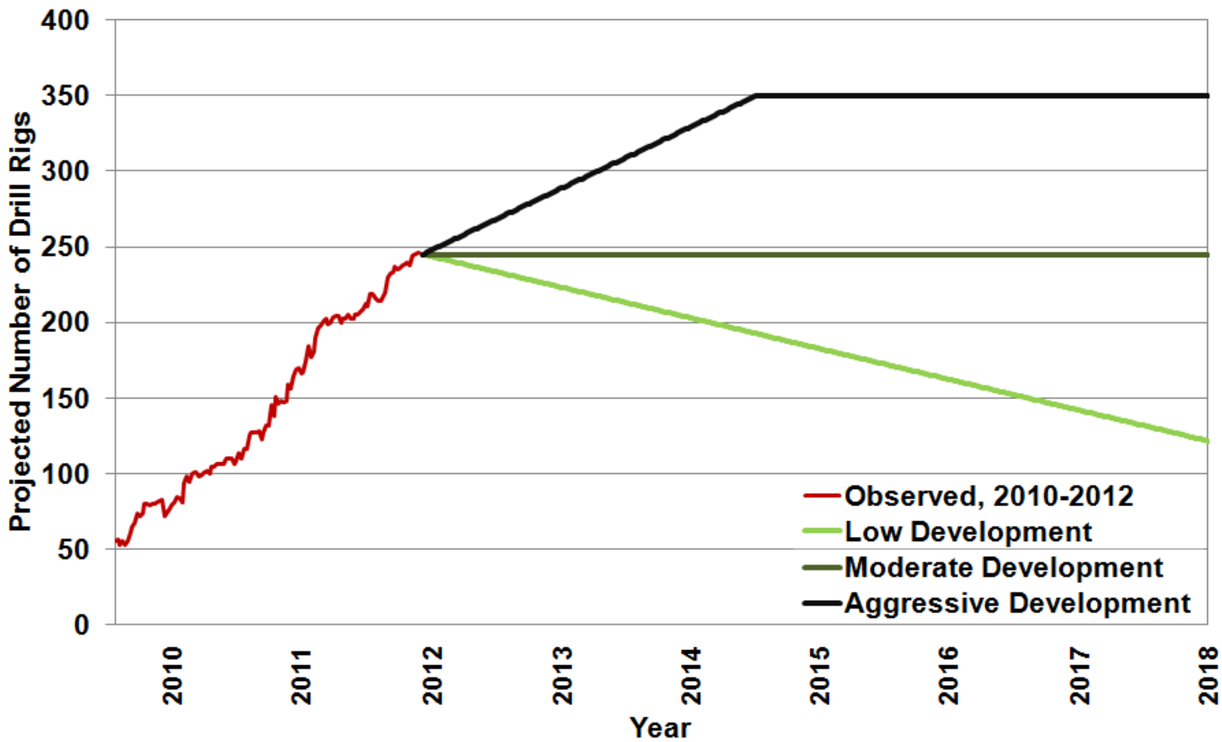
[407] Chesapeake Energy, June 2012. "Investor presentation". Available online: http://www.chk.com/investors/documents/latest_ir_presentation.pdf. Accessed: 06/13/2012.
[408] Toreador Resources Corporation, August 10, 2011. "Toreador Resources Corporation Merger With ZaZa Energy LLC Creating a Resource-Focused E&P Company". Slide 17 of 31. Available online: http://www.zazaenergy.com/oil-gas-company.asp. Accessed: 04/06/2012.
[409] Business Wire, A Berkshire Hathaway Company, Feb 6, 2012. "Pioneer Natural Resources Reports Fourth Quarter 2011 Financial and Operating Results and Announces 2012 Capital Budget ". Available online: http://www.businesswire.com/news/home/20120206006456/en/Pioneer-Natural-Resources-Reports-Fourth-Quarter-2011. Accessed: 04/13/2012.
[410] Available online: http://eaglefordshaleblog.com/2011/08/25/future-of-eagle-ford-shale-well-spacing/. Accessed 06/13/2012.
[411] Baker Hughes. "Interactive US Rig Counts". Available online: http://gis.bakerhughesdirect.com/RigCounts/default2.aspx. Accessed 06/05/2012.

Where,

RPROJ$_B$ = Number of drill rigs for Year B
RCUR$_A$ = Number of current drill rigs in Year A, 245 for June 8, 2012 (from Schlumberger Limited)
RNEW = Increase in the number of drill rigs each year under each scenario (-10 rigs for Low, 0 rigs for Moderate, 20 rigs for Aggressive Development with a cap of 350 rigs total)
YEAR$_B$ = Projection year B, June 2015 or June 2018.
YEAR$_A$ = Base year A, June 8, 2012

The aggressive projection scenario is capped at 350 rigs to prevent unrealistic high number of drill rigs operating in the Eagle Ford. The maximum of 350 rigs operating in the Eagle Ford represents 18 percent of the 1,900 on-shore drill rigs operating in the United States in 2011. Under the Aggressive growth scenario, the maximum number of rigs reaches 350 before 2016 (Figure 8-8). Table 8-2 lists the number of drill rigs by year under each growth scenario. Drill rigs are expected to decrease under all scenarios after 2018, but the emission inventory does not project emissions beyond 2008.

Figure 8-8: Projected Horizontal Trajectory Rig Counts in the Eagle Ford, 2010-2018



Projected equipment types and emission factors will be based on manufacturing, industry, and local data. "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."[412] The future trend for shale wells "is towards the use of

[412] Eastern Research Group, Inc. July 15, 2009. "Drilling Rig Emission Inventory for the State of Texas". Prepared for: Texas Commission on Environmental Quality. Austin, Texas. p. 3-3 – 3.4. Available online:

electrical rigs, and the average age of the engines used on the electrical rigs for these well types are only two years."[413]

Table 8-2: Projected Horizontal Trajectory Rig Counts in the Eagle Ford, 2010-2018

Year	Low Development	Moderate Development	Aggressive Development
2010	79	79	79
2011	166	166	166
2012	243	245	248
2013	223	245	289
2014	203	245	329
2015	183	245	350
2016	163	245	350
2017	142	245	350
2018	122	245	350

Future projection of emission factors for drill rig engines will be based on Tier emission factors provided in Table 8-3 for large diesel generators. Emission factors for Tier 2 generators will be based on emission factors for engines ≥ 750 from TCEQ's Texas Emissions Reduction Plan (TERP).[414] NO_X emission factors for Tier 4 Interim and Tier 4 engines >900 bkW will be based on EPA emission limit requirements[415], while VOC and CO emission factors for these engines will be based on certified engine data from Caterpillar.[416] For large generators, Tier 4 Interim engines and Tier 4 engines calculated emission factors are the same.

Table 8-3: Tier Emission Factors for Generators.

Pollutant	Tier 2 hp ≥ 750, 2006-2010 (TCEQ)	Certified Tier 4 Interim (Caterpillar Inc.)	Tier 4 Emission Limits for NO_X and Certified for VOC and CO (Caterpillar Inc.)
NOX EF (g/kw-hr)	3.40	0.67	0.67
VOC EF (g/kw-hr)	0.18	0.17	0.17
CO EF (g/kw-hr)	1.99	0.50	0.50

Only Tier 2 and 4 engines will be used because EPA stationary diesel generators emission limits and timing for Tier 3 Engines do not apply to generators >560 bkW.[417] Almost all generators used on drill rigs are >560 bkW and new generators are increasing in power output. All engines in 2011 are estimated to be Tier 2 because the rapid construction of

http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820783985FY0901-20090715-ergi-Drilling_Rig_EI.pdf. Accessed: 04/09/2012.

[413] Eastern Research Group, Inc. July 15, 2009. "Drilling Rig Emission Inventory for the State of Texas". Prepared for: Texas Commission on Environmental Quality. Austin, Texas. p. 6-14. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820783985FY0901-20090715-ergi-Drilling_Rig_EI.pdf. Accessed: 04/09/2012.

[414] TCEQ, April 24, 2010. "Texas Emissions Reduction Plan (TERP): Emissions Reduction Incentive Grants Program Technical Supplement No. 2, Non-Road Equipment". Austin, Texas. p. 5.

[415] California Environmental Protection Agency Air Resources Board, March 30, 2011. "New Off-Road Compression-Ignition Engines: Caterpillar Inc.".

[416] Caterpillar, 2011. "TIER 4 Interim EPA Emissions Requirements for Diesel Generator Sets".

[417] Caterpillar, 2011. "Tier 4 Interim EPA Emission Requirements for Diesel Generator Sets".

electric drill rigs and increase in power output needed for the Eagle Ford has removed most of the Tier 0 and Tier 1 generators operating in the region.

Table 8-4 shows the breakdown by type of engine, percentage of engines that meet each standard, and combined emission factors for generators/motors used to operate drill rigs. It is estimated that there will be a 20 percent turnover rate for generators per year and all mechanical drill rigs will be remove from service by 2015. Mechanical drill rigs only make up 13.7 percent of the local fleet in 2011 and are being removed from service because they are not as efficient or flexible as new electric drill rigs. To calculate emissions from generators, the factor used to convert from kw-hr to hp-hr is 1.34.[418]

Projections do not include any re-fracturing of existing wells. There is plenty of undeveloped acreage in the Eagle Ford that oil companies can developed before using existing horizontal wells. AACOG will continue to work with local industry and engine suppliers to refining projected emission factors and estimations.

Drilling of disposal wells is also occurring in the Eagle Ford to deposit wastewater from drilling and hydraulic fracturing operations. According to data from the Railroad Commission of Texas, there were 75 disposal wells drilled in the Eagle Ford region between 2008 and March 2012. It is expected that the number of disposal wells will continue to slowly increase as the Eagle Ford shale is developed. In the Barnett Shale, the Texas Railroad Commission has permitted 100 commercial disposal wells in the field. The Commission expects the Eagle Ford activity to match and exceed 100 commercial disposal wells.[419] Projections will not take into account drilling new disposal wells.

8.3.1 Pump Engines

Since hydraulic pump engines used for fracturing are becoming more efficient and total horsepower is increasing, initial well production has increased. Raymond James & Associates projections show that the average days pumping will decrease from 6 days to 4.3 days between 2009 and 2013. However, total horsepower used during hydraulic fracturing will increase from 31,850 to 37,623 between 2009 and 2013. [420]

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[418] Diesel Service & Supply, 2011. “Electrical Power Calculators”. Available online: http://www.dieselserviceandsupply.com/power_calculator.aspx. Accessed: 05/04/2012.

[419] Feb. 2, 2012. “Railroad Commission of Texas”. Slide 39. Available online: http://baysfoundation.com/wp-content/uploads/2012/02/February-2012-AO-Eagle-Ford-Master-02-12-2012.pdf. Accessed: 04/05/2012.

[420] J. Marshall Adkins, Collin Gerry, and Michael Noll, Jan. 10, 2011. “Energy: Industry Overview: We Don`t Hear Her Singing, the Pressure Pumping Party Ain’t Over Yet”.. Available online: http://gesokc.com/sites/globalenergy/uploads/documents/Energy_by_Raymond_James.pdf. Accessed: 04/20/2012.

Table 8-4: Drill Rigs and Pump Engines Emission Parameters, 2011 - 2018.

Parameter		2011	2012	2013	2014	2015	2016	2017	2018
Percent of Electric Drill Rigs		86.3%	86.3%	90.9%	95.4%	100%	100%	100%	100%
Percent of Mechanical Drill Rigs		13.7%	13.7%	9.1%	4.6%	-	-	-	-
Percent of Engines Tier 2		100%	80%	60%	40%	20%	-	-	-
Percent of Engines Tier 4 Interim		-	20%	40%	60%	80%	80%	60%	40%
Percent of Engines Tier 4		-	-	-	-	-	20%	40%	60%
Combine EF for Generators (Electric Drill Rigs and Pump Engines)	NO_X EF (g/kw-hr)	3.40	2.86	2.31	1.76	1.22	0.67	0.67	0.67
	VOC EF (g/kw-hr)	0.18	0.18	0.18	0.17	0.17	0.17	0.17	0.17
	CO EF (g/kw-hr)	1.99	1.69	1.40	1.10	0.80	0.50	0.50	0.50
EF for Mechanical Rigs	NO_X EF (g/hp-hr)	5.13	5.13	5.13	5.13	-	-	-	-
	VOC EF (g/hp-hr)	0.48	0.48	0.48	0.48	-	-	-	-
	CO EF (g/hp-hr)	1.99	1.99	1.99	1.99	-	-	-	-

The same emission factors used for generators operating on electric drill rigs will be used to estimate emissions from pump engines during hydraulic fracturing since generators that power electric drill rigs are similar to the ones used on pump engines. In the U.S. according to pump engine manufacture WEIR, 20% of the fleet's pumps are replaced each year.[421] Total pump engine horsepower, 13,500 hp, and activity rate, 54 hours, will remain the same in the projections. Projection estimates of pump engine activity only takes into account hydraulic fracturing on new wells and does not include re-fracturing existing horizontal wells. If improved local data becomes available, the results will be included in the projection years.

8.3.2 Non-Road Equipment

Activity rate, horsepower, load factor, and equipment population of other non-road equipment used for pad construction, drilling, and hydraulic fracturing will remain the same for each projection year. Emission factors for other non-road equipment will be projected using existing data in the TexN model. Calculated VOC, NO_X and CO emission factors are projected to decrease each year from 2011 to 2018 (Table 8-5).

8.3.3 Completion Venting and Flares

According to EPA air rules for the oil and natural gas industry, "beginning Jan. 1, 2015, operators must capture the gas and make it available for use or sale, which they can do through the use of green completions. EPA estimates that use of green completions for the three- to 10-day flowback period reduces VOC emissions from completions and recompletions of hydraulically fractured wells by 95 percent at each well. Both combustion and green completions will reduce the VOCs that currently escape into the air during well completion. However, capturing the gas through a green completion prevents a valuable resource from going to waste and does not generate NO_X, which is a byproduct of combustion."[422] Based on local interviews with industry representatives, it is estimated that all gas released during completion before 2015 will be combusted. After 2015, all wells will be using green completion and uncontrolled VOC emissions from completion venting will be reduced by 95 percent.

8.3.4 On-Road Emissions

Number of on-road trips, vehicle speed, vehicle type, distance travelled, and idling hours per trip will remain the same during pad construction, drilling, and hydraulic fracturing for each projection year. The number of vehicles will be multiplied by future projections of wells drilled and emission factors developed from the MOVES model. Emission factors for on-road light duty and heavy duty trucks used in the oil industry are provided in Appendix B

[421] WEIR, June 21, 2011. "2011 Capital Markets Day: Weir Oil & Gas Upstream". London, England. Slide 29. Available online: http://www.weir.co.uk/PDF/2011-06-21-WeirCapitalMarketsDay-pres.pdf. Accessed 05/20/2012.
[422] EPA, April 18. 2012. "EPA's Air Rules for the Oil & Natural Gas Industry: Summary Of Requirements for Processes and Equipment at Natural Gas Well Sites". Available online: http://www.epa.gov/airquality/oilandgas/pdfs/20120417summarywellsites.pdf. Accessed: 04/18/2012.

Table 8-5: TexN Model Emission Factors for Non-Road Equipment, 2011, 2015, and 2018.

Equipment Type	SCC	Pollutant	2011	2012	2013	2014	2015	2016	2017	2018
Other Diesel Oil Field Equipment	2270010010	VOC	#DIV/0!							
		NO_x	#DIV/0!							
		CO	#DIV/0!							
Diesel Signal Boards/Light Plants	2270002027	VOC	0.58							
		NO_x	4.42							
		CO	2.49							
Diesel Bore/Drill Rigs	2270002033	VOC	0.48							
		NO_x	5.13							
		CO	1.99							
Diesel Cranes	2270002045	VOC	0.28							
		NO_x	3.66							
		CO	1.07							
Diesel Tractors/ Loaders/Backhoes	2270002066	VOC	1.25							
		NO_x	5.04							
		CO	6.15							
Diesel Crawler Tractor/Dozers	2270002069	VOC	0.24							
		NO_x	2.90							
		CO	1.50							
Diesel Forklift	2270003020	VOC	0.25							
		NO_x	2.99							
		CO	2.69							
Diesel Generator Sets	2270006005	VOC	0.66							
		NO_x	5.00							
		CO	2.67							
Diesel Pumps	2270006010	VOC	0.63							
		NO_x	5.00							
		CO	2.70							
Diesel Scrapers	2270002018	VOC	0.16							
		NO_x	2.51							
		CO	1.38							
Diesel Off-highway trucks	2270002051	VOC	0.24							
		NO_x	3.71							
		CO	1.22							
Diesel Rollers	2270002015	VOC	0.54							
		NO_x	5.11							
		CO	3.08							
Diesel Loaders	2270002060	VOC	0.34							
		NO_x	4.00							
		CO	1.91							
Diesel Excavators	2270002036	VOC	0.36							
		NO_x	4.69							
		CO	1.93							
Diesel Graders	2270002048	VOC	0.30							
		NO_x	3.10							
		CO	1.44							
Diesel Gas Compressors		VOC	#DIV/0!							
		NO_x	#DIV/0!							
		CO	#DIV/0!							

8.4 Production Emission Projections

8.4.1 Oil and Natural Gas Wells Projections

To estimate emissions from production sources, future projections of oil, condensate, and natural gas will be calculated. Projections of liquid and gas production in the Eagle Ford are based on three factors,

1. The number of new production wells drilled each year
2. Estimated ultimate recovery (EUR) for each well
3. Decline curve for each well

Future projections of wells are based on the number of drill rigs operating in the Eagle Ford. The number of new production wells is based on the average number of days between spud to spud for each drill rig. As drill rigs become more efficient, operate with higher horsepower engines, technology improves, and crews increase their experience, the amount of time between spuds has decreased.

Chesapeake Energy Corporation states that typical duration for drilling a horizontal well is 20 to 24 days in the Eagle Ford.[423] The drill rig runs 24 hours 7 days a week to maintain the integrity of the drill hole.[424] In 2011, one of the fastest Eagle Ford shale drilling operation was 15,467 feet in 13 days or 20.17 hours/1,000 feet by EOG.[425] Spud-to-release time has decreased from 27 days to 15 days "and pad development allows the rig to mobilize in hours rather than the previous five to seven days."[426] Other companies had similar results including Swift Energy Co. needing 21 days per well.[427]

Marathon has a "targeted spud-to-spud time is 25 days, with a typical spud to total depth of 15 days. Completions involve an average 5,000-foot lateral, 15 to 17 stages and 250 to 300 feet between stages."[428] Bentek Energy, an energy market analytics company, found that the average time to drill horizontal wells in the Eagle Ford was 28 days.[429] H&P averaged 9 days to drill approximately 13,500 feet based on the last 10 wells in the Eagle Ford in 2011.[430] Raymond James & Associates projections show that the average drilling days

[423] Chesapeake Energy, Feb. 17, 2012. "Chesapeake Energy Corporation". presented at Greater San Antonio Chamber of Commerce – Energy & Sustainability Committee.
[424] Chesapeake Energy Corporation, 2012. "Part 1 – Drilling". Available online: http://www.askchesapeake.com/Barnett-Shale/Multimedia/Educational-Videos/Pages/Information.aspx. Accessed: 04/22/2012.
[425] Nov. 15, 2011. "Fastest Eagle Ford Shale Well Drilled By EOG". Available online: http://eaglefordshaleblog.com/2011/11/15/fastest-eagle-ford-shale-well-drilled-by-eog/. Accessed: 04/03/2012.
[426] Steve Toon, Oil and Gas Investor, Oct. 1, 2011. "Eagle Ford Output Continues To Soar". E&P Buzz, Houston, Texas. Available online: http://www.epmag.com/Production-Drilling/Eagle-Ford-Output-Continues-Soar_90533. Accessed: 04/02/2012.
[427] Colter Cookson, June 2011. "Operators Converge On Eagle Ford's Oil And Liquids-Rich Gas". The American Oil and Gas Reporter. Available online: http://www.laredoenergy.com/sites/default/files/0611LaredoEnergyEprint.pdf. Accessed: 04/02/2012.
[428] Steve Toon February 1, 2012. "Boom Days In The Eagle Ford". The Champion Group". Available online: http://www.championgroup.com/news/boom-days-in-the-eagle-ford/. Accessed: 04/20/2012.
[429] Bentek Energy LLC, April 18, 2011. "Eagle Ford Shale – Deep in the Heart of Texas". p. 8. Evergreen, CO.
[430] Helmerich & Payne, Inc., Feb 2012. "H&P Inc." presented at the Credit Suisse Energy Summit. Available online: http://idc.api.edgar-online.com/efx_dll/edgarpro.dll?FetchFilingConvPDF1?SessionID=nnXuFtmYWf79CIS&ID=8379673. Accessed: 04/20/2012.

decreased from 26 to 22 days.[431] The results are similar to Rosetta Resources production rate of 16 wells per year, or 23 days per well, for each drill rig.[432] In 2011, 2,340 wells were drilled by an average of 181 drill rigs which is equal to 28 days for spud to spud. Equation 8-2 will be used to forecast the number of production wells for each year.

Equation 8-2, Projection of cumulative production wells per year

$WPROJ_B = (WCUR_A) + [RPROJ_B \times 365.24 \text{ days per year} / DAYS]$

Where,

- $WPROJ_B$ = Projected number of Wells in Year B
- $WCUR_A$ = Number of production wells drilled in Year A in Table 6-1, 2,340 in 2011 (from Schlumberger Limited)
- $RPROJ_B$ = Number of Drill Rigs in Year B which is one year later than Year A (from Equation 8-1)
- DAYS = Spud-to-spud time for each drill rig, 25 days (from Marathon)

Based on this formula, the cumulative number of production wells drilled in the Eagle Ford increases rapidly between 2011 and 2018 (Figure 8-9). The number of disposal wells drilled in the future will be insignificant and they are not included in the projections.

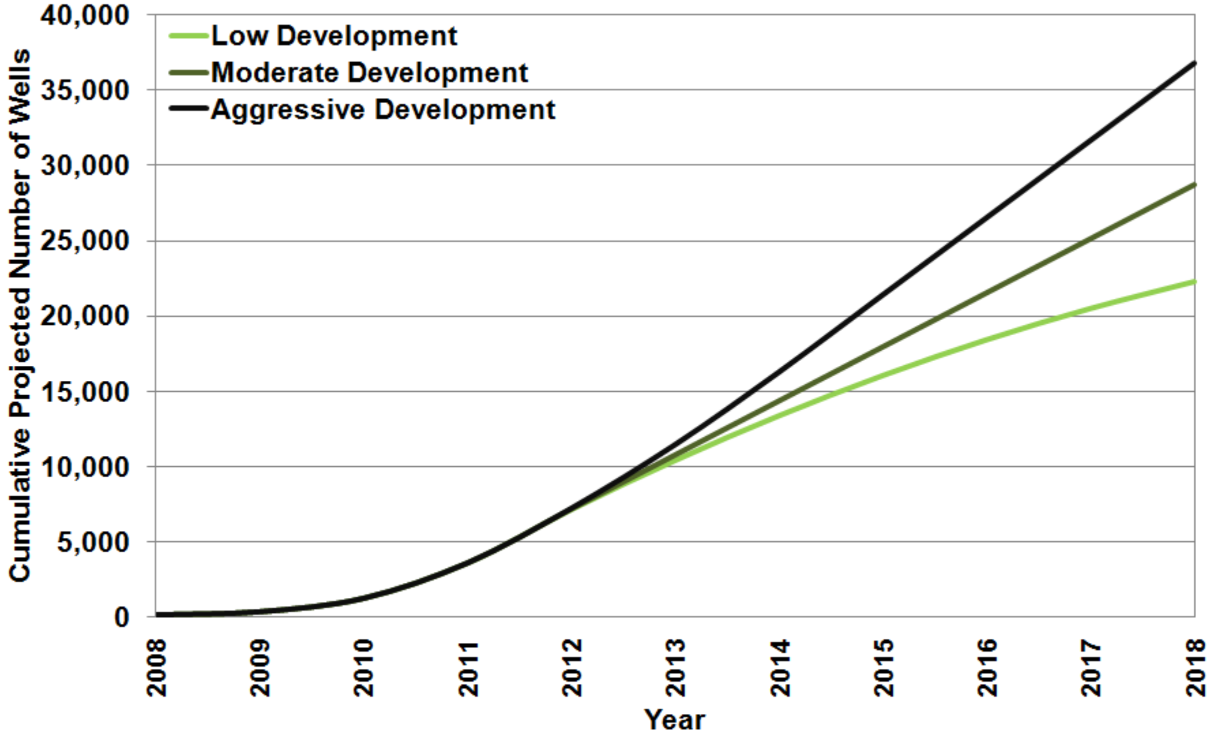
To provide a breakdown between natural gas and liquid wells, the number of natural gas wells drilled under the low scenario decrease 20 percent per year and under the other two scenarios the number of natural gas wells drilled decrease 15 percent. The number of drill rigs has decreased rapidly in other natural gas shale formations including the Barnett, 66% reduction since 2008, and the Fayetteville, 47% reduction since 2008. Natural gas wellhead prices have significantly decreased from $5.69/Mscf in Jan. 2010 to $2.25/Mscf in March 2012.[433] However, the number of natural gas wells drilled in the Eagle Ford should not decrease rapidly as other shale plays because natural gas wells in the Eagle Ford can produce significant amount of valuable condensate and the cost of development is lower in the Eagle Ford.

[431] J. Marshall Adkins, Collin Gerry, and Michael Noll, Jan. 10, 2011. “Energy: Industry Overview: We Don`t Hear Her Singing, the Pressure Pumping Party Ain’t Over Yet”.. Available online: http://gesokc.com/sites/globalenergy/uploads/documents/Energy_by_Raymond_James.pdf. Accessed: 04/20/2012.

432 Randy L. Limbacher, Feb. 7, 2012. “Rosetta Resources Inc.”. presented at Credit Suisse 2012 Energy Summit”. Slide 22. Available online: http://www.rosettaresources.com/downloads/020712%20Rosetta%20Resources%20Inc.pdf?ID=165360&CID=. Accessed: 04/22/2012.

[433] U.S. Energy Information Administration, April 30, 2012. “U.S. Natural Gas Wellhead Price”. Available online: http://www.eia.gov/dnav/ng/hist/n9190us3m.htm. Accessed 05/04/2012.

Figure 8-9: Cumulative Number of Production Wells Drilled in the Eagle Ford, 2008-2018



The projected number of new production wells drilled per year in the Eagle Ford is provided in Table 8-6, while cumulative number of production wells drilled is listed in Table 8-7. The number of new production wells drilled per year is projected to be 1,777 under the low scenario, 3579 under the moderate scenario, and 5,113 under aggressive scenario in 2018. It is expected that only 227 new natural gas wells will be drilled under the low scenario, while there will be 347 new natural gas wells under the moderate and aggressive scenarios. The cumulative growth of wells in the Eagle ford is projected to be between 22,323 and 36,748 wells drilled by 2018.

Under the low development scenario, there will be a 20% annual decrease in drill rigs searching for natural gas. There is a projected 15% annual decrease in the number of drill rigs drilling for natural gas under the other two scenarios. In comparison, there was a 20% annual decline in drill rigs in the Haynesville between 2nd quarter of 2010 and 4th quarter 2011, while there was a 18% annual decline in drill rigs in the Barnett between 2nd quarter 2008 and 4th quarter 2011.

"When an oil producer begins de-risking its acreage, it will drill and complete wells one at a time in different areas until that acreage is held by production. Once this is done, the oil company has the luxury to work its acreage as it sees fit, and in most cases the best acreage will see the bulk of company capital expenditures." Increase pipeline capacity has removed a potential bottleneck to production and can increase drilling activities. Pipeline companies have "committed more than $1 billion to add 940,000 barrels per day (bpd) of pipeline capacity by the end of 2012."[434]

[434] Mark J. Perry, Feb 1, 2012. "Shale Oil Revolution Comes to Eagle Ford Texas". Available online: http://mjperry.blogspot.com/2012/02/shale-revolution-comes-to-eagle-ford.html. Accessed: 04/15/2012.

Table 8-6: Number of New Production Wells Drilled per Year in the Eagle Ford, 2008-2018

Year	Low Development		Moderate Development		Aggressive Development	
	Oil Wells	Gas Wells	Oil Wells	Gas Wells	Oil Wells	Gas Wells
2008	89	109	89	109	89	109
2009	63	150	63	150	63	150
2010	337	558	337	558	337	558
2011	1,259	1,081	1,259	1,081	1,259	1,081
2012	2,692	865	2,661	919	2,706	919
2013	2,569	692	2,798	781	3,435	781
2014	2,412	553	2,916	664	4,143	664
2015	2,227	443	3,015	564	4,549	564
2016	2,020	354	3,100	480	4,634	480
2017	1,790	283	3,172	408	4,706	408
2018	1,551	227	3,233	347	4,767	347

Table 8-7: Cumulative Number of Production Wells Drilled in the Eagle Ford, 2008-2018

Year	Low Development		Moderate Development		Aggressive Development	
	Oil Wells	Gas Wells	Oil Wells	Gas Wells	Oil Wells	Gas Wells
2008	89	109	89	109	89	109
2009	152	259	152	259	152	259
2010	489	817	489	817	489	817
2011	1,748	1,898	1,748	1,898	1,748	1,898
2012	4,440	2,763	4,409	2,817	4,454	2,817
2013	7,009	3,455	7,207	3,598	7,889	3,598
2014	9,421	4,008	10,122	4,262	12,032	4,262
2015	11,648	4,451	13,137	4,826	16,582	4,826
2016	13,668	4,805	16,237	5,306	21,215	5,306
2017	15,457	5,088	19,409	5,713	25,921	5,713
2018	17,008	5,315	22,642	6,060	30,688	6,060

8.4.2 Estimated Ultimate Recovery

Estimated Ultimate Recovery (EUR) is the estimate amount of product recovered over the lifetime of a producing well. According to the EIA, Eagle Ford EUR is 300,000 bbl for oil, 5,500,000 MCF for the dry gas zone and 4,500,000 MCF for the condensate zone.[435] Texas Oil & Gas Association estimates that the eastern oil zone has EUR of 750,000 BOE, western oil zone has EUR of 250,000 BOE, and the wet gas zone has an EUR of 5-6,000,000 MCFe.[436] Oil and Gas analyst Michael Filloon determined that in the central part of the Eagle Ford, well costs are $7.9 million/well. This area has EURs of 965 Mboe and acre spacing of 80 to 160 acres is expected per well. In the condensate window, well costs are between $7.7 and $8.1 million and have EURs of 645 Mboe. The black oil window has

[435] U.S. Energy Information Administration, July 2011. “Review of Emerging Resources: U.S. Shale Gas and Shale Oil Plays”. p. 30. Available online: http://www.eia.gov/analysis/studies/usshalegas/pdf/usshaleplays.pdf. Accessed 05/07/2012.
[436] “Drill Baby Drill!: Eagle Ford Shale Update”. presented at Texas Oil & Gas Association’s, 2011 Annual Property Tax Conference, Feb. 22nd – 23rd, 2011. Slide 8 of 33. Available online: http://www.property-tax.com/articles/TXOGADrillBabyDrill.pdf. Accessed: 04/13/2012.

well costs of $7.9 million and EURs of 445 Mboe are expected in the most western part of the Eagle Ford play.[437]

From reviewing current production data from the Railroad Commission of Texas, industry sources maybe over estimating EUR for each well drilled. The railroad commission has reported 572 producing gas wells and 831 producing oil wells in the Eagle Ford between Jan. 2004 and August 2011. There was 18,653,124 bbl of oil produced, 25,184,186 MCF of casing head natural gas, 342,972,974 MCF of natural gas, and 24,960,840 bbl of condensate produced from Jan 2004 to Oct 2011.[438] Using this data, there was an average of 33,915 bbl of oil produced per oil well, 45,789 MCF of casing head natural gas produced per oil well, 604,891 MCF of natural gas produced per natural gas well, and 44,023 bbl of condensate produced per natural gas well.

To calculate estimated EUR per well, a conservative approach was used. While oil wells production are broken down into 150,000 bbl for oil and 50,000 MCF for casinghead gas, natural gas wells production are broken down into an average of 75,000 bbl of condensate and 1,000,000 MCF of natural gas per gas well. The breakdown between natural gas and condensate is similar to data provided by the Railroad Commission of Texas. Eagle Ford natural gas wells produced 71,798,050 BOE (71%) of Natural gas and 29,025,262 BOE (29%) of condensate from January 2004 to January 2012.[439] EURs for each substance were estimated for the whole Eagle Ford Shale Development. Although the eastern section of the Eagle Ford may have higher EURs, there was not enough detailed information to break down the EUR for each field or region in the Eagle Ford.

Over time, higher hp drill rigs, increase in hp used for hydraulic fracturing, reduced time needed to move rigs and equipment, and increase experience has raised the estimated EUR from each Eagle Ford well. Improved technology, such as improved drill bits, hydraulics, drilling technology, and hydraulic fracturing technology has also increase estimate EUR from each well. As companies increase the lengths of laterals in the wells, production from each well increases. As technology improves, laterals get longer, and there is an increase in experience working in the Eagle Ford, average EUR per well has increased. Under the moderate development scenario, the average EUR per well is expected to increase 5 percent per year and under the aggressive scenario it is expected to increase 10 percent per year. The EUR under the low development scenario will remain the same.

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437 Michael Filloon, March 19, 2012. “Bakken Update: Well Spacing Defined, Production Outlined”. Available online: http://seekingalpha.com/article/442981-bakken-update-well-spacing-defined-production-outlined. Accessed 05/20/2012.

438 Railroad Commission of Texas. April, 3, 2012. “Eagle Ford Information: Currently 20 Fields”. Available online: http://www.rrc.state.tx.us/eagleford/EagleFord_Fields_and_Counties_201203.xls. Accessed 05/08/2012.

439 Railroad Commission of Texas. April, 3, 2012. “Eagle Ford Information: Currently 20 Fields”. Available online: http://www.rrc.state.tx.us/eagleford/EagleFord_Fields_and_Counties_201203.xls. Accessed 05/08/2012.

Table 8-8: Increase in Estimated Ultimate Recovery (EUR) per Year per Well drilled, Aggressive Development Scenario, 2008-2018

Year	Percent increase in EUR per year (from 2011)	Oil Wells			Natural Gas Wells		
		Estimate Oil EUR per Oil Well (bbl)	Estimated Casinghead EUR per Oil Well (MCF)	Total Estimated BOE EUR per Oil Well (bbl)	Estimate Condensate EUR per Gas Well (bbl)	Estimate Natural Gas EUR per Gas Well (MCF)	Total Estimated BOE EUR per Gas Well (bbl)
2008	0%	150,000	50,000	197,000	75,000	1,000,000	237,167
2009	0%	150,000	50,000	197,000	75,000	1,000,000	237,167
2010	0%	150,000	50,000	197,000	75,000	1,000,000	237,167
2011	0%	150,000	50,000	197,000	75,000	1,000,000	237,167
2012	10%	165,000	55,000	216,700	82,500	1,100,000	260,883
2013	20%	180,000	60,000	236,400	90,000	1,200,000	284,600
2014	30%	195,000	65,000	256,100	97,500	1,300,000	308,317
2015	40%	210,000	70,000	275,800	105,000	1,400,000	332,033
2016	50%	225,000	75,000	295,500	112,500	1,500,000	355,750
2017	60%	240,000	80,000	315,200	120,000	1,600,000	379,467
2018	70%	255,000	85,000	334,900	127,500	1,700,000	403,183

8.4.3 Well Decline Curves for the Eagle Ford

The decline curve measures the amount of liquids or natural gas produced by individual wells over time. "Typically, a well will have its maximum production immediately after drilling and then productivity decreases with time as the reservoir is drained. Well decline curves for individual wells can be used to estimate the production for the field as a whole, since the number of producing wells in the field and the age of each well is known."[440] U.S. Energy Information Administration computed a typical decline curve for Eagle Ford with 30 percent of production occurring within the 1st year (Figure 8-10). The curve was developed by Petrohawk based on data for condensate in the Hawkville Field.[441]

Schlumberger, a large worldwide oilfield services provider, examined production trends in horizontal shale gas wells over time for several basins in North America. The company compared "the production profiles between shale basins, historical production of vertical and horizontal Barnett Shale wells, and the production profiles of horizontal tight gas sandstone and shale formations." To develop an Eagle Ford decline curve, Figure 8-11, Schlumberger used data from 59 wells.[442] Other companies show similar decline curves in the Eagle ford including BHP Billiton Petroleum.[443]

Decline curves calculated from other studies varied from 56 percent decline in the Barnett[444] to 82 percent decline in the Bakken[445] during the first year. Schlumberger found a 76 percent decline in the Eagle Ford during the first year[446] while Goodrich Petroleum had an 81 percent decline in the Haynesville.[447] All decline curves from previous studies show a similar pattern: from high initial output followed by a rapid decline in production as the well

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[440] John Grant, Lynsey Parker, Amnon Bar-Ilan, Sue Kemball-Cook, and Greg Yarwood, ENVIRON International Corporation. August 31, 2009. "Development of an Emission Inventory for Natural Gas Exploration and Production in the Haynesville Shale and Evaluation of Ozone Impacts". Novato, CA. p. 13. Available online: http://www.netac.org/UserFiles/File/NETAC/9_29_09/Enclosure_2b.pdf. Accessed: 04/19/2012.

[441] U.S. Energy Information Administration, July 2011. "Review of Emerging Resources: U.S. Shale Gas and Shale Oil Plays". p. 32. Available online: http://www.eia.gov/analysis/studies/usshalegas/pdf/usshaleplays.pdf. Accessed 05/07/2012.

[442] Jason Baihly, Raphael Altman, Raj, Malpani & Fang Luo, Schlumberger. "SPE 135555: Shale Gas Production Decline Trend Comparison over Time and Basins". Slide 26 of 33. Available online: http://www.greencenturyresources.com/TempDownloadFiles/Schlumberger-ShaleGasComparisonOverTimeandBasins.pdf. Accessed: 04/09/2012.

[443] PetroHawk Energy Corporation, March 24, 2010. "Will the Real Eagle Ford Shale Please Stand Up?". Presented at the SPE Business Development. Houston, Texas. Available online: http://www.spegcs.org/attachments/studygroups/2/2010_03_Bus%20Dev%20-%20Petrohawk_Stoneburner.pdf. Accessed: 04/12/2012.

[444] Pickering Energy Partners, Inc. "Barnett Shale Decline Curves Vertical and Horizontal Wells". Available online: http://hillcountygasboom.blogspot.com/2008_01_01_archive.html. Accessed: 04/13/2012.

[445] John Seidle & Leslie O'Connor, MHA Petroleum Consultants LLC. June 2011. "Well Performance & Economics of Selected U.S. Shales". Presented at SPEE Annual Convention, Amelia Island, Florida. Slides 11, 18, and 26. Available online: http://www.spee.org/wp-content/uploads/pdf/2011Convention/WellPerformanceandEconomicsofSelectedU.S.GasShales.pdf. Accessed: 05/02/2012.

[446] Jason Baihly, Raphael Altman, Raj, Malpani & Fang Luo, Schlumberger. "SPE 135555: Shale Gas Production Decline Trend Comparison over Time and Basins". Slide 26 of 33. Available online: http://www.greencenturyresources.com/TempDownloadFiles/Schlumberger-ShaleGasComparisonOverTimeandBasins.pdf. Accessed: 04/09/2012.

[447] Robert Hutchinson, March 24, 2009. "Decline Curves". The Haynesville Shale. Available online: http://www.haynesvilleplay.com/2009/03/decline-curves.html. Accessed: 04/13/2012.

matures (Table 8-9). When the well is 10 years old, production from the well will be minimal because of the rapid decline.

Figure 8-10: Typical Decline curve for the Eagle Ford

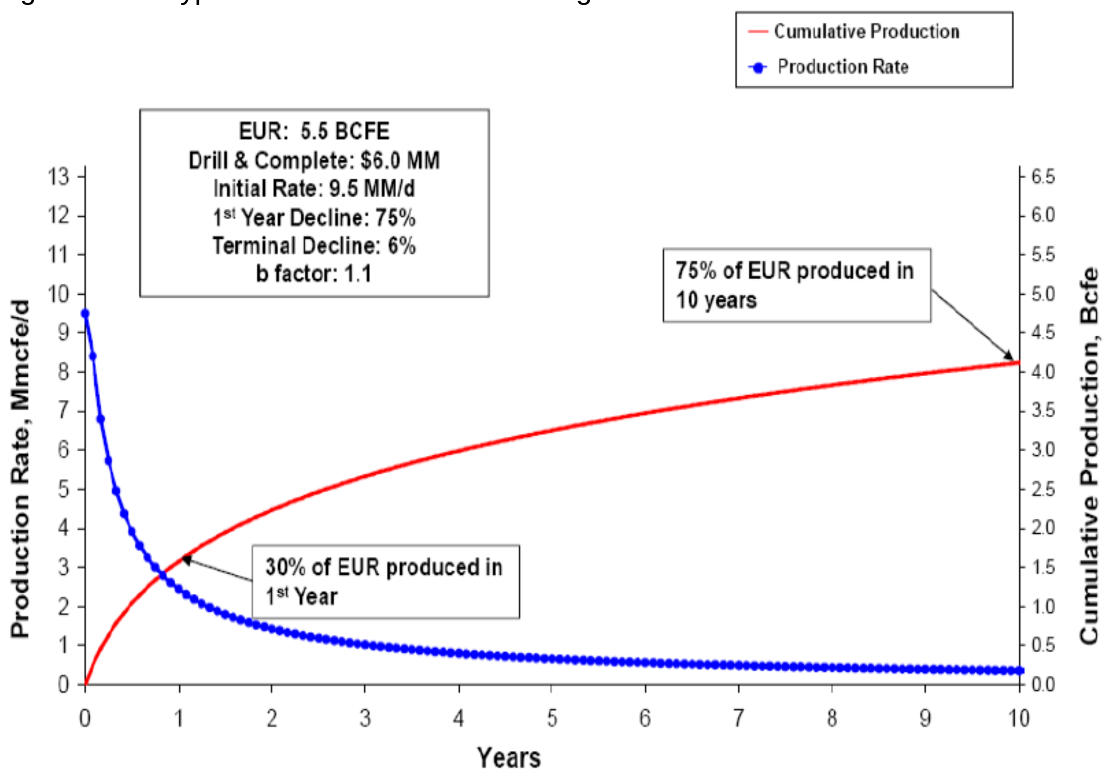


Figure 8-11: Decline Curves for Horizontal Sandstone and Shale Plays

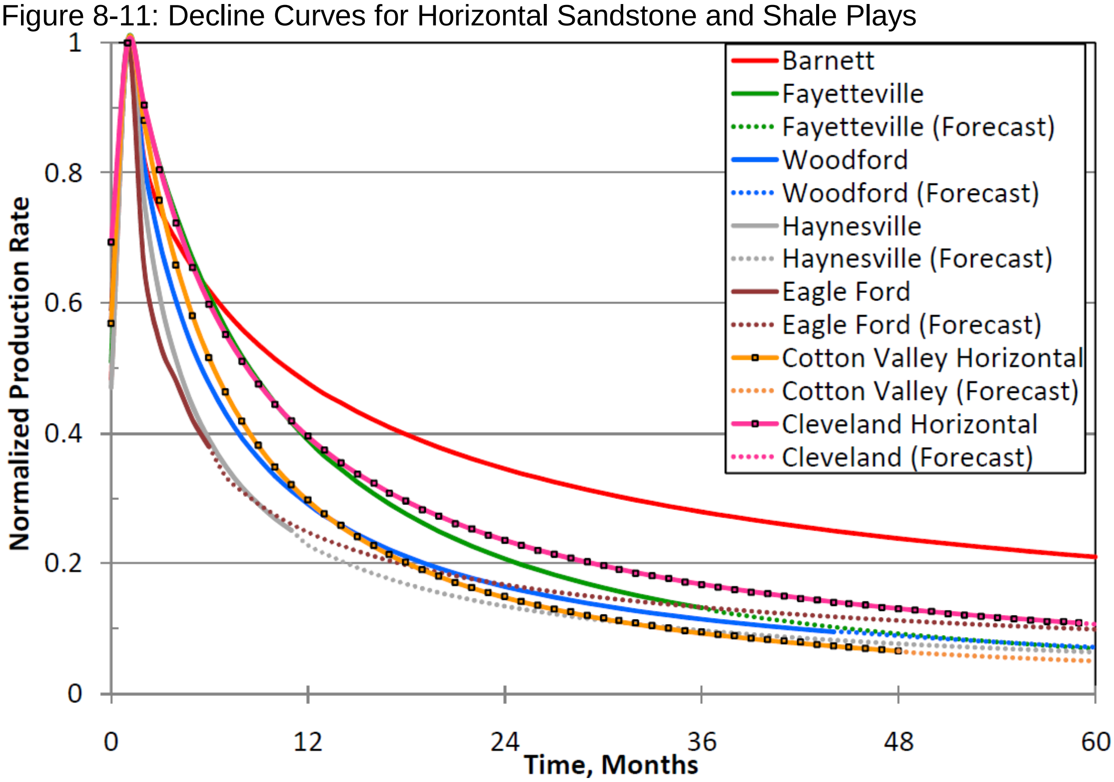


Table 8-9: Examples of Decline Curves from Previous Studies

Production Month	Pickering Energy Partners, Barnet	Midland Basin, Wolfcamp [448]	Goodrich Petroleum, Haynesville	C. K. Cooper & Company. Eagle Ford[449]	Schlumberger Eagle Ford	HPDI, Barnett [450]	ENVIRON Haynesville [451]	MHA Petroleum Consultants			**Eagle Ford based on RRC Data**
								Haynesville Industry	Marcellus	Bakken	
12 months	56%	62%	81%	62%	76%	60%	71%	70%	68%	82%	64%
24 months	27%	31%	34%	20%	29%	35%	32%	42%	24%	34%	45%
36 months	18%	21%	22%	18%	24%	20%	22%	30%	12%	20%	48%
48 months	12%	16%	17%	16%	15%	8%	16%	25%	11%	14%	68%
60 months	8%	13%	13%		9%	0%	13%	19%	10%	12%	***18%****
72 months	8%	11%	11%			18%	11%	15%	8%	10%	***15%****
84 months		9%	9%				9%	13%	6%	7%	***13%****
96 months		8%	8%				8%	10%	3%	6%	***12%****
108 months		7%	7%				7%	10%	3%	6%	***10%****

*Based on projected EUR using local data to calculate exponential equation $y = e^{-0.077x}$

[448] Approach Resources Inc. Jan. 12, 2012. "Approach Resources Inc. Investor Presentation".. p. 18. Available online: http://www.faqs.org/sec-filings/120112/Approach-Resources-Inc_8-K/d281592dex991.htm. Accessed: 04/13/2012.
[449] C. K. Cooper & Company. "Lucas Energy, Inc." Ivrine, California. p. 11. Available online: http://www.billchippasshow.com/files/46180526.pdf. Accessed: 04/15/2012.
[450] Arthur E. Berman and Lynn F. Pittinger, Aug 5, 2011. "U.S. Shale Gas: Less Abundance, Higher Cost". Available online: http://www.theoildrum.com/node/8212. Accessed: 04/15/2012.
[451] John Grant, Lynsey Parker, Amnon Bar-Ilan, Sue Kemball-Cook, and Greg Yarwood, ENVIRON International Corporation. August 31, 2009. "Development of an Emission Inventory for Natural Gas Exploration and Production in the Haynesville Shale and Evaluation of Ozone Impacts". Novato, CA. p. 23. Available online: http://www.netac.org/UserFiles/File/NETAC/9_29_09/Enclosure_2b.pdf. Accessed: 04/19/2012.

Decline curve analysis (DCA) from operating wells in the Eagle Ford was used to forecasting future production. In order to make a general conclusion about the decline curve, the number of wells required for an accurate representation is an important concern. Since determining a suitable sample size is not always clear-cut, several major factors must be considered. Due to time and budget constraints, a 90% level of confidence, which is the risk of error the researcher is willing to accept, was chosen. Similarly, the confidence interval, which determines the level of sampling accuracy, was set at +/- 10%. Since the population is finite, the following equation was used to select the sample size.[452]

Equation 8-3: Number of Wells needed to develop a decline curve

$$RN = [CLV^2 \times 0.25 \times POP] / [CLV^2 \times 0.25 + (POP - 1)\ CIN^2]$$

Where,

RN = Number of survey responses needed to accurately represent the population
CLV = 90% confidence level, 1.64
POP = Population size, 1,748 wells (from Railroad Commission of Texas)
CIN = ± 10% confidence interval, 0.1

For a 10% confidence interval:

$$RN = [(1.64)^2 \times (0.25) \times 29] / [(1.64)^2 \times (0.25) + (29 - 1) \times (0.1)^2]$$
$$= 64.71 \text{ wells}$$

Thus, data from 65 wells will be needed in order to meet the 95% level of confidence, and the ±10% confidence interval for equipment population. Since 66 wells were included in the initial analysis, the sampling meets the required sample size for a 90% confidence level with a ± 10% confidence interval. Wells with at least 2 years of production were selected from a random sampling across the basin and at least one well was selected from every county.[453] Wells outside of the core area are less productive then in the core, but they were included in the DCA to develop a complete analysis of well decline curves for the whole basin. Once one well was selected from a lease, all other wells from the same lease were removed from consideration. Date of first production (DOFP) for the wells selected in the analysis was between 2008 and June 2010.

There is a large number of variability in production data and decline curves. Efforts were made to get accurate and complete data from representative well in the Eagle Ford. Following the methodology used by Schlumberger, any well that had any abrupt changes in monthly production rates were removed from the DCA calculations.[454] Some wells may have a tighter chokes to flattening out the decline curves and increase the amount of product recovered on the back end of a well's productive lifetime. The wells selected for the initial analysis of the decline curve are listed below.

- Traylorrth, Lease: 15229
- Moglia, Lease: 254895, Well: 5h
- Kallina, Lease: 247729, Well: 2h
- Eskewrth Unit, Lease: 256977, Well: 1
- Hullabaloo, Lease: 25251
- Mansker Ranch Gas Unit, Lease: 253314, Well: 4
- Winton Unit, Lease: 15049
- Lastly Unit, Lease: 25168

[452] Rea, L. M. and Parker, R. A., 1992. "Designing and Conducting Survey Research". Jossey-Bass Publishers: San Francisco.
[453] Railroad Commission of Texas. "Specific Lease Query". Austin, Texas. Available online: http://webapps.rrc.state.tx.us/PDQ/quickLeaseReportBuilderAction.do. Accessed 06/01/2012.
[454] Jason Baihly, Raphael Altman, Raj Malpani, and Fang Luo, Schlumberger, 2010. "Shale Gas Production Decline Trend Comparison Over Time and Basins". SPE 135555. Presented at the SPE Annual Technical Conference, Florence, Italy, Sept. 19-22, 2010.

- Billings "B", Lease: 256253, Well: 12h
- Lowe, Lease: 257679, Well: 3h
- Gus Tips Gas Unit 1, Lease: 257651, Well: 2
- Beinhorn Ranch, Lease: 255507, Well: 2h
- Bermuda, Lease: 15176
- Galvan Ranch, Lease: 257818, Well: 2h
- Plomero Ranch, Lease: 256501, Well: 2
- Galvan Ranch, Lease: 257683, Well: 6h
- Henderson-Cenizo, Lease: 255994, Well: 3h
- Asche Ranch, Lease: 255524, Well: 1h
- Myers Cattle, Lease: 249148, Well: E 1
- Nunley-Bathe, Lease: 25503
- Marrs-Quinn Unit, Lease: 250811, Well: 1re
- Friedrichs Gas Unit, Lease: 254465, Well: 1
- Triplitt Unit, Lease: 15152
- Beinhorn Ranch, Lease: 256717, Well: 3h
- Baumann Gas Unit, Lease: 251990, Well: 1h
- Briscoe Catarina West, Lease: 256010, Well: 5h
- Ledezma, Consuelo, Lease: 15165
- Eyhorn Gas Unit 1, Lease: 257673, Well: 1
- Neller Gas Unit 1, Lease: 250464, Well: 1
- Wessendorff Gas Unit 1, Lease: 249352, Well: 2
- Gallagher, Gloria B., Lease: 242046, Well: 7h
- Donnell, Lease: 248927
- King, Gail, Lease: 253026, Well: 37h
- Weston, Lease: 254609, Well: 1
- Kowalik 228-1, Lease: 246035, Well: 1
- Wessendorff Gas Unit 6, Lease: 244762, Well: 1
- Varibus, Lease: 255962, Well No: 7H
- Vaquillas Borrego, Lease: 238068, Well: 28h
- Staggs, Lease: 245000, Well: 12h
- Kleinschmidt, Lease: 25253
- Miss Ellie, Lease: 25197
- Galloping Ghost Unit, Lease: 25214
- Allee-Bowman Unit, Lease: 14974
- Nathalie, Lease: 25243
- Fun, Lease: 25269
- Tlapek, Lease: 14956
- Zingara, Lease: 256453
- Benge Unit, Lease: 25266
- Fred Buchel Gas Unit 1, Lease: 239214, Well: 2
- La Rosita, Lease: 14994
- Lease Name: Rally, Lease: 15051
- Baumann Gas Unit, Lease: 250086, Well: 2h
- Caroline Pielop, Lease: 254447, Well: 4h
- La Bandera Ranch, Lease: 254472, Well: 1h
- Tovar West-Lloyd 77 Unit, Lease: 15307
- Dulaney-Bruni, Lease: 251652, Well: 1
- Chaparrosa "A", Lease: 15228
- Woolum, Lease: 25377
- Chhorn Gas Unit, Lease: 250898, Well: 1h
- Evangeline Gas Unit 1, Lease: 249492, Well: 1
- Gail King, Lease: 259341, Well: 43
- Hundley, Lease: 09426
- Vaquillas-State, Lease: 251129, Well: 5h
- Molak, Lease: 15111
- Darlene Unit, Lease: 09552
- Eskew west unit, Lease: 254315, Well No: 1

Average decline curves by product are provided in Figure 8-12, while decline curves by DOFP are shown in Figure 8-13. Gas, Condensate and Casinghead gas have very similar decline curves for the first 48 months of production. Oil has a steeper decline curve in the first 12 months of production, but the decline curve is similar to the other products by the 24^{th} month of production. When comparing wells with different DOFP, 2010 wells had a more gradual decline curve compared for 2008 and 2009. Further research is needed as Eagle Ford production matures to determine if wells will have a more gradual decline curves in the future.

When the decline curves for all wells are averaged, Figure 8-14, production was reduced by 64% in the first year, 47% in the second year, and 48% in the third year. Since Eagle Ford is still a developing basin, long term production rates are unknown. The decline curve is projected beyond 48 months using an exponential equation of $y = e^{-0.077x}$ based on local production data.

Figure 8-12: Normalized Eagle Ford Decline Curves by Product

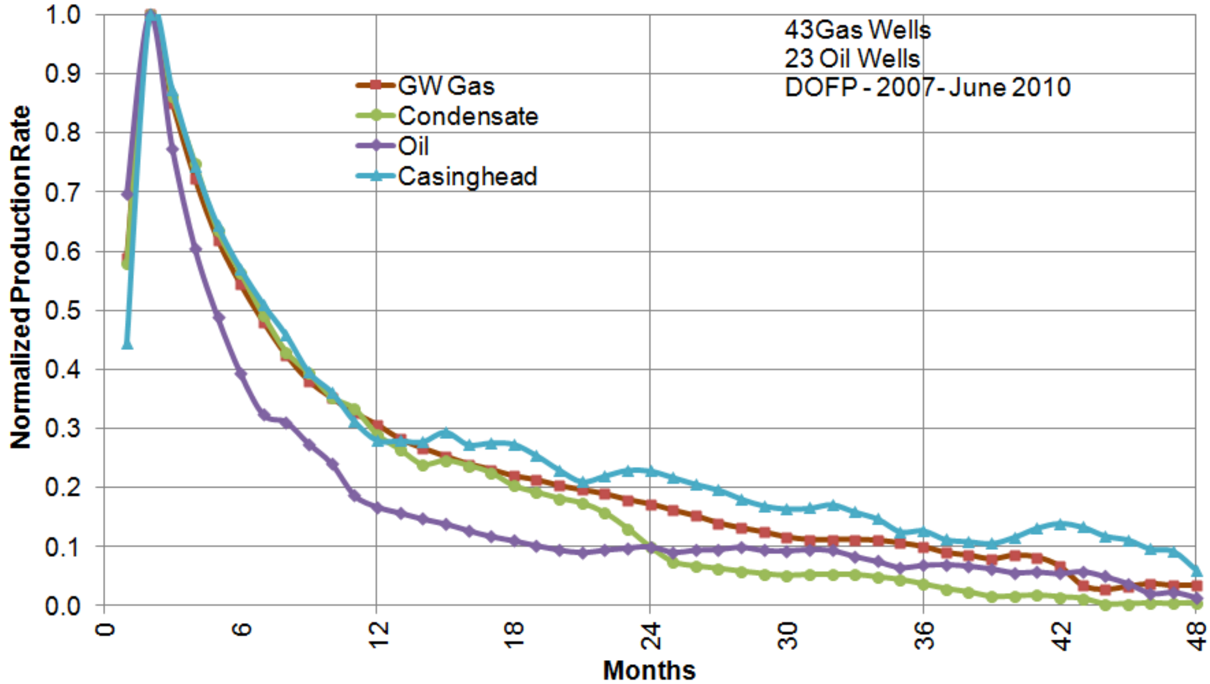


Figure 8-13: Normalized Eagle Ford Decline Curves by DOFP

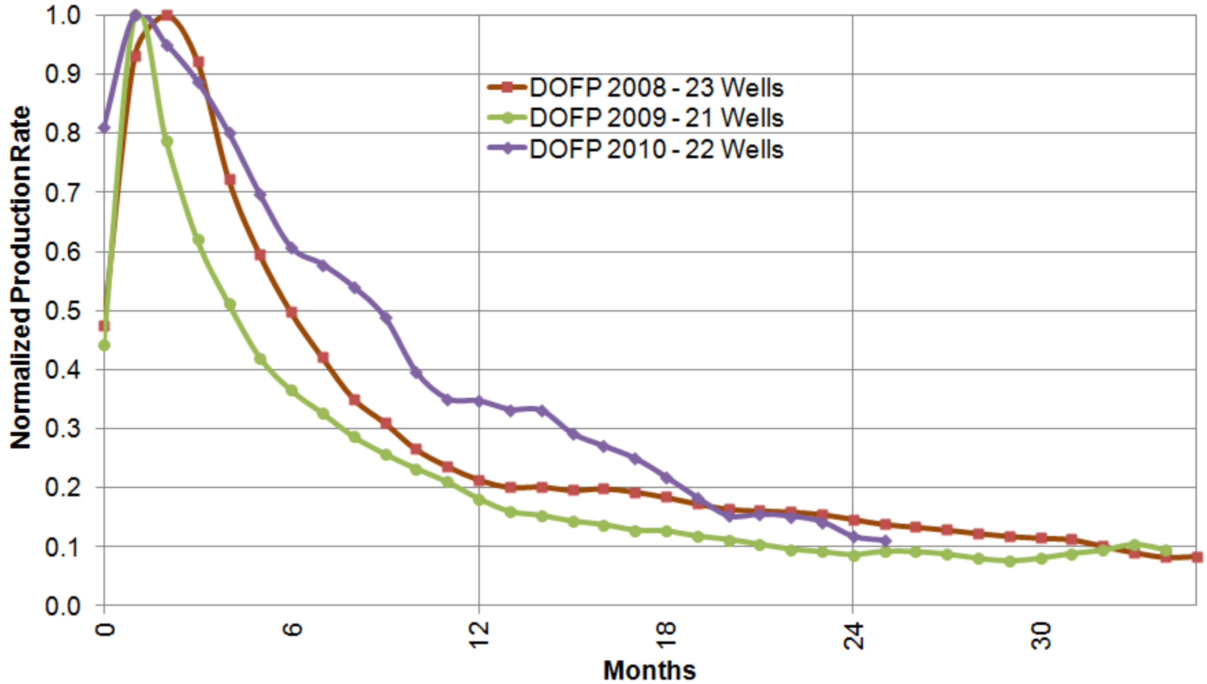
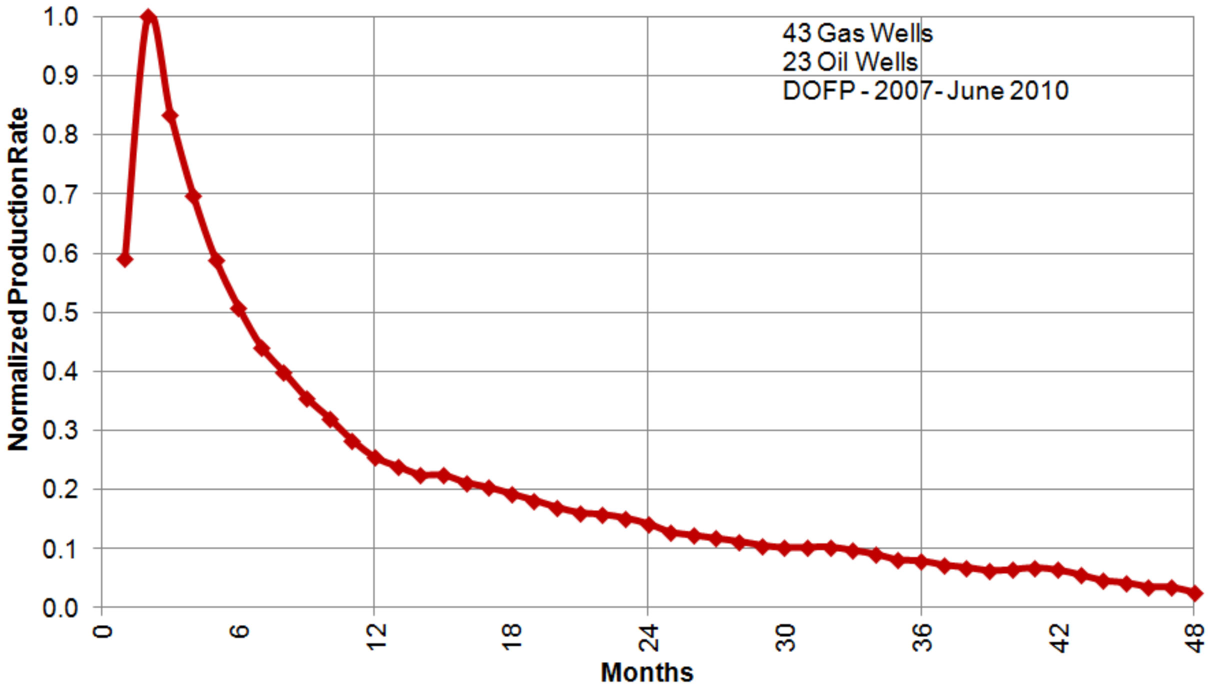


Figure 8-14: Average Normalized Eagle Ford Decline Curve



The calculated normalized decline curve for Eagle Ford wells in the first year of production is not as steep as compared to other studies: 64% calculated for Eagle Ford wells compared to a 69% average from other studies. However, the decline curve is more rapid in the following years. For example the decline curve is 47% in year 2 and 48% in year 3, while other studies had an average of only 31% and 21%. Once the well has been in production for 3 to 4 years, most of the product has been removed from the well and future production is minimal.

Decline curves can vary across the Eagle Ford depending on the region; however there was not enough information to develop a representative decline curve for each Eagle Ford field or region. Production data will be continually collect in the Eagle Ford to improve production forecasts and the decline curve will be updated when more recent production data is available from the Railroad Commission of Texas.

8.4.4 Production Projections

There can be significant time delayed between when a well is drilled and when the well starts to produce. Of the 3,646 wells drilled from 2008 to 2011, there were only 1,403 producing wells between 2004 and August 2011 according the Railroad Commission of Texas.[455] " In fact, Eagle Ford drilling is moving faster than completion services (pressure pumping, etc.) can keep up. The number of non-completed wells may be more than 1,600 wells at the beginning of April 2012. "It does seem to be getting better as frac crews are moving into the Eagle Ford from other plays where activity has been falling off."[456]

[455] Railroad Commission of Texas. April, 3, 2012. "Eagle Ford Information: Currently 20 Fields". Available online: http://www.rrc.state.tx.us/eagleford/EagleFord_Fields_and_Counties_201203.xls. Accessed 05/08/2012.
[456] Rusty Braziel, April 4, 2012. "Fly Like an Eagle Ford. Production headed toward 1.5 MMb/d. Could there be more?". RBN Energy LLC. Available online: http://www.rbnenergy.com/Fly-Like-an-Eagle-Ford. Accessed 05/11/2012.

According to RT Dukes, drilling has raced ahead of completions by 4-6 months.[457] Of the 895 wells drilled in 2010, the Railroad Commission of Texas reported that 417 wells had not started producing. To account for the delay between spud and production, a factor of 33 percent was applied to the first calendar year of production while 33% were allocated to each year afterwards.

As mentioned, the U.S. Energy Information Administration estimated 30 percent of production occurs within the 1st year.[458] However, in the analysis of the 66 wells that were used to develop the decline in the Eagle Ford, 50.7 percent of estimated total production occurred in the first year. To estimate production in the first year, 40% of EUR was used (Table 8-10). Producers in the Eagle Ford are expected to concentrate efforts on the liquid portion of the play including increased drilling for condensate instead of natural gas.

Table 8-10: Inputs for the Three Projection Scenarios

Factor	Low Development	Moderate Development	Aggressive Development
Number of New drill rigs per year	-10	10	20
Maximum number of Drill Rigs	-	245	350
Drill Rig Spud to Spud time (Days)	25	25	25
Percent of new wells that go into production per year	33%	33%	33%
Oil EUR per well (bbl)	150,000	150,000	150,000
Casinghead Gas EUR per well (MCF)	50,000	50,000	50,000
Condensate EUR per well (bbl)	75,000	75,000	75,000
Natural Gas EUR per well (MCF)	1,000,000	1,000,000	1,000,000
Amount of EUR produced in the first year	40%	40%	40%
Annual Growth in EUR per Well	0%	5%	10%
Annual Decrease in Natural Gas Wells	20%	15%	15%
Annual increase in Condensate Production per Well	5%	5%	5%
Annual increase in Natural Gas Production per Well	-5%	-5%	-5%
Annual Increase in Mid Stream Sources	5%	10%	15%

Estimate 2012-2018 production of oil, casinghead, condensate, and natural gas in the Eagle Ford will be calculated using the following formula.

Equation 8-4, Estimate production by age of oil or gas wells

$$PPROJ_{AC} = PWELL_{AC} \times [EUR_{Total} \times (1 + GROW_A)] \times EUR_{First.Year} (1 - DECLINE_A) \times (1 + CON_A)$$

Where,

$PPROJ_{AC}$ = Projected production in Year A for Eagle Ford development well type C

$PWELL_{AC}$ = Number of Eagle Ford development well type C in Year A (from Table 8-6)

EUR_{Total} = Total EUR for Eagle Ford development well type C, 150,000 bbl per oil well, 50,000 MCF for casinghead gas, 75,000 bbl for condensate for gas wells, or 1,000,000 MCF for gas wells in 2011, Table 8-8

[457] RT Dukes, Eagle Ford Shale News, Marketplace, jobs, June 6, 2012. "1,500 Eagle Ford Wells Waiting to Be Completed". Available online: http://www.eaglefordshale.com/news/1500-eagle-ford-wells-waiting-to-be-completed/#more-1731. Accessed 06/08/2012.

[458] U.S. Energy Information Administration, July 2011. "Review of Emerging Resources: U.S. Shale Gas and Shale Oil Plays". p. 32. Available online: http://www.eia.gov/analysis/studies/usshalegas/pdf/usshaleplays.pdf. Accessed 05/07/2012.

$GROW_A$ = Growth in EUR in year A due to improvements in technology, 0% for low development, 5 percent for moderate growth, 10% for aggressive development

$EUR_{First.Year}$ = Percentage of EUR is produced in first year of production, 0.40 (average between 30% from EIA and 50.7% from actual Eagle Ford production data)

$DECLINE_A$ = Percentage of decline from decline curve in year A of production, Table 8-9 (calculated using local data from Railroad Commission of Texas production data)

CON_A = Factor to account of the percent increase in condensate production from gas wells per year, 0 percent for oil, 0 percent for casinghead gas, 5 percent increase per year for condensate, and 5 percent decrease per year for Natural Gas after 2011

Sample Equation, 2012 Oil production from Eagle Ford oil wells in the second year of production under moderate development scenario

$$PPROJ_{ABC} = 2{,}661 \text{ wells} \times [150{,}000 \text{ bbl EUR} \times (1 + 0.05)] \times 0.40 \times (1 - 0.64) \times (1 + 0.0)$$
$$= 61{,}011{,}696 \text{ bbl}$$

Sample Equation, 2012 Casinghead gas production from Eagle Ford oil wells in the second year of production under moderate development scenario

$$PPROJ_{ABC} = 2{,}661 \text{ wells} \times [50{,}000 \text{ MCF EUR} \times (1 + 0.05)] \times 0.40 \times (1 - 0.64) \times (1 + 0.0)$$
$$= 20{,}337{,}232 \text{ MCF}$$

Sample Equation, 2012 Condensate production from Eagle Ford natural gas wells in the second year of production under moderate development scenario

$$PPROJ_{ABC} = 919 \text{ wells} \times [75{,}000 \text{ bbl EUR} \times (1 + 0.05)] \times 0.40 \times (1 - 0.64) \times (1 + 0.05)$$
$$= 11{,}062{,}413 \text{ bbl}$$

Sample Equation, 2012 Natural gas production from Eagle Ford natural gas wells in the second year of production under moderate development scenario

$$PPROJ_{ABC} = 919 \text{ wells} \times [1{,}000{,}000 \text{ MCF EUR} \times (1 + 0.05)] \times 0.40 \times (1 - 0.64) \times (1 + -0.05)$$
$$= 133{,}451{,}333 \text{ MCF}$$

A detailed production projection table by well year and production year is provided in Appendix F. Production projections for each product are calculated using Equation 8-5.

Equation 8-5, Production projection for each year

$$TPROD_{AC} = (\Sigma\ PPROJ_{AC} \times PROD_{Factor})$$

Where,

$TPROD_{AC}$ = Total Production for Year A for Eagle Ford development well type C

$PPROJ_{AC}$ = Projected production in Year A for Eagle Ford development well type C

$PROD_{Factor}$ = Percentage of production occurring in each year, 0.33

Sample Equation, 2013 Oil production from Eagle Ford oil wells under the moderate projection scenario

$$PPROJ_{ABC} = (548{,}205 \text{ bbl} \times 0.33) + (176{,}066 \text{ bbl} \times 0.33) + (144{,}103 \text{ bbl} \times 0.33) + (753{,}450 \text{ bbl} \times 0.33) + (388{,}055 \text{ bbl} \times 0.33) + (124{,}631 \text{ bbl} \times 0.33) + (7{,}360{,}148 \text{ bbl} \times 0.33) + (4{,}030{,}358 \text{ bbl} \times 0.33) + (2{,}075{,}788 \text{ bbl} \times 0.33) + (76{,}270{,}086 \text{ bbl} \times 0.33) + (27{,}496{,}814 \text{ bbl} \times 0.33) + (15{,}057{,}037 \text{ bbl} \times 0.33)$$

+ (169,232,959 bbl x 0.33) + (61,011,696 bbl x 0.33) + (0 bbl x 0.33) +
(186,476,205 bbl x 0.33) + (0 bbl x 0.33) + (0 bbl x 0.33) +
= 183,715,201 bbl of oil produced in 2013

Under the low development scenario, 259 MMbbl BOE is projected to be produced by Eagle Ford wells in 2018 (Table 8-11). It is projected that 499 MMbbl BOE will be produced under the moderate development scenario and 834 MMbbl BOE under the aggressive development scenario. In all three scenarios there will be a gradual decline in natural gas production after 2015 after reaching a peak between 520 and 580 BCF (Figure 8-15). Similar to Natural gas, it is projected that Condensate will slow start to decline after 2015 under each scenario (Figure 8-16). Oil production from Eagle Ford is projected to increase rapidly to 411 MMbbl under the moderate development and 731 MMbbl under the aggressive development (Figure 8-17). Production is expected to increase under the low scenario until at least 2013 even though the projected number of drill rigs operating in the shale is decreasing. This is similar to observations in the Barnett Shale where the number of drill rigs has decreased, but production of natural gas is increasing as existing wells are brought into production and the remaining rigs are drilling new wells.

Projected total oil production was between 1,438 MMbbl to 3,100 MMbbl from 2008 to 2018, while natural gas production was 3,516 BCF to 4,920 BCF. These totals are less then estimated total recoverable resources in the Eagle Ford including Toreador Resources Corporation estimation of 3.4 Billion bbls of oil and 20.8 TCF of gas in the Eagle Ford.[459] Energy Policy Research Foundation estimates that the recoverable liquids range from three to seven billion barrels in the Eagle Ford.[460]

Projections of oil and gas production are similar to the results from other studies. According to Bentek, current Eagle Ford production is now over 500 Mb/d and is expected to be 1,500 Mb/d in 2016 or 547.5 MMbbl in 2016.[461] These results, and Citigroup estimation of 800 MMbbl from the Eagle Ford in 2018,[462] are similar to the aggressive development scenario. However they are about twice higher than Energy Policy Research Foundation estimation of 350 MMbbl in 2017[463] and three times higher than Wood Mackenzie Ltd estimation of 172 MMbbl in 2015[464].

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[459] Toreador Resources Corporation, August 10, 2011. "Toreador Resources Corporation Merger With ZaZa Energy LLC Creating a Resource-Focused E&P Company". Slide 15 of 31. Available online: http://www.zazaenergy.com/oil-gas-company.asp. Accessed: 04/06/2012.

[460] Lou Pugliaresi, President, Energy Policy Research Foundation, Feb 7, 2012. Building Blocks of the North American Petroleum Renaissance". Washington, DC. presented at JOGMEC Petroleum Seminar, Tokyo, Japan. Slide 45. Available online: http://oilgas-info.jogmec.go.jp/pdf/4/4597/1202_JOGMEC_Seminar01_Pugliaresi.pdf. Accessed: 04/16/2012.

[461] Rusty Braziel, April 4, 2012. "Fly Like an Eagle Ford. Production headed toward 1.5 MMb/d. Could there be more?". RBN Energy LLC. Available online: http://www.rbnenergy.com/Fly-Like-an-Eagle-Ford. Accessed 05/11/2012.

[462] Citigroup Global Markets, Feb 15. 2012. "Resurging North American Oil Production and the Death of the Peak Oil Hypothesis The United States' Long March Toward Energy Independence". p. 2. Available online: http://hourofthetime.com/1-LF/Death_Of_Peak_Oil.pdf. Accessed: 04/09/2012.

[463] Lou Pugliaresi, President, Energy Policy Research Foundation, Feb 7, 2012. Building Blocks of the North American Petroleum Renaissance". Washington, DC. presented at JOGMEC Petroleum Seminar, Tokyo, Japan. Slide 8. Available online: http://oilgas-info.jogmec.go.jp/pdf/4/4597/1202_JOGMEC_Seminar01_Pugliaresi.pdf. Accessed: 04/16/2012.

[464] Aaron Clark, Feb 1, 2012. "Eagle Ford Oil May Back Out Bakken Demand, Trafigura VP Says". Bloomberg. Available online: http://mobile.bloomberg.com/news/2012-02-01/eagle-ford-oil-may-back-out-bakken-demand-trafigura-vp-says-1-.html. Accessed: 04/13/2012.

Table 8-11: Summary of Production Projections for the Three Scenarios, 2008-2018

Year	Low Development					Moderate Development					Aggressive Development				
	Oil (MMbbl)	Casing-head (BCF)	Conden-sate (MMbbl)	Gas (BCF)	BOE (MMbbl)	Oil (MMbbl)	Casing-head (BCF)	Conden-sate (MMbbl)	Gas (BCF)	BOE (MMbbl)	Oil (MMbbl)	Casing-head (BCF)	Conden-sate (MMbbl)	Gas (BCF)	BOE (MMbbl)
2008	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0
2009	0	2	1	17	4	0	2	1	17	4	0	2	1	17	4
2010	4	3	7	105	28	4	3	7	105	28	4	3	7	105	28
2011	38	13	22	288	106	38	13	22	288	106	38	13	22	288	106
2012	101	34	34	443	207	103	34	35	455	212	107	36	36	461	217
2013	170	57	41	517	295	183	61	45	555	318	209	70	46	573	348
2014	223	74	40	472	339	259	86	47	543	393	334	111	50	577	477
2015	236	79	37	397	337	308	103	46	495	434	454	151	51	541	592
2016	233	78	32	320	317	346	115	44	434	460	562	187	50	488	691
2017	221	74	28	254	289	379	126	42	374	480	652	217	49	432	770
2018	204	68	24	201	259	409	136	39	321	499	727	242	47	380	834
Total	1,431	481	265	3,016	2,183	2,028	680	328	3,589	2,935	3,088	1,033	358	3,862	4,068

Figure 8-15: Annual Projected Gas Production in the Eagle Ford for the Three Scenarios

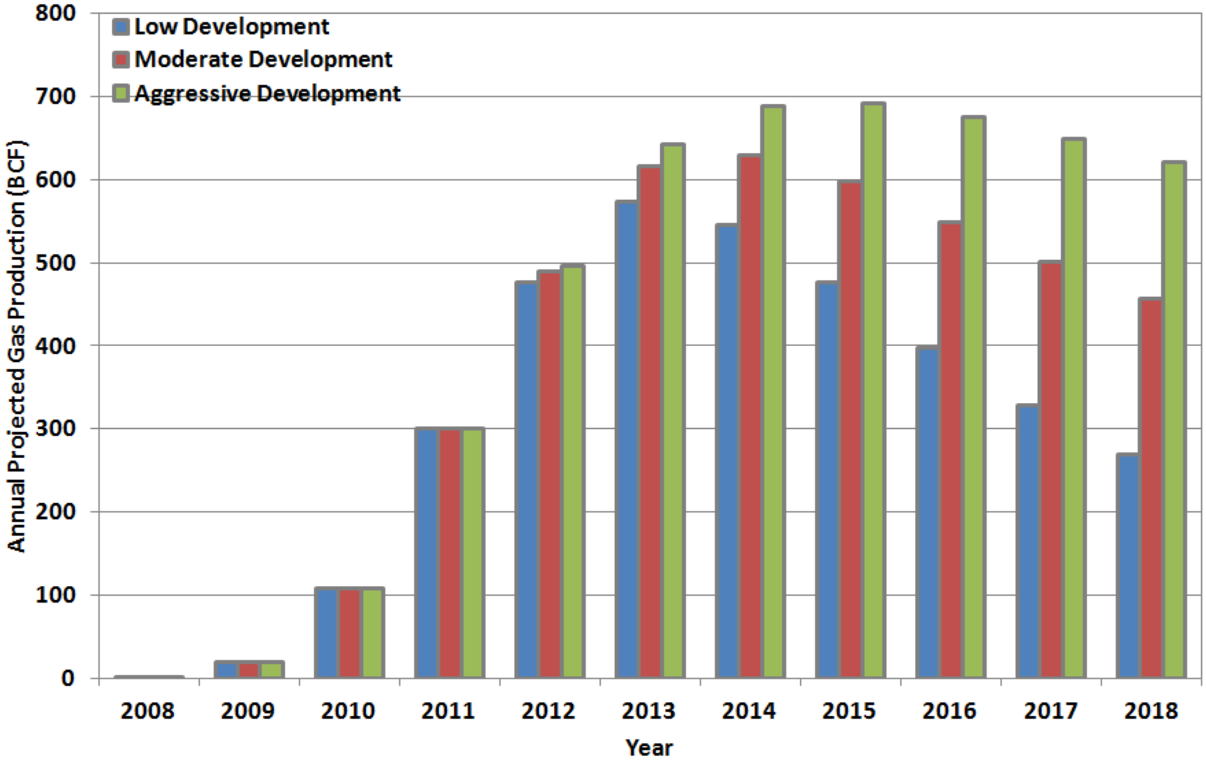


Figure 8-16: Annual Projected Condensate Production in the Eagle Ford for the Three Scenarios

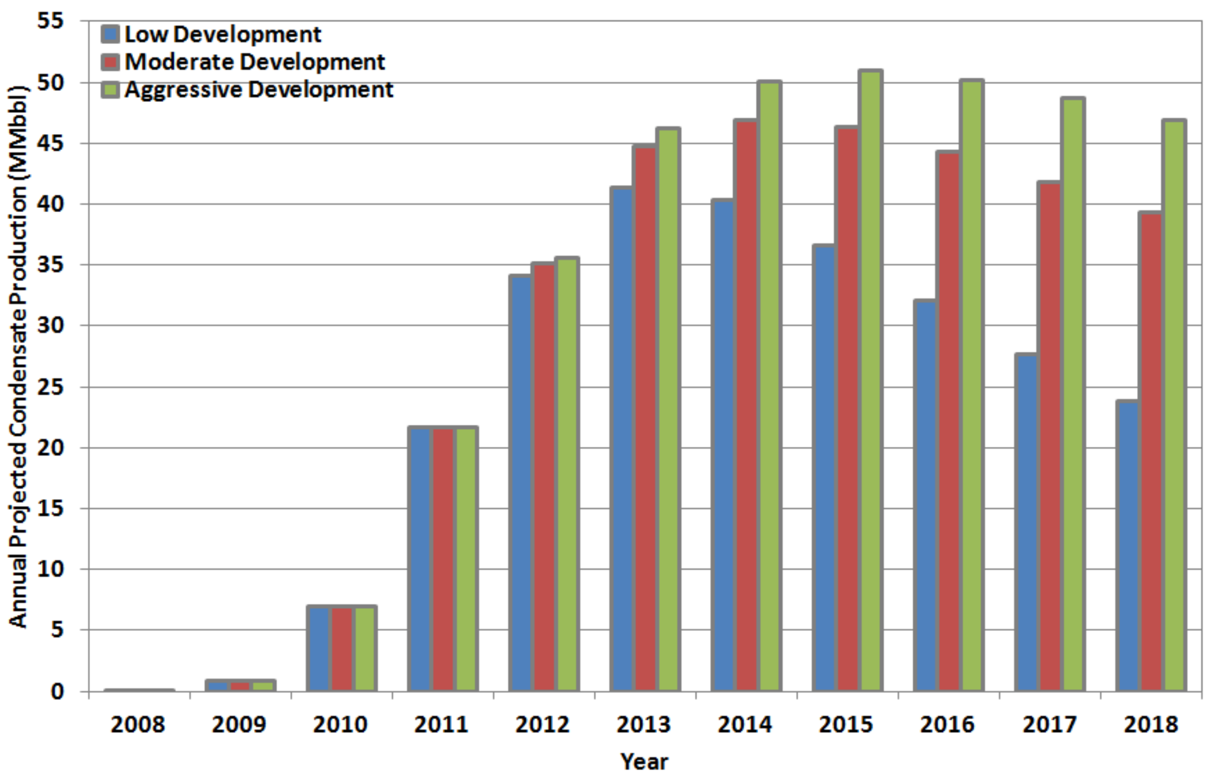
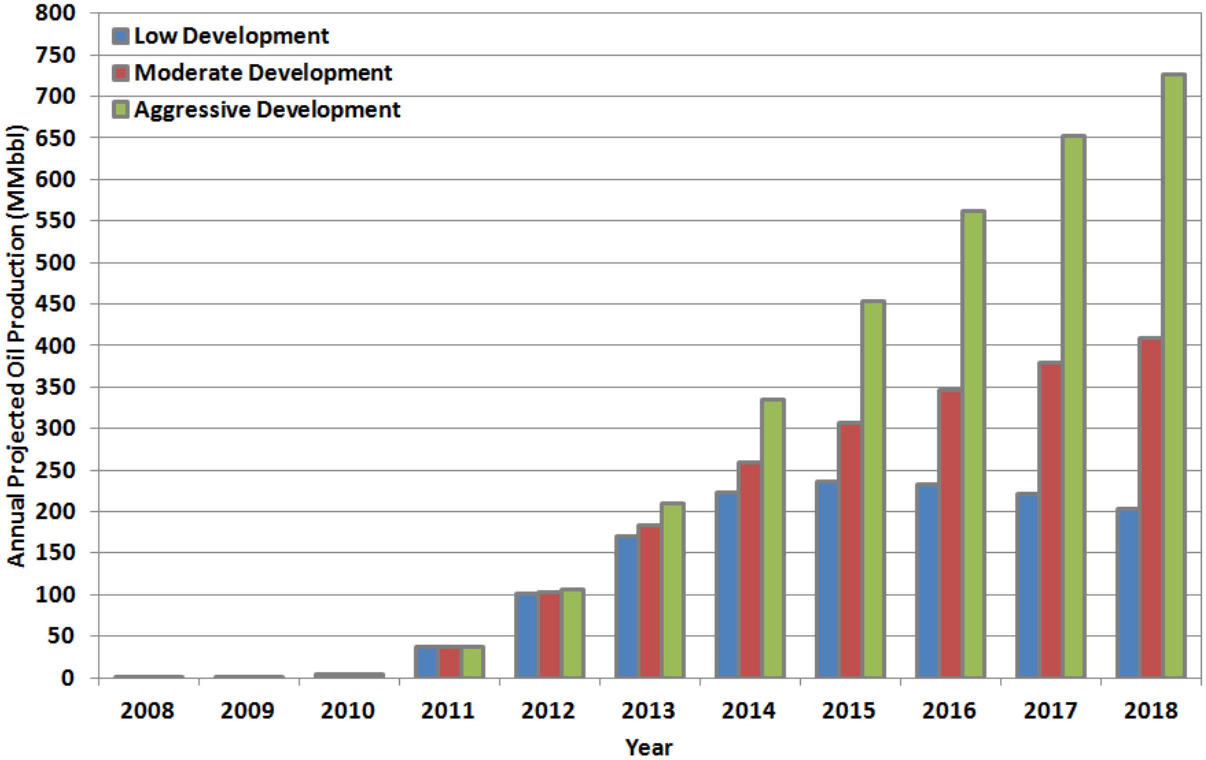


Figure 8-17: Annual Projected Oil Production in the Eagle Ford for the Three Scenarios



Pioneer Natural Resources estimate that Eagle Ford production will be approximately 1,250 MMBOE in 2020.[465] Although the calculated projections do not go out to 2020, the estimations from Pioneer are higher than the results from any of the scenarios. A Sanford C. Bernstein report in August estimated that Eagle Ford production will reach 1.2 million barrels of oil equivalent a day in 2015, with 750,000 of that being liquids.[466] Trevor Sloan, director of energy research at ITG Investment Research, estimates that production in the Eagle Ford could reach 1 million barrels a day by 2016.[467] This estimation matches closes with the moderate scenario. Future production estimates will be used to calculate emissions from oil and gas production in the Eagle Ford for 2015 and 2018 and projections will be updated as new data becomes available.

8.4.5 Production Emissions

Emissions from production will be based on the estimate number of total wells drilled (Table 8-7) and annual production totals (Table 8-11) under each scenario. Future emissions for each source will be calculated using the methodologies provided in chapter 6. Any state or federal mandated controls will be included in the projection scenarios.

[465] Feb 8, 2012. “Pioneer Natural Resources”. Credit Suisse 2012 Energy Summit. Slide 27. Available online: http://media.corporate-ir.net/media_files/irol/90/90959/2012-02-08_Credit_Suisse_Conference.pdf. Accessed: 04/13/2012.
[466] Edward Klump, Bloomberg News, March 23, 2012. “Crude-oil output soaring in South Texas' Eagle Ford Shale”. Star-Telegram. Available online: http://www.star-telegram.com/2012/03/23/3831777/crude-oil-output-soaring-in-south.html
[467] Vicki Vaughan, San Antonio Express News, May 17, 2012. “Eagle Ford Oil Levels Expected to Sore”. Available online: http://www.mysanantonio.com/news/local_news/article/Eagle-Ford-oil-levels-expected-to-soar-3564103.php. Accessed 06/05/2012.

8.4.6 On-Road Emissions

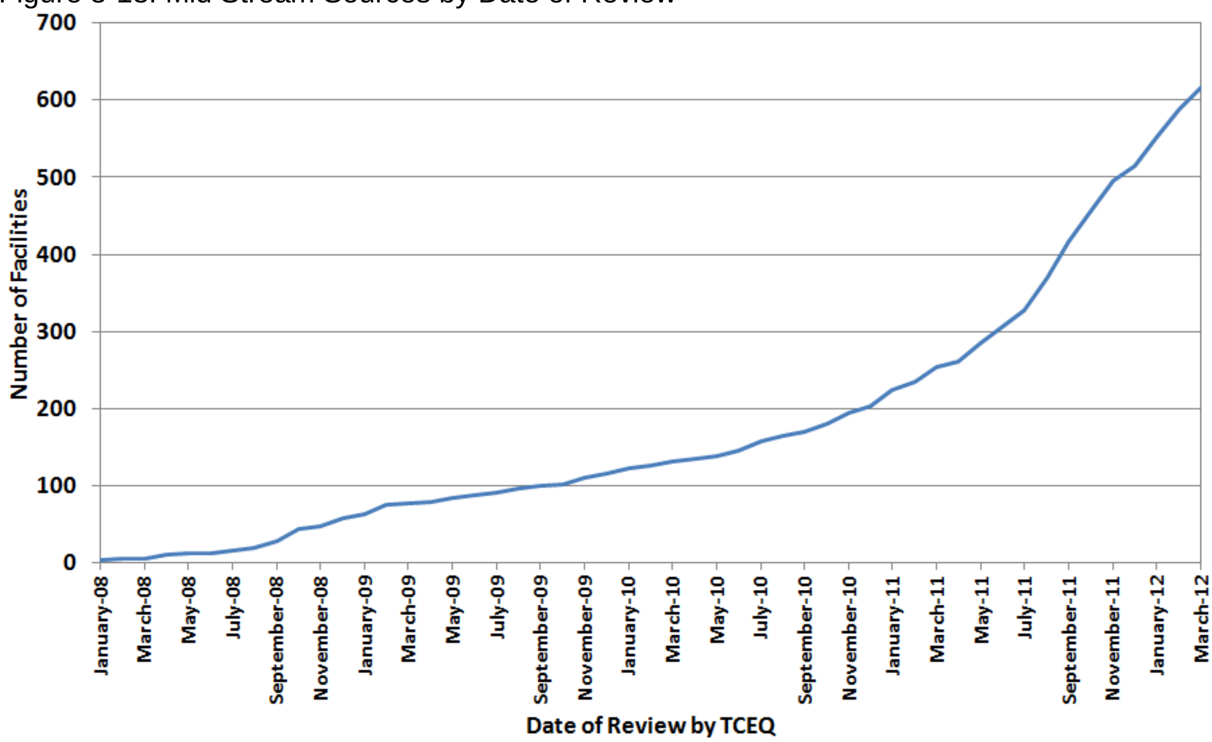
The number of truck trips will decrease over time due to steep decline curves at wells in the Eagle Ford. As the well ages, production will significantly decline and fewer truck visits will be needed for each well. It is estimated that on-road vehicle trips per well will decrease the same rate as the decline curve prepared in Figure 8-14 as the well ages and production decreases. Future development may include increasing the number of wells per well pad and the number of laterals per well. By increasing the production per well pad, and the addition of pipeline capacity, further reduction in on-road emissions could occur.

Vehicle speed, vehicle type, distance travelled, and idling hours per trip will remain the same during production for each projection year. The number of vehicles will be multiplied by future projections of wells drilled and emission factors developed from the MOVES model. Emission factors for on-road light duty and heavy duty trucks used in the oil industry are provided in Appendix B. All state or federal mandated controls, including rules incorporated in the MOVES model, will be included in the projection scenarios.

8.5 Mid-Stream Sources Projections

Midstream sources are expanding rapidly in the Eagle Ford and the facilities can be a significant source of ozone precursor emissions. RBC Energy "estimates that investments in gas processing, NGL transportation, fractionation, crude/condensate transportation, storage and terminaling will hit $6.5 billion over the next few years."[468] Figure 8-18 shows that there were 617 midstream oil and gas facilities permitted by TCEQ between 2008 and March 2012 in Eagle Ford counties.

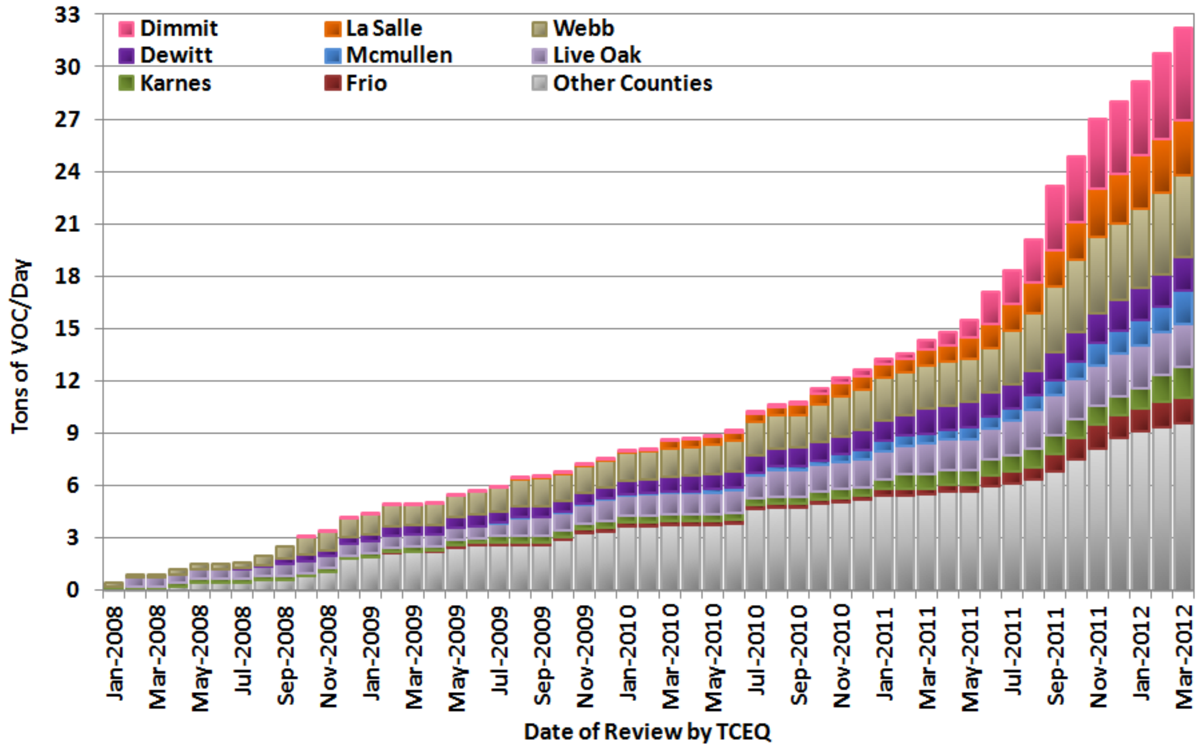
Figure 8-18: Mid Stream Sources by Date of Review



[468] Rusty Braziel, April 4, 2012. "Fly Like an Eagle Ford. Production headed toward 1.5 MMb/d. Could there be more?". RBN Energy LLC. Available online: http://www.rbnenergy.com/Fly-Like-an-Eagle-Ford. Accessed 05/11/2012.

Allowable VOC emissions from permitted facilities increased to 31.0 tons/day (Figure 8-19) and allowable NO_X emissions increased to 33.8 tons/day (Figure 8-20). From March 2010 to March 2012, the annual increase in the number of midstream sources was 177% while permitted VOC emissions increased 268% and permitted NO_X emissions increased 158%. The counties with the highest permitted emissions from midstream sources were Dimmit, La Salle, and Webb counties.

Figure 8-19: Mid Stream Sources NO_X emissions by County and Date of Review by TCEQ



Future projection of midstream sources will be based on the emission calculation methodology provided in Section 7. Midstream source emission factors will be based on the Barnett Shale special inventory and TCEQ permit database. For each midstream facility, it is estimated that it takes 9 months from when the facility is permitted to when the facility starts operating. Projections will be based on 3 scenarios with a 5% increase in midstream source emissions under low development, 10% under moderate development and 15% under aggressive development.

Draft VOC and NO_X emissions projections under each scenario are presented in Table 8-12, and shown in Figure 8-21 and Figure 8-22. Under the low development scenario, emissions from midstream sources increase to 55 tons/day of VOC and 29 tons/day of NO_X by 2012. For the high development scenario, total emissions are projected to be 91 tons of VOC and 52 tons of NO_X.

Figure 8-20: Mid Stream Sources VOC emissions by County and Date of Review by TCEQ

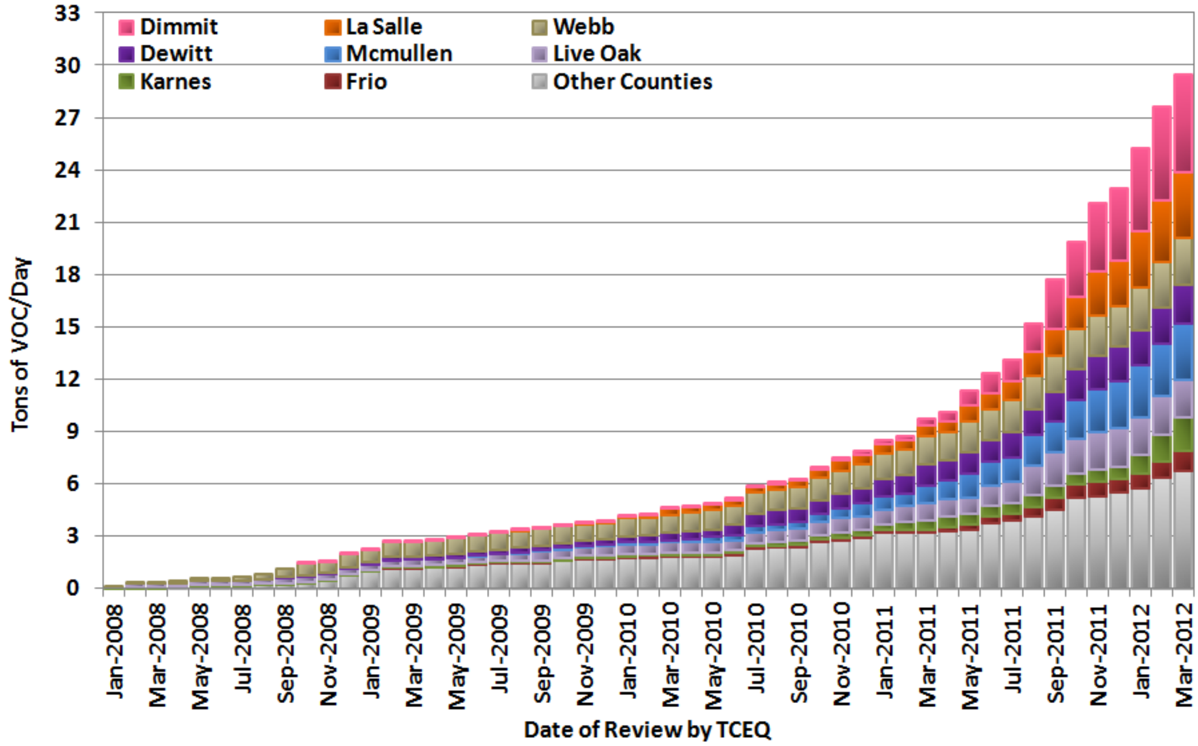


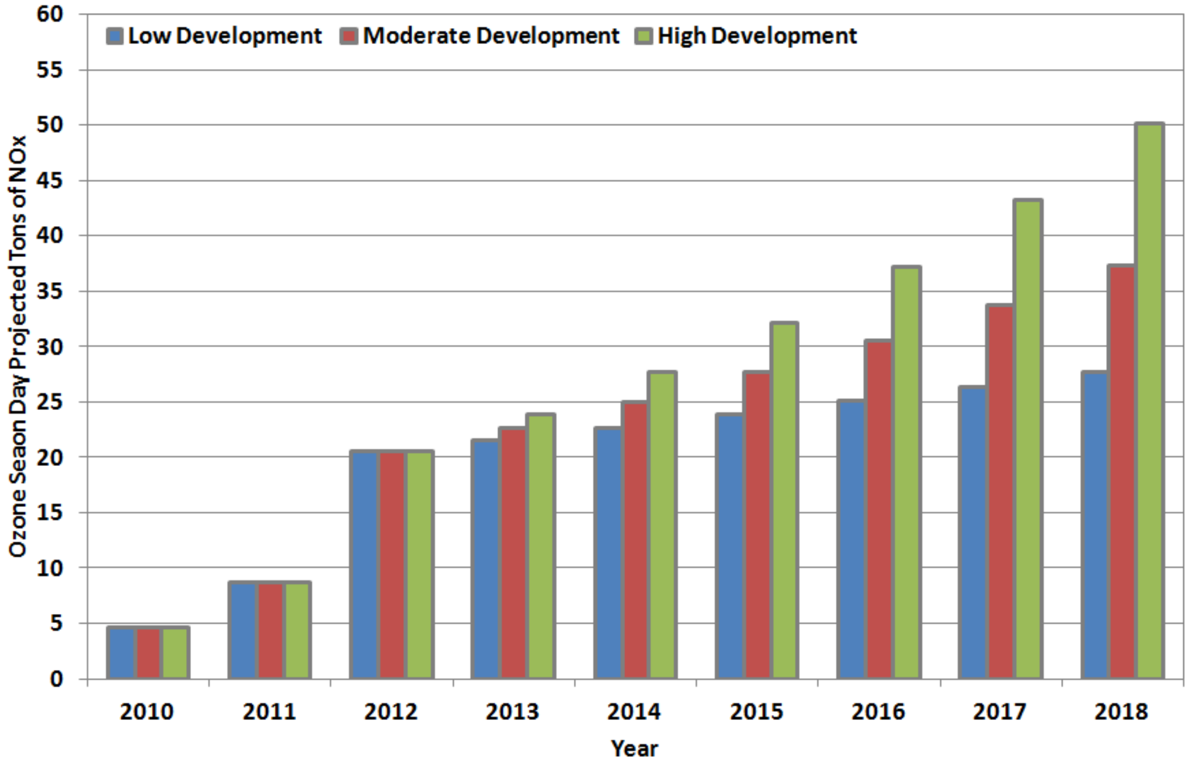
Table 8-12: Draft Ozone Season Projected NO_X and VOC Emissions from Mid-Stream Sources in Eagle Ford for the Three Scenarios

Year	Low Development			Moderate Development			High Development		
	Total VOC	Total NO_X	Total CO	Total VOC	Total NO_X	Total CO	Total VOC	Total NO_X	Total CO
2008	0	0	0	0	0	0	0	0	0
2009	2	4	4	2	4	4	2	4	4
2010	6	5	9	6	5	9	6	5	9
2011	12	9	14	12	9	14	12	9	14
2012	39	21	30	39	21	30	39	21	30
2013	46	23	35	48	24	36	50	25	38
2014	48	24	37	53	26	40	58	29	44
2015	50	25	38	58	29	44	67	33	51
2016	52	26	40	62	32	49	73	39	60
2017	54	28	42	66	35	54	82	45	69
2018	55	29	45	71	39	60	91	52	80

State and federal mandated controls will be included in the projection scenarios including EPA's "Proposed Amendments to Air Regulations for the Oil and Natural Gas Industry". EPA is "proposing to amend the existing NSPS for natural gas processing plants to strengthen the leak detection and repair requirements that apply to these plants to reduce VOC emissions." VOC emission limits for pneumatic controllers will be reduced for "new or replaced pneumatic controllers at gas processing plants, the proposed limits would eliminate VOC emissions". "For controllers used at other sites, such as compressor stations, the emission limits could be met by using controllers that emit no more than six cubic feet of gas per hour."[469]

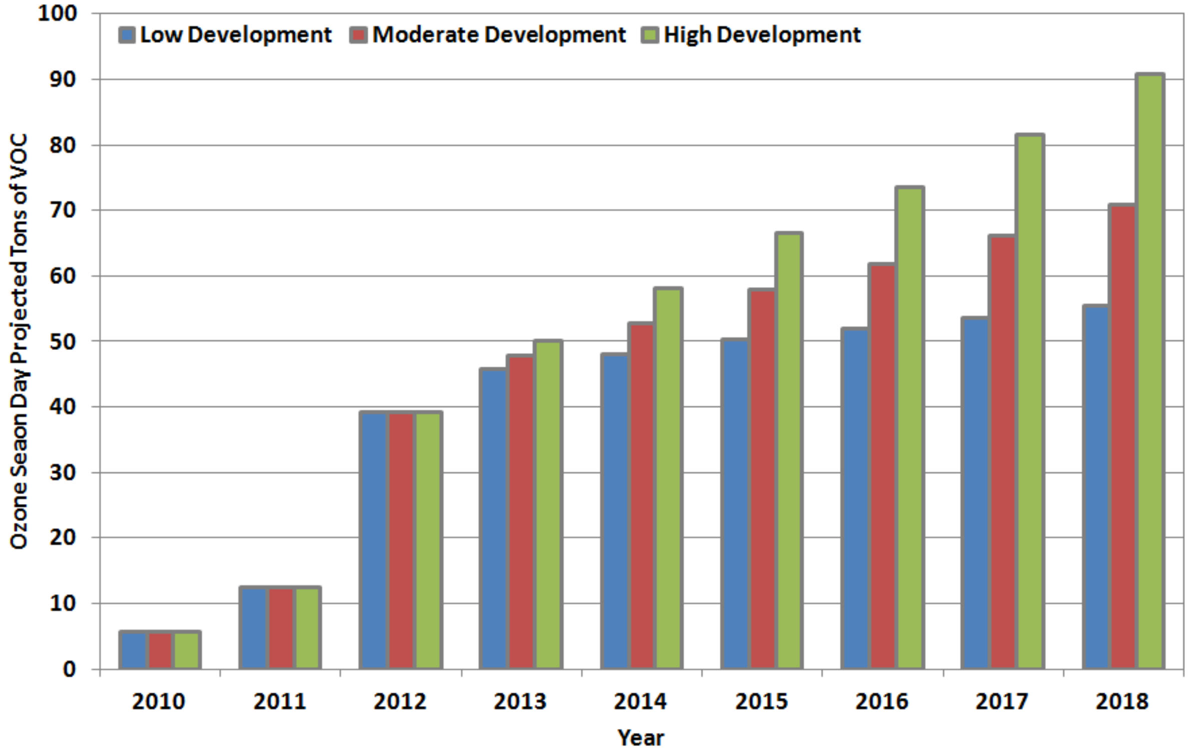
According to EPA's Proposed Amendments to Air Regulations for the Oil and Natural Gas Industry, "new storage tanks with VOC emissions of 6 tons a year or more must reduce VOC emissions by at least 95 percent" at natural gas well sites.[470] The average emission factor of mid-stream storage tanks from the Barnett Shale special inventory was 2.42 tons/year for crude storage tanks, 0.39 tons/year for produced water storage tanks, and 6.43 tons/year for condensate tank. Since many of the facilities are located near well sites, any storage tank that emits more than 6 tons/year will be reduced by 95 percent for all new projected mid-stream facilities built after 2014. Further research will be conducted to determine impacts from federal and state regulations on midstream emission sources.

Figure 8-21: Ozone Season Projected NO_X Emissions from Mid-Stream Sources in Eagle Ford for the Three Scenarios



[469] EPA. "Proposed Amendments to Air Regulations for the Oil and Natural Gas Industry: Fact Sheet". p. 4. Available online: http://www.epa.gov/airquality/oilandgas/pdfs/20110728factsheet.pdf. Accessed 04/13/2012.
[470] *Ibid*.

Figure 8-22: Ozone Season Projected VOC Emissions from Mid-Stream Sources in Eagle Ford for the Three Scenarios



9 MODELING INPUTS

Results from the Eagle Ford emission inventory for 2011, 2015, 2018 or other suitable years will be geo-coded to the 4km grid squares in the photochemical model. Photochemical modeling files, including afs and tmprl inputs, will be developed for all emission sources in the Eagle Ford.

9.1 Spatial Allocation of Emissions

Emissions will be geo-coded based on the locations of wells in each county. Development of input files for photochemical model emission processing will be based on a grid system consistent with EPA's Regional Planning Organizations (RPO) Lambert Conformal Conic map projection with the following parameters:

- First True Latitude (Alpha): 33°N
- Second True Latitude (Beta): 45°N
- Central Longitude (Gamma): 97°W
- Projection Origin: (97°W, 40°N)
- Spheroid: Perfect Sphere, Radius: 6,370 km

By geo-coding to these parameters, the results can be used for any future TCEQ photochemical model.

The location of producing oil and gas wells are displayed in Figure 9-1[471], while Figure 9-2 contains the locations of Eagle Ford disposal drilled in 2011[472]. The largest concentrations of oil wells are located in northern Karnes County and the far northern section of Live Oak County and southern section of Gonzales County. There are also oil wells located from Maverick County to southern Atascosa County. Natural gas wells are located in Webb County and Southern sections of Dimmit County, La Salle County, McMullen County, and Live Oak County. There are very few producing oil and gas wells in the northern section of the Eagle Ford. Disposal Wells in the Eagle Ford are concentrated in the highly productive regions of Karnes, Frio, Atascosa, Dimmit, and La Salle counties.

Pad construction, drilling operations, and hydraulic fracturing emissions will be geo-coded to the location of all permitted Eagle Ford wells. Emissions from natural gas production will be geo-coded to the location of natural gas wells in the Eagle Ford, while emissions from oil production will be geo-coded to the location of oil wells. Emission from condensate production will be geo-coded to natural gas wells located in the condensate window. Emissions from the pad construction and drilling of disposal wells will be allocated to the location of disposal wells. Future improvements can include geo-coding midstream facilities to improve the accuracy of the photochemical model.

[471] Railroad Commission of Texas, 2012. "Digital Map Information". Austin, Texas.
[472] *Ibid*.

DRAFT

Figure 9-1: Locations of Wells Drilled in the Eagle Ford Shale Play, 2012

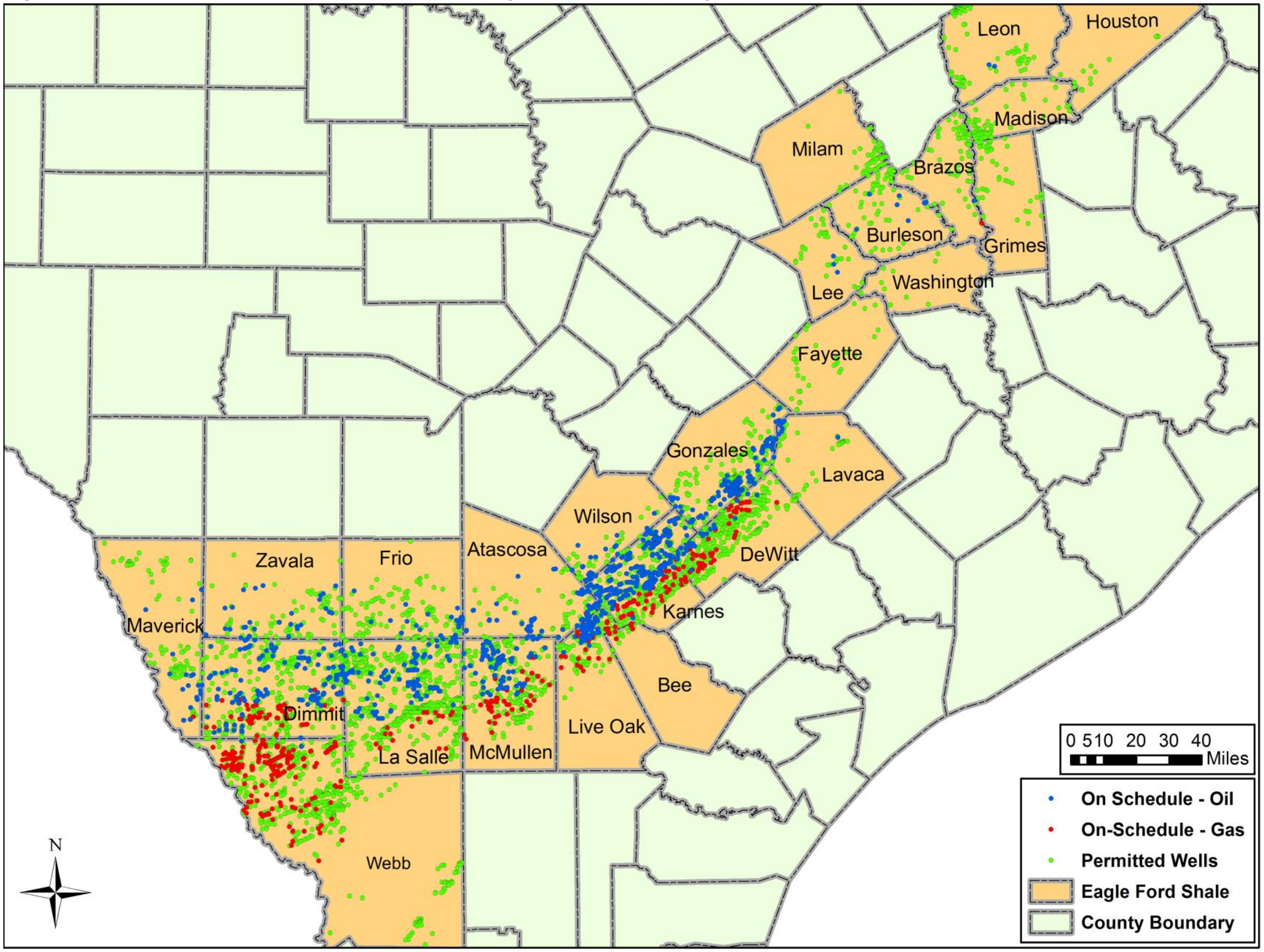
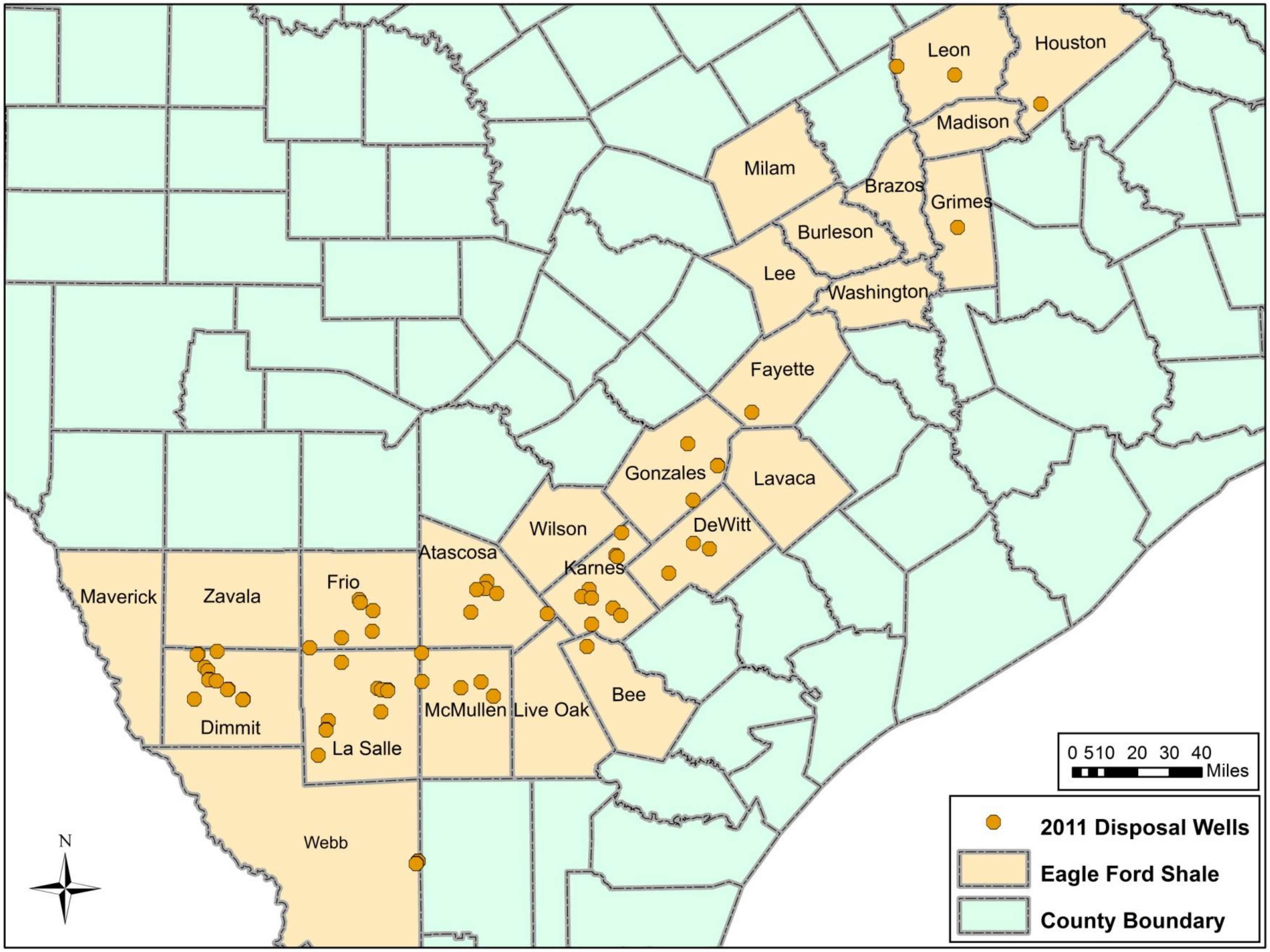


Figure 9-2: Locations of 2011 Disposal Wells in the Eagle Ford Shale Play



APPENDIX A: DRILL RIGS LOCATED IN THE EAGLE FORD

Contractor	Name	Rig Type	Draw Works			Generators/Engines			Mud Pumps			Light Plants		
			Num.	hp/each	Fuel	Num.	hp/each	Fuel	Num.	hp/each	Fuel	Num.	hp/each	Fuel
Patterson[473]	25	Electric				3	1,476	Diesel						
	229	Electric				3	1,476	Diesel						
	4	Mechanical				2	525	Diesel	2	1,000	Diesel	2	325	Diesel
	9	Electric				3	1,380	Diesel						
	11	Electric				3	1,380	Diesel						
	14	Electric				3	1,000	Diesel						
	36	Mechanical				2	525	Diesel	2	915	Diesel	2	525	Diesel
	50	Electric				3	1,476	Diesel						
	100	Electric				2	525	Diesel	2	1,476	Diesel	2	764, 530	Diesel
	135	Electric				3	1,512	Diesel						
	160	Electric				3	1,476	Diesel						
	173	Electric				3	1,750	Diesel						
	204	Electric				3	1,750	Diesel						
	211	Electric				3	1,750	Diesel						
	220	Electric				3	1,750	Diesel						
	221	Electric				3	1,750	Diesel						
	222	Electric				3	1,750	Diesel						
	226	Electric				3	1,750	Diesel						
	225	Electric				3	1,750	Diesel						
	229	Electric				3	1,750	Diesel						
	509	Electric				3	1,750	Diesel						
	518	Mechanical				2	525	Diesel	2	1,300	Diesel	2	325	Diesel
	520	Electric				3	1,476	Diesel						
	521	Mechanical				2	760	Diesel	2	1,300	Diesel	2	530	Diesel
	522	Mechanical				2	450	Diesel	2	1,000	Diesel	2	325	Diesel
	526	Mechanical				2	760	Diesel	2	915	Diesel	2	530	Diesel
	527	Mechanical				2	760	Diesel	2	1,000	Diesel	2	325	Diesel
	528	Mechanical				2	550	Diesel	4	1,000	Diesel	2	325	Diesel
	531	Mechanical				2	760	Diesel	2	1,300	Diesel	2	325	Diesel
	533	Mechanical				2	450	Diesel	2	1,000	Diesel	2	325	Diesel

[473] Patterson-UTI Drilling Company. “Rigs”. Available online: http://patdrilling.com/rigs. Accessed: 04/01/2012.

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	539	Electric				3	1,000	Diesel						
Lantern Drilling[474]	12	Mechanical	2	550	Diesel	2	515	Diesel	2	900, 1,100	Diesel			
	16	Electric				3	1,500	Diesel						
	17	Electric				3	1,500	Diesel						
Energy Drilling[475]	7	Mechanical	2	950	Diesel	2	626	Diesel	2	1,300	Diesel			
	9	Mechanical	2	830	Diesel	2	626	Diesel	2	936	Diesel			
	12	Mechanical	2	950	Diesel	2	626	Diesel	2	1,300	Diesel			
Ensign Energy[476]	150	Electric				3	1,800, 1,000	Diesel						
	730	Electric				4	1,500, 2,100	Diesel						
	751	Electric				4	1,200	Diesel						
	761	Electric				4	1,500	Diesel						
	766	Electric				4	1,500	Diesel						
	767	Electric				4	1,500	Diesel						
	768	Electric				4	1,500	Diesel						
	786	Electric				4	1,500	Diesel						
	735	Electric				4	1,200	Diesel						
	763	Electric				4	1,500	Diesel						
	754	Electric				4	1,200	Diesel						
Unison Drilling[477]	2	Mechanical	1	450	Diesel	2	300	Diesel	2	550	Diesel			
	4	Mechanical	1	475	Diesel	2	475	Diesel	2	450	Diesel			
	5	Mechanical	2	475	Diesel	2	300	Diesel	2	1,200	Diesel			
	6	Mechanical	2	325	Diesel	2	350	Diesel	2	1,000	Diesel			
	7	Mechanical	2	540	Diesel	2	540	Diesel	2	1,000	Diesel			
Pioneer Drilling[478]	1	Electric				2	1,215	Diesel						
	2	Electric				2	1,215	Diesel						
	4	Electric				3	1,500	Diesel						
	7	Electric				3	1,500	Diesel						

474 Lantern Drilling, Rigs. Available online: http://lanterndrilling.com/index.cfm/ID/2/Rigs/. Accessed: 04/01/2012.
475 Energy Drilling Company. "Rig Fleet". Available online: http://www.energydrilling.com/index.php?option=com_content&view=article&id=61&Itemid=57. Accessed: 04/01/2012.
476 Ensign Energy Service Inc. "Ensign RigFinder", Available online: http://www.ensignenergy.com/_layouts/ensign.rigfinder/rigfinder.aspx. Accessed: 2/8/2012.
477 Unison Drilling Inc. "Rig List". Available online: http://www.unisondrilling.com/riglist.html. Accessed: 04/09/2012.
478 Pioneer Drilling Company. "Rig Fleet". Available online: http://www.pioneerdrlg.com/rig-fleet.aspx?id=1. Accessed: 04/09/2012.

	8	Electric				3	1,500	Diesel						
	12	Mechanical				4	515, 475	Diesel	2	1,000	Diesel			
	15	Mechanical				4	515, 475	Diesel	2	1,000	Diesel			
	24	Electric				3	1,500	Diesel						
	25	Electric				3	1,500	Diesel						
	26	Electric				3	1,500	Diesel						
	27	Mechanical				4	515, 575	Diesel	2	1,300	Diesel			
	28	Electric				3	1,215	Diesel						
	31	Mechanical				4	515, 475	Diesel	2	1,000	Diesel			
	45	Mechanical				4	515	Diesel	2	1,300	Diesel			
	58	Electric				3	1,500	Diesel						
	62	Electric				2	1,500	Diesel						
Trinidad[479]	52	Electric				3	1,500	Diesel						
	100	Electric				3	1,500	Diesel						
	103	Electric				3	1,500	Diesel						
	106	Electric				3	1,500	Diesel						
	107	Electric				3	1,500	Diesel						
	109	Electric				3	1,500	Diesel						
	110	Electric				3	760	Diesel						
	112	Electric				3	1,500	Diesel						
	117	Electric				3	1,500	Diesel						
	120	Electric				3	1,500	Diesel						
	121	Electric				3	1,500	Diesel						
	128	Electric				3	1,500	Diesel						
	137	Electric				3	1,500	Diesel						
	138	Electric				3	1,500	Diesel						
	139	Electric				3	1,500	Diesel						
	222	Electric				3	1,500	Diesel						
Big E Drilling Co.[480]	1	Electric				3	1,500	Diesel						
	2	Electric				3	1,500	Diesel						
	4	Electric				4	1,500	Diesel						
	5	Electric				4	1,500	Diesel						

[479] Trinidad Drilling. "Rig Fleet". Available online: http://www.trinidaddrilling.com/Services/RigFleet.aspx. Accessed: 04/10/2012.
[480] Big E Drilling Company. "Rig Specifications and Information". Available online: http://www.bigedrilling.com/bige/our-rigs/items/Rig_4.html. Accessed: 04/10/2012.

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	6	Electric				4	760	Diesel						
Justiss Oil Co.[481]	56	Mechanical	2	550	Diesel	2	515	Diesel	2	1,000	Diesel			
Keen Drilling[482]	22	Electric				3	1,500	Diesel						
Scan Drilling[483]	Eagle	Electric				3	1,365	Diesel						
	Freedom	Electric				3	1,215	Diesel						
	Glory	Electric				3	1,215	Diesel						
	Texas	Electric				3	1,215	Diesel						
Savana Drilling[484]	439	Electric				2	630	Diesel						
Unit[485]	38	Electric				3	1,215	Diesel						
	203	Electric				4	1,215	Diesel						
	325	Electric				3	1,500	Diesel						
	324	Electric				3	1,500	Diesel						
Wisco Moran[486]	Rig-5	Mechanical				2	540	Diesel	1	1,215	Diesel			

[481] Justiss Oil Company, Inc. “Drilling Rigs”. Available online: http://justissoil.com/MyWebs5/drilling_rigs.htm. Accessed: 04/01/2012
[482] KeenEnergy Services. “Rigs”. Available online: http://keenenergyservices.com.dnnmax.com/Rigs.aspx. Accessed: 04/10/2012
[483] Scandrill Inc. “Rig Specifications”. Available online: http://www.scandrill.com/rig-specifications.htm. Accessed: 04/13/2012.
[484] Savana Energy Service Corp. “Savana US Drilling Rigs”. Available online: http://www.savannaenergy.com/default.asp?id=104. Accessed: 04/13/2012
[485] Unit Corporation, Golf Coast Division. Available online: http://www.unitcorp.com/houston.html. Accessed: 04/13/2012.
[486] Wisco Moran Drilling Co. “Rigs”. Available online: http://www.wiscomoran.com/rig-5.htm. Accessed: 04/13/2012.

APPENDIX B: MOVES ON-ROAD EMISSION FACTORS, EAGLE FORD

Type	Vehicle	Fuel Type	Year	VOC (g/mile)	NO_X (g/mile)	CO (g/mile)
Light Duty Vehicle (35 mph)	Passenger Trucks	Gasoline	2011	0.26	1.15	9.37
			2015	0.18	0.82	7.38
			2018	0.13	0.64	6.32
		Diesel	2011	0.50	4.32	3.21
			2015	0.29	2.85	2.19
			2018	0.20	2.15	1.79
	Light Commercial Trucks	Gasoline	2011	0.28	1.25	9.60
			2015	0.20	0.92	7.66
			2018	0.15	0.75	6.66
		Diesel	2011	0.63	5.07	3.91
			2015	0.41	3.60	2.80
			2018	0.29	2.76	2.23
	Average Light Duty Vehicle	Gasoline and Diesel	2011	0.28	1.33	9.18
			2015	0.19	0.95	7.23
			2018	0.14	0.75	6.21
Heavy Duty Vehicle (35 mph)	Combination Short Haul Trucks	Diesel	2011	0.51	10.10	2.75
			2015	0.30	5.98	1.68
			2018	0.19	3.95	1.11

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APPENDIX C: EAGLE FORD COMPRESSOR STATIONS, PRODUCTION FACTITIES, AND SALTWATER DISPOSAL FACILITIES IN THE AACOG REGION, 2008-2012.

County	Permit Number	Company Name	Site/Area Name	Point Source	Parameter	Heater/ Boiler	Glycol Dehydration	Amine Unit	Compressor Engine	Pumps	Gas Cooler Engine	Crude Storage Tanks	Produced Water Storage Tanks	Condensate Tank	Oil Loading Facility	Produced Water Loading Facility	Condensate Loading	Flare/ Combustor	Fugitives	Other	Total
Atascosa	99767	Marathon Oil EF LLC	74 Ranch Central Tank Battery	No	Pop	4	2	-	5	-	-	-	2	-	-	1	-	2	1	-	16
					VOC	0.09	3.61	-	10.60	-	-	-	-	-	-	1.09	-	2.58	3.35	-	21.32
					NOx	1.49	1.85	-	23.33	-	-	-	-	-	-	-	-	0.61	-	-	27.28
					CO	1.26	1.54	-	9.54	-	-	-	-	-	-	-	-	1.22	-	-	13.56
Atascosa	89093	Regency Field Services, LLC	Atascosa Interconnect	No	Pop	3	1	-	1	-	-	-	-	3	-	-	1	-	1	-	9
					VOC	0.06	3.67	-	0.20	-	-	-	-	12.27	-	-	7.70	-	0.66	-	24.56
					NOx	0.99	0.22	-	3.92	-	-	-	-	-	-	-	-	-	-	-	5.13
					CO	0.84	0.19	-	5.88	-	-	-	-	-	-	-	-	-	-	-	6.91
Atascosa	99751	MARATHON OIL EF LLC	Central Excelsior Central Facility	No	Pop	1	2	-	5	-	-	-	-	-	-	1	1	2	1	1	12
					VOC	0.70	0.63	-	26.63	-	-	-	-	-	-	2.44	-	6.70	11.91	0.11	49.12
					NOx	1.50	0.21	-	23.33	-	-	-	-	-	-	-	-	1.30	-	-	26.34
					CO	1.26	0.18	-	11.40	-	-	-	-	-	-	-	-	2.08	-	-	14.92
Atascosa	84562	Bill H. Pearl Productions, Inc.	Coward Oil and Gas Production Facility	No	Pop	-	-	-	-	-	-	2	4	-	-	1	-	1	1	-	8
					VOC	-	-	-	-	-	-	1.96	2.61	-	-	-	-	0.83	3.25	-	8.65
					NOx	-	-	-	-	-	-	-	-	-	-	-	-	0.44	-	-	0.44
					CO	-	-	-	-	-	-	-	-	-	-	-	-	0.92	-	-	0.92
Atascosa	95719	El Paso E&P Company, LP	Davis-McCrary #1H Facility	No	Pop	1	-	-	1	-	-	4	1	-	-	1	1	1	-	-	9
					VOC	0.01	-	-	0.13	-	-	-	-	-	-	0.08	0.11	22.23	1.34	0.04	23.94
					NOx	0.20	-	-	5.91	-	-	-	-	-	-	-	-	3.79	-	-	9.90
					CO	0.17	-	-	10.51	-	-	-	-	-	-	-	-	7.56	-	-	18.24
Atascosa	98586	XTO Energy Inc.	Emma Tartt Pad	No	Pop	2	-	-	1	-	-	-	3	5	-	-	1	1	1	-	13
					VOC	0.05	-	-	0.42	-	-	-	0.03	5.05	-	-	2.97	6.92	3.39	-	18.83
					NOx	0.88	-	-	0.70	-	-	-	-	-	-	-	-	1.09	-	-	2.67
					CO	0.73	-	-	0.70	-	-	-	-	-	-	-	-	2.92	-	-	4.35
Atascosa	97826	Cinco Natural Resources Corporation	F Crain 1 Production Facility	No	Pop	1	-	-	-	-	-	-	1	5	-	1	1	1	1	-	10
					VOC	0.01	-	-	-	-	-	-	-	-	-	0.05	6.64	13.09	3.07	-	22.86
					NOx	0.11	-	-	-	-	-	-	-	-	-	-	-	4.71	-	-	4.82
					CO	0.09	-	-	-	-	-	-	-	-	-	-	-	9.43	-	-	9.52
Atascosa	72118	Regency Field Services LLC	Fashing Gas Treating Plant	Yes	Pop	1	1	1	5	-	-	-	1	2	-	1	1	1	1	1	14
					VOC	0.04	0.05	0.59	9.98	-	-	-	-	0.90	-	11.58	0.75	2.08	10.27	2.48	38.72
					NOx	0.77	0.86	6.57	94.52	-	-	-	-	-	-	-	-	5.73	-	-	108.45
					CO	0.65	0.73	4.38	90.96	-	-	-	-	-	-	-	-	3.82	-	-	100.54
Atascosa	98940	Marathon Oil Company	Flores 1H Production Facility	No	Pop	1	-	-	-	-	-	-	2	6	-	1	1	2	1	-	13
					VOC	0.01	-	-	-	-	-	-	-	-	-	-	3.60	10.26	2.08	-	15.95
					NOx	0.21	-	-	-	-	-	-	-	-	-	-	-	1.82	-	-	2.03
					CO	0.18	-	-	-	-	-	-	-	-	-	-	-	2.49	-	-	2.67
Atascosa	97996	Marathon Oil EF LLC	Heirholzer 1 Production Facility	No	Pop	2	1	-	1	-	-	-	1	5	-	1	1	1	1	-	13
					VOC	0.01	2.51	-	0.71	-	-	-	-	-	-	0.02	3.96	1.26	3.36	-	11.83
					NOx	0.22	0.09	-	3.92	-	-	-	-	-	-	-	-	0.25	-	-	4.48
					CO	0.18	0.07	-	7.84	-	-	-	-	-	-	-	-	0.50	-	-	8.59

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Atascosa	95939	EOG Resources, Inc.	Jack Rips Production Facility	No	Pop	1	-	-	-	-	-	1	2	-	1	1	-	1	1	-	7
					VOC	0.01	-	-	-	-	-	-	-	-	0.02	-	-	1.12	3.39	-	4.54
					NOx	0.22	-	-	-	-	-	-	-	-	-	-	-	0.22	-	-	0.44
					CO	0.18	-	-	-	-	-	-	-	-	-	-	-	0.83	-	-	1.01
Atascosa	97160	EOG Resources, Inc.	Jendrusch Barnes Production Facility	No	Pop	1	-	-	-	-	-	1	2	-	-	-	-	1	1	-	5
					VOC	0.02	-	-	-	-	-	-	-	-	-	0.63	-	4.63	4.93	-	10.21
					NOx	0.28	-	-	-	-	-	-	-	-	-	-	-	0.85	-	-	1.13
					CO	0.34	-	-	-	-	-	-	-	-	-	-	-	3.40	-	-	3.74
Atascosa	92556	Escambia Operating Co. LLC	Jourdanton Compressor Station	No	Pop	-	-	-	1	-	-	1	1	-	1	1	-	1	1	1	6
					VOC	-	-	-	6.98	-	-	-	-	-	10.99	-	-	2.32	1.29	0.04	21.62
					NOx	-	-	-	25.88	-	-	-	-	-	-	-	-	0.78	-	-	26.66
					CO	-	-	-	38.82	-	-	-	-	-	-	-	-	4.24	-	-	43.06
Atascosa	91562	EOG Resources Inc.	Little L&C Production Facility	No	Pop	1	-	-	1	-	-	3	3	-	1	1	-	1	1	-	11
					VOC	0.01	-	-	0.08	-	-	-	-	-	0.09	-	-	1.03	8.37	-	9.58
					NOx	0.18	-	-	8.50	-	-	-	-	-	-	-	-	0.30	-	-	8.98
					CO	0.15	-	-	0.72	-	-	-	-	-	-	-	-	1.21	-	1.00	2.08
Atascosa	89093	Regency Field Services LLC	Condensate Stabilization System	No	Pop	3	1	-	1	-	-	-	1	3	-	-	1	1	1	-	10
					VOC	0.03	3.66	-	0.18	-	-	-	-	11.42	-	-	5.47	-	0.64	-	21.40
					NOx	0.88	-	-	14.49	-	-	-	-	-	-	-	-	-	-	-	15.37
					CO	0.75	-	-	2.75	-	-	-	-	-	-	-	-	-	-	-	3.50
Atascosa	97163	EOG Resources, Inc.	Vapor Recovery Unit	No	Pop	4	-	-	-	-	-	-	1	3	-	-	1	1	1	-	10
					VOC	0.03	-	-	-	-	-	-	0.38	-	-	-	0.63	0.82	14.91	-	16.77
					NOx	0.56	-	-	-	-	-	-	-	-	-	-	-	0.12	-	-	0.68
					CO	0.46	-	-	-	-	-	-	-	-	-	-	-	0.50	-	-	0.96
Frio	96886	Cabot Oil & Gas Corporation	Arminius 1 & 2 Production Facility	No	Pop	2	-	-	1	-	-	-	4	8	-	1	1	1	1	-	20
					VOC	0.02	-	-	3.12	-	-	-	-	-	-	0.05	0.12	11.60	4.90	-	19.81
					NOx	0.43	-	-	29.61	-	-	-	-	-	-	-	-	2.69	-	-	32.73
					CO	0.36	-	-	3.38	-	-	-	-	-	-	-	-	5.37	-	-	9.12
Frio	97064	Cabot Oil & Gas Corporation	Arminius 5 Production Facility	No	Pop	1	-	-	-	-	-	-	2	6	-	1	1	1	1	-	13
					VOC	0.01	-	-	-	-	-	-	0.12	12.18	-	0.07	13.94	0.96	3.62	-	30.90
					NOx	0.73	-	-	-	-	-	-	-	-	-	-	-	2.00	-	-	2.73
					CO	1.19	-	-	-	-	-	-	-	-	-	-	-	3.98	-	-	5.17
Frio	96251	VirTex Operating Company, Inc.	Beever Tank Battery	No	Pop	-	-	-	-	-	-	-	1	1	-	-	2	1	1	-	6
					VOC	-	-	-	-	-	-	-	-	-	-	-	0.10	1.60	4.53	-	6.23
					NOx	-	-	-	-	-	-	-	-	-	-	-	-	0.25	-	-	0.25
					CO	-	-	-	-	-	-	-	-	-	-	-	-	0.50	-	-	0.50
Frio	95125	Chesapeake Operating, Inc.	Berry Family Ranch A Pad	No	Pop	1	-	-	-	-	-	3	1	-	1	1	-	1	1	-	9
					VOC	0.01	-	-	-	-	-	0.36	-	-	8.16	0.04	-	13.84	1.48	-	23.89
					NOx	0.22	-	-	-	-	-	-	-	-	-	-	-	0.88	-	-	1.10
					CO	0.18	-	-	-	-	-	-	-	-	-	-	-	0.74	-	-	0.92
Frio	100439	Goodrich Petroleum Company, L.L.C.	Carnes W A B7 H1 Oil And Gas Production Facility	No	Pop	1	-	-	-	-	-	2	-	-	1	-	-	2	1	-	7
					VOC	0.01	-	-	-	-	-	-	-	-	13.43	-	-	3.52	2.64	-	19.61
					NOx	0.20	-	-	-	-	-	-	-	-	-	-	-	0.38	-	-	0.58
					CO	0.17	-	-	-	-	-	-	-	-	-	-	-	0.31	-	-	0.49
Frio	93219	Taylor Transfer Services, LLC	Dilley Station	No	Pop	-	-	-	-	-	-	2	-	-	-	-	-	-	1	-	3
					VOC	-	-	-	-	-	-	18.24	-	-	-	-	-	-	0.09	-	18.33
					NOx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
					CO	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Frio	87290	Virtex Petroleum Management, LLC	Doering Ranch Production Facility	No	Pop	1	1	-	3	-	-	-	-	1	-	-	-	1	1	-	8
					VOC	0.06	-	-	8.17	-	-	-	-	0.29	-	-	-	0.93	3.84	-	13.29
					NOx	1.18	-	-	16.55	-	-	-	-	-	-	-	-	0.59	-	-	18.32
					CO	0.99	-	-	9.02	-	-	-	-	-	-	-	-	5.05	-	-	15.06

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Frio	88366	Texstar Midstream Operating, L.L.C.	Hiner Compressor Station	No	Pop	-	-	-	1	-	-	1	-	-	-	-	1	-	1	1	5
					VOC	-	-	-	0.31	-	-	0.57	-	-	-	-	0.01	-	1.45	0.10	2.45
					NOx	-	-	-	44.69	-	-	-	-	-	-	-	-	-	-	-	44.69
					CO	-	-	-	2.94	-	-	-	-	-	-	-	-	-	-	-	2.94
Frio	94152	Frio LaSalle Pipeline, LP	Lancaster Ranch Compressor Station And Treating Facility	No	Pop	-	1	-	4	-	-	-	-	4	-	-	-	1	1	-	11
					VOC	-	2.21	-	12.55	-	-	-	-	16.91	-	-	-	0.44	2.34	-	34.91
					NOx	-	0.82	-	87.59	-	-	-	-	-	-	-	-	0.05	-	-	96.44
					CO	-	0.68	-	80.33	-	-	-	-	-	-	-	-	0.63	-	-	88.34
Frio	94318	VirTex Operating Company, Inc.	Marrs-McLean Production Facility	No	Pop	-	-	-	-	-	-	-	-	3	-	-	1	1	1	-	6
					VOC	-	-	-	-	-	-	-	-	-	-	-	0.07	0.44	4.16	-	4.66
					NOx	-	-	-	-	-	-	-	-	-	-	-	-	0.09	-	-	0.09
					CO	-	-	-	-	-	-	-	-	-	-	-	-	0.18	-	-	0.18
Frio	91162	VirTex Operating Company, Inc.	McWilliams A1 Production Facility	No	Pop	-	-	-	-	-	-	-	2	4	-	-	1	1	1	-	9
					VOC	-	-	-	-	-	-	-	-	-	-	-	0.32	4.49	4.53	-	9.34
					NOx	-	-	-	-	-	-	-	-	-	-	-	-	1.77	-	-	1.77
					CO	-	-	-	-	-	-	-	-	-	-	-	-	3.53	-	-	3.53
Frio	96248	VirTex Operating Company, Inc.	McWilliams B-1 Production Facility	No	Pop	-	-	-	-	-	-	-	2	4	-	-	1	1	1	-	9
					VOC	-	-	-	-	-	-	-	-	-	-	-	0.32	4.49	4.53	-	9.33
					NOx	-	-	-	-	-	-	-	-	-	-	-	-	1.77	-	-	1.77
					CO	-	-	-	-	-	-	-	-	-	-	-	-	3.53	-	-	3.53
Frio	94322	Frio LaSalle Pipeline LP	Pals No 9 Compressor Facility	No	Pop	-	-	-	1	-	-	-	-	-	-	-	-	-	1	1	3
					VOC	-	-	-	0.54	-	-	-	-	-	-	-	-	-	0.70	0.46	1.70
					NOx	-	-	-	48.62	-	-	-	-	-	-	-	-	-	-	-	48.62
					CO	-	-	-	75.64	-	-	-	-	-	-	-	-	-	-	-	75.64
Frio	98480	Cabot Oil & Gas Corporation	Pat West 1	No	Pop	1	-	-	-	-	-	2	1	-	1	1	-	1	1	-	8
					VOC	0.01	-	-	-	-	-	13.96	0.07	-	0.52	0.00	-	3.85	2.57	-	20.98
					NOx	0.22	-	-	-	-	-	-	-	-	-	-	-	2.03	-	-	2.24
					CO	0.18	-	-	-	-	-	-	-	-	-	-	-	4.05	-	-	4.23
Frio	94796	El Paso E&P Company, L.P.	Pearsall 1h Facility	No	Pop	-	-	-	-	-	-	-	-	5	-	-	1	1	1	1	9
					VOC	-	-	-	-	-	-	-	-	-	-	-	9.82	11.92	1.55	1.62	24.91
					NOx	-	-	-	-	-	-	-	-	-	-	-	-	2.60	-	-	2.60
					CO	-	-	-	-	-	-	-	-	-	-	-	-	5.19	-	-	5.19
Frio	95313	Enterprise Products Operating LLC	Pearsall Compressor Station	No	Pop	-	-	-	4	-	-	2	-	4	-	-	1	4	1	1	17
					VOC	-	-	-	12.44	-	-	-	-	-	-	-	0.24	3.91	4.22	2.75	23.52
					NOx	-	-	-	77.64	-	-	-	-	-	-	-	-	6.27	-	-	83.90
					CO	-	-	-	7.16	-	-	-	-	-	-	-	-	10.16	-	-	17.30
Frio	96255	Faraday Pipeline Co.	Pearsall Compressor Station	No	Pop	-	-	-	1	-	-	1	-	-	1	-	-	1	1	-	6
					VOC	-	-	-	1.93	-	-	-	-	-	0.10	-	-	1.63	4.53	-	8.18
					NOx	-	-	-	24.33	-	-	-	-	-	-	-	-	0.26	-	-	24.59
					CO	-	-	-	5.41	-	-	-	-	-	-	-	-	0.51	-	-	5.92
Frio	97323	Cabot Oil & Gas Corporation	Pickens A 1 Production Facility	No	Pop	2	-	-	1	-	-	-	-	-	-	1	1	1	1	-	7
					VOC	0.02	-	-	5.56	-	-	-	-	-	-	0.22	3.93	16.31	5.69	-	31.73
					NOx	0.43	-	-	7.42	-	-	-	-	-	-	-	-	3.37	-	-	11.22
					CO	0.36	-	-	4.45	-	-	-	-	-	-	-	-	6.74	-	-	11.55
Frio	100368	Cabot Oil & Gas Corporation	Pickens A No 6h Production Facility	No	Pop	2	-	-	1	-	-	-	4	-	-	1	1	2	1	-	12
					VOC	0.02	-	-	3.90	-	-	-	-	-	-	0.14	4.91	15.86	5.01	-	28.65
					NOx	0.44	-	-	29.61	-	-	-	-	-	-	-	-	3.39	-	-	33.44
					CO	0.36	-	-	3.38	-	-	-	-	-	-	-	-	6.76	-	-	10.53
Frio	100366	Cabot Oil & Gas Corporation	Pickens B 2H Production Facility	No	Pop	2	-	-	1	-	-	-	4	10	-	1	1	1	1	-	21
					VOC	0.02	-	-	5.56	-	-	-	-	-	-	0.40	4.91	20.20	5.01	-	36.12
					NOx	0.44	-	-	7.42	-	-	-	-	-	-	-	-	4.11	-	-	11.95
					CO	0.36	-	-	4.45	-	-	-	-	-	-	-	-	8.15	-	-	13.00

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Frio	96880	Cabot Oil & Gas Corporation	Santa Cruz No. 1 Production Facility	No	Pop	1	-	-	-	-	-	-	4	6	-	1	1	1	1	-	14
					VOC	0.01	-	-	-	-	-	-	-	-	-	0.05	7.96	8.14	3.74	-	19.88
					NOx	0.22	-	-	-	-	-	-	-	-	-	-	-	1.65	-	-	1.86
					CO	0.18	-	-	-	-	-	-	-	-	-	-	-	3.29	-	-	3.46
Frio	93887	Frio LaSalle Pipeline, LP	Shiner Ranch Compressor Station And Treating Facility	No	Pop	3	1	-	3	-	-	-	-	1	-	-	1	1	1	1	9
					VOC	0.09	3.67	-	1.11	-	-	-	-	2.77	-	-	0.12	1.12	1.66	0.74	11.28
					NOx	1.71	-	-	16.50	-	-	-	-	-	-	-	-	0.81	-	3.11	22.13
					CO	1.45	-	-	43.98	-	-	-	-	-	-	-	-	6.98	-	8.30	60.71
Frio	91152	VIRTEX OPERATING COMPANY,INC.	Talasek No. 1 Production Facility	No	Pop	-	-	-	-	-	-	-	1	1	-	-	1	-	1	-	2
					VOC	-	-	-	-	-	-	-	0.18	1.81	-	-	0.07	-	1.53	-	3.59
					NOx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
					CO	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Frio	88361	TexStar Midstream Operating LLC	Urban Compressor Station	No	Pop	-	-	-	1	-	-	-	-	2	-	-	1	-	1	1	3
					VOC	-	-	-	3.25	-	-	-	-	3.17	-	-	0.12	-	1.45	0.42	8.41
					NOx	-	-	-	97.60	-	-	-	-	-	-	-	-	-	-	-	97.60
					CO	-	-	-	5.78	-	-	-	-	-	-	-	-	-	-	-	5.78
Karnes	99894	Marathon Oil EF LLC	Best Fenner-Best Huth Production Facility	No	Pop	2	-	-	2	-	-	-	-	2	-	-	1	2	1	-	8
					VOC	0.06	-	-	2.48	-	-	-	-	-	-	-	0.64	15.55	9.91	-	28.64
					NOx	0.59	-	-	3.92	-	-	-	-	-	-	-	-	2.78	-	-	7.29
					CO	0.50	-	-	3.92	-	-	-	-	-	-	-	-	5.55	-	-	9.96
Karnes	95546	Hawk Field Services, LLC	Black Hawk Enterprise Tap Facility	No	Pop	-	-	-	1	-	-	1	1	1	-	-	2	-	1	1	7
					VOC	-	-	-	3.24	-	-	0.49	0.04	14.56	-	-	4.00	-	1.37	0.59	24.28
					NOx	-	-	-	16.59	-	-	-	-	-	-	-	-	-	-	-	16.59
					CO	-	-	-	16.35	-	-	-	-	-	-	-	-	-	-	-	16.35
Karnes	98443	Marathon Oil EF LLC	Buehring 1 Production Facility	No	Pop	1	1	-	1	-	-	-	1	5	-	1	1	1	1	-	13
					VOC	0.02	5.31	-	0.71	-	-	-	-	-	-	0.04	7.90	6.37	2.92	-	23.27
					NOx	0.31	-	-	3.92	-	-	-	-	-	-	-	-	1.17	-	-	5.40
					CO	0.25	-	-	7.84	-	-	-	-	-	-	-	-	2.34	-	-	10.43
Karnes	85119	Regency Field Services, LLC	CDP No. 2 Compressor Station	No	Pop	1	1	-	3	-	-	1	1	1	-	1	1	-	1	-	9
					VOC	0.01	5.85	-	12.27	-	-	-	0.05	1.14	-	0.01	0.87	-	1.90	-	21.60
					NOx	0.21	-	-	23.25	-	-	-	-	-	-	-	-	-	-	-	23.46
					CO	0.18	-	-	56.03	-	-	-	-	-	-	-	-	-	-	-	56.21
Karnes	92568	Murphy Exploration & Production Company	Drees Production Facility	No	Pop	1	1	-	1	-	-	-	2	8	1	-	-	-	1	1	13
					VOC	0.03	0.01	-	0.05	-	-	-	0.00	9.63	5.54	-	-	-	8.91	0.15	24.31
					NOx	0.46	-	-	3.68	-	-	-	-	-	-	-	-	-	-	-	4.13
					CO	0.39	-	-	6.19	-	-	-	-	-	-	-	-	-	-	-	6.58
Karnes	99759	Marathon Oil EF LLC	East Longhorn Central Facility	No	Pop	1	2	-	5	-	-	-	-	-	1	-	-	2	1	1	13
					VOC	0.07	1.26	-	26.63	-	-	-	-	-	2.44	-	-	6.70	16.90	0.11	54.10
					NOx	1.29	0.42	-	23.33	-	-	-	-	-	-	-	-	1.30	-	-	26.40
					CO	1.08	0.36	-	11.40	-	-	-	-	-	-	-	-	2.08	-	-	14.90
Karnes	100493	Marathon Oil EF LLC	East Sugarloaf Central Facility	No	Pop	9	2	-	5	-	-	-	-	-	-	1	-	2	1	-	10
					VOC	0.30	3.56	-	10.60	-	-	-	-	-	-	1.09	-	5.11	3.19	-	23.85
					NOx	6.60	-	-	23.33	-	-	-	-	-	-	-	-	1.70	-	-	31.63
					CO	5.56	-	-	9.54	-	-	-	-	-	-	-	-	3.39	-	-	18.49
Karnes	94249	Talisman Energy USA Inc.	Eyhorn Gas Unit 1 Well 1-4	No	Pop	-	-	-	1	-	-	-	1	4	-	-	2	-	1	1	8
					VOC	-	-	-	-	-	-	-	0.49	5.26	-	-	6.42	-	3.93	1.76	17.87
					NOx	-	-	-	-	-	-	-	-	-	-	-	-	0.21	-	11.35	11.56
					CO	-	-	-	-	-	-	-	-	-	-	-	-	1.14	-	2.70	3.84
Karnes	98580	Hilcorp Energy Company	George 1 Production Facility	No	Pop	2	1	-	1	-	-	-	-	-	-	1	1	1	1	-	7
					VOC	0.02	2.75	-	0.71	-	-	-	-	-	-	0.10	6.47	4.94	2.92	-	17.90
					NOx	0.31	-	-	3.92	-	-	-	-	-	-	-	-	0.86	-	-	5.08
					CO	0.25	-	-	7.84	-	-	-	-	-	-	-	-	1.73	-	-	9.81

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Karnes	94355	Copano Field Services/Karnes, L.P.	Highway 81 Compressor Station	No	Pop	1	-	-	2	-	-	-	-	2	-	-	-	-	1	-	5
					VOC	0.82	-	-	8.57	-	-	-	-	4.48	-	-	-	-	2.38	-	18.03
					NOx	0.21	-	-	60.26	-	-	-	-	-	-	-	-	-	-	-	60.47
					CO	0.18	-	-	49.88	-	-	-	-	-	-	-	-	-	-	-	50.06
Karnes	93741	Hilcorp Energy Company	Weston No. 1 Production Facility	No	Pop	-	-	-	1	-	-	-	1	5	-	-	1	1	1	-	9
					VOC	-	-	-	3.36	-	-	-	-	-	-	-	0.86	14.34	3.04	-	21.61
					NOx	-	-	-	25.88	-	-	-	-	-	-	-	-	3.52	-	-	29.39
					CO	-	-	-	3.49	-	-	-	-	-	-	-	-	7.03	-	-	10.51
Karnes	98156	Murphy Exploration & Production Company	KAS Central Facility	No	Pop	2	1	-	2	-	-	-	2	7	-	1	1	2	1	1	18
					VOC	0.08	0.04	-	1.23	-	-	-	0.22	-	-	0.02	2.57	6.95	5.69	0.01	17.07
					NOx	1.28	0.05	-	8.12	-	-	-	-	-	-	-	-	1.20	-	-	11.15
					CO	1.08	0.05	-	12.36	-	-	-	-	-	-	-	-	2.06	-	-	16.52
Karnes	99213	Select Energy Services LLC	Kenedy Saltwater Disposal Facility	No	Pop	-	-	-	-	-	-	2	8	-	-	-	-	-	-	-	10
					VOC	-	-	-	-	-	-	2.02	8.08	-	-	-	-	-	-	-	10.10
					NOx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
					CO	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Karnes	97931	Marathon Oil EF LLC	Kowalik 1 Production Facility	No	Pop	2	1	-	1	-	-	-	1	5	-	1	1	1	1	-	13
					VOC	0.02	5.22	-	0.71	-	-	-	-	-	-	0.03	8.40	6.32	2.92	-	23.62
					NOx	0.31	-	-	3.92	-	-	-	-	-	-	-	-	1.17	-	-	5.40
					CO	0.25	-	-	7.84	-	-	-	-	-	-	-	-	2.34	-	-	10.43
Karnes	79456	Regency Field Services, L.L.C.	Kunkle Compressor Station	No	Pop	-	1	-	4	-	-	-	-	2	-	-	1	1	1	1	9
					VOC	-	-	-	18.32	-	-	-	-	-	-	-	1.13	0.27	1.79	0.69	22.20
					NOx	-	0.05	-	71.01	-	-	-	-	-	-	-	-	0.09	-	-	71.15
					CO	-	0.04	-	91.89	-	-	-	-	-	-	-	-	0.75	-	-	92.68
Karnes	99968	EOG Resources, Inc.	Manchaca And Lazy Oaks Production Facility	No	Pop	4	-	-	-	-	-	16	4	-	-	-	-	1	1	-	25
					VOC	0.04	-	-	-	-	-	4.18	1.21	-	-	-	-	3.64	9.79	-	18.85
					NOx	0.60	-	-	-	-	-	-	-	-	-	-	-	0.55	-	-	1.15
					CO	0.48	-	-	-	-	-	-	-	-	-	-	-	2.20	-	-	2.69
Karnes	94317	Pecan Pipeline Company	Milton Hub	No	Pop	1	1	-	5	-	-	-	2	-	-	1	-	1	1	-	11
					VOC	0.28	0.24	-	18.58	-	-	-	0.26	-	-	0.73	-	0.18	6.37	-	26.64
					NOx	5.06	-	-	35.66	-	-	-	-	-	-	-	-	0.14	-	-	40.85
					CO	4.25	-	-	15.64	-	-	-	-	-	-	-	-	0.54	-	-	20.43
Karnes	98594	Plains Exploration & Production	Nieschwietz Kowalik Production Facility	No	Pop	1	1	-	5	-	-	-	3	5	-	1	1	1	1	-	11
					VOC	-	-	-	0.05	-	-	-	0.12	21.25	-	0.03	4.13	0.11	7.16	-	32.90
					NOx	0.32	-	-	1.35	-	-	-	-	-	-	-	-	0.03	-	-	1.70
					CO	0.28	-	-	0.10	-	-	-	-	-	-	-	-	0.16	-	-	0.54
Karnes	99778	Marathon Oil EF LLC	North Longhorn Central Tank Battery-2	No	Pop	4	1	-	5	-	-	-	-	-	-	1	-	1	1	-	12
					VOC	0.09	1.74	-	10.60	-	-	-	-	-	-	1.09	-	1.66	3.35	-	18.50
					NOx	1.49	0.77	-	23.33	-	-	-	-	-	-	-	-	0.48	-	-	26.10
					CO	1.26	0.65	-	9.54	-	-	-	-	-	-	-	-	0.95	-	-	12.40
Karnes	99876	Marathon Oil EF LLC	Pfeifer No 1	No	Pop	2	1	-	1	-	-	-	-	-	-	-	1	1	1	-	6
					VOC	0.01	0.06	-	1.24	-	-	-	-	-	-	-	0.28	13.13	5.18	-	19.90
					NOx	0.33	-	-	1.96	-	-	-	-	-	-	-	-	2.36	-	-	4.65
					CO	0.28	-	-	1.96	-	-	-	-	-	-	-	-	4.70	-	-	6.94
Karnes	98397	Marathon Oil EF, LLC	PMT Oil 1 Production Facility	No	Pop	2	1	1	1	-	-	-	1	5	-	1	1	1	1	-	14
					VOC	0.02	5.23	-	0.71	-	-	-	-	-	-	0.03	9.05	6.77	2.92	-	24.71
					NOx	0.31	-	-	3.92	-	-	-	-	-	-	-	-	1.61	-	-	5.81
					CO	0.25	-	-	7.84	-	-	-	-	-	-	-	-	3.17	-	-	11.27
Karnes	94663	Marathon Oil EF LLC	Rancho Grande 1 Production Facility	No	Pop	2	1	1	1	-	-	-	1	5	-	1	1	1	1	-	13
					VOC	0.02	5.28	0.03	4.38	-	-	-	0.13	2.96	-	0.07	0.05	0.07	3.75	-	16.73
					NOx	0.32	0.15	0.02	12.94	-	-	-	-	-	-	-	-	0.67	-	-	14.10
					CO	0.27	0.21	0.15	14.23	-	-	-	-	-	-	-	-	1.33	-	-	16.19

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Karnes	97072	Fountain Quail Management, LLC	Eagle Ford Shale Kenedy Recycle Station	No	Pop	-	-	-	2	-	-	-	-	-	-	-	-	-	1	-	2
					VOC	-	-	-	3.16	-	-	-	-	-	-	-	-	-	0.77	-	3.93
					NOx	-	-	-	20.16	-	-	-	-	-	-	-	-	-	-	-	20.16
					CO	-	-	-	16.42	-	-	-	-	-	-	-	-	-	-	-	16.42
Karnes	81885	Copano Field Services/Karnes Lp	Runge Compressor Station	No	Pop	2	1	-	1	-	-	-	1	-	-	-	1	-	1	-	6
					VOC	0.02	0.06	-	20.70	-	-	-	1.08	-	-	-	0.31	-	0.98	-	23.15
					NOx	0.32	-	-	51.76	-	-	-	-	-	-	-	-	-	-	-	52.08
					CO	0.27	-	-	51.76	-	-	-	-	-	-	-	-	-	-	-	52.03
Karnes	93472	Burlington Resources Oil & Gas Company, L.P.	Schendel Unit 1 SWF	No	Pop	-	-	-	1	-	-	-	1	3	-	-	1	1	1	1	7
					VOC	-	-	-	4.02	-	-	-	-	-	-	-	2.81	3.71	6.09	3.13	19.76
					NOx	-	-	-	6.28	-	-	-	-	-	-	-	-	0.46	-	-	6.74
					CO	-	-	-	12.55	-	-	-	-	-	-	-	-	3.87	-	-	16.42
Karnes	100488	Marathon Oil EF LLC	South Sugarloaf Central Facility	No	Pop	2	2	-	5	-	-	-	-	-	-	1	-	2	1	-	12
					VOC	0.28	3.58	-	10.60	-	-	-	-	-	-	1.42	-	5.11	3.19	-	24.10
					NOx	4.48	2.12	-	23.33	-	-	-	-	-	-	-	-	1.09	-	-	31.10
					CO	3.78	1.78	-	9.54	-	-	-	-	-	-	-	-	2.18	-	-	17.30
Karnes	99763	Marathon Oil EF LLC	Sugarhorn Central Facility	No	Pop	2	2	-	5	-	-	-	-	-	-	1	-	2	1	1	10
					VOC	0.07	1.26	-	24.40	-	-	-	-	-	-	2.44	-	6.70	15.50	0.11	50.48
					NOx	1.29	0.42	-	23.33	-	-	-	-	-	-	-	-	1.30	-	-	26.34
					CO	1.08	0.36	-	11.40	-	-	-	-	-	-	-	-	2.08	-	-	14.92
Karnes	82598	Pioneer Natural Resources USA Inc.	SW Kenedy Amine Plant	No	Pop	4	1	1	2	-	-	-	-	3	-	1	1	2	1	-	15
					VOC	0.26	-	-	1.11	-	-	-	-	0.56	-	-	-	0.14	0.73	-	2.80
					NOx	4.22	-	-	36.33	-	-	-	-	-	-	-	-	0.26	-	-	40.81
					CO	3.56	-	-	58.25	-	-	-	-	-	-	-	-	0.49	-	-	62.30
Karnes	98436	Marathon Oil EF LLC	Turnbull 4 Production Facility	No	Pop	1	1	-	1	-	-	-	-	-	-	-	-	-	1	-	3
					VOC	0.01	12.65	-	0.71	-	-	-	-	-	-	-	-	-	2.01	-	15.40
					NOx	0.09	-	-	3.92	-	-	-	-	-	-	-	-	-	-	-	4.01
					CO	0.07	-	-	7.84	-	-	-	-	-	-	-	-	-	-	-	7.91
Karnes	94744	Hilcorp Energy Company	Turnbull No 2 Production Facility	No	Pop	1	-	-	3	-	-	-	1	5	-	1	1	-	1	-	12
					VOC	0.02	-	-	5.42	-	-	-	0.14	10.35	-	0.08	5.47	-	3.15	-	24.63
					NOx	0.32	-	-	16.51	-	-	-	-	-	-	-	-	-	-	-	16.83
					CO	0.27	-	-	21.64	-	-	-	-	-	-	-	-	-	-	-	21.91
Karnes	100498	Marathon Oil EF LLC	West Sugarloaf Central Facility	No	Pop	9	1	-	5	-	-	-	-	-	-	1	-	2	1	-	18
					VOC	0.30	3.56	-	10.60	-	-	-	-	-	-	1.09	-	5.11	3.19	-	23.80
					NOx	6.60	-	-	23.33	-	-	-	-	-	-	-	-	1.70	-	-	31.70
					CO	5.56	-	-	9.54	-	-	-	-	-	-	-	-	3.39	-	-	18.50
Wilson	98090	EOG Resources, Inc.	Pawelek Moy Production Facility	No	Pop	5	-	-	-	-	-	6	2	-	1	1	-	1	1	-	16
					VOC	0.05	-	-	-	-	-	13.75	-	-	-	2.93	-	0.88	6.16	-	23.77
					NOx	0.75	-	-	-	-	-	-	-	-	-	-	-	0.13	-	-	0.88
					CO	0.65	-	-	-	-	-	-	-	-	-	-	-	0.52	-	-	1.17
Wilson	97318	Hunt Oil Company	Bar None 1 Facility	No	Pop	1	1	1	1	-	-	6	3	-	1	1	-	1	1	-	16
					VOC	0.03	1.61	0.51	1.89	-	-	-	-	-	-	-	-	6.01	2.91	-	12.96
					NOx	0.49	-	-	2.70	-	-	-	-	-	-	-	-	2.87	-	-	6.06
					CO	0.41	-	-	1.89	-	-	-	-	-	-	-	-	5.64	-	-	7.94
Wilson	95896	EOG Resources, Inc.	Borgfeld Production Facility	No	Pop	3	-	-	1	-	-	10	2	-	1	1	-	1	1	-	19
					VOC	0.03	-	-	0.51	-	-	-	-	-	1.96	-	-	7.74	4.97	-	15.21
					NOx	0.55	-	-	1.04	-	-	-	-	-	-	-	-	1.46	-	-	3.05
					CO	0.46	-	-	1.04	-	-	-	-	-	-	-	-	5.83	-	-	7.33
Wilson	97997	EOG Resources, Inc.	Casares Production Facility	No	Pop	2	-	-	-	-	-	5	1	-	1	1	-	1	1	-	11
					VOC	0.04	-	-	-	-	-	-	-	-	3.30	-	-	12.10	6.55	-	21.99
					NOx	0.64	-	-	-	-	-	-	-	-	-	-	-	2.32	-	-	2.96
					CO	0.52	-	-	-	-	-	-	-	-	-	-	-	9.25	-	-	9.77

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Wilson	97166	Marathon Oil Company	Chandler 1 Production Facility	No	Pop	-	-	-	-	-	-	1	1	-	1	-	-	-	1	-	3
					VOC	-	-	-	-	-	-	6.76	0.49	-	0.09	-	-	-	0.48	-	7.82
					NOx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
					CO	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wilson	99998	EOG Resources, Inc.	Coates Trust Production Facility	No	Pop	1	-	-	-	-	-	1	1	-	1	-	-	1	1	-	5
					VOC	0.01	-	-	-	-	-	-	0.65	-	2.63	-	-	0.57	20.10	-	23.96
					NOx	0.16	-	-	-	-	-	-	-	-	-	-	-	0.09	-	-	0.25
					CO	0.13	-	-	-	-	-	-	-	-	-	-	-	0.34	-	-	0.47
Wilson	98582	Hunt Oil Company	Felux 1 Facility	No	Pop	1	-	-	-	-	-	1	1	-	-	1	-	1	1	-	5
					VOC	0.02	-	-	-	-	-	3.31	-	-	-	0.26	-	16.18	2.38	-	22.15
					NOx	0.28	-	-	-	-	-	-	-	-	-	-	-	5.14	-	-	5.42
					CO	0.24	-	-	-	-	-	-	-	-	-	-	-	10.17	-	-	10.41
Wilson	96370	Marathon Oil Company	Haese Production Facility	No	Pop	2	-	-	-	-	-	2	4	-	-	1	-	1	1	-	10
					VOC	0.04	-	-	-	-	-	-	-	-	-	-	-	16.14	1.41	-	17.59
					NOx	0.71	-	-	-	-	-	-	-	-	-	-	-	3.93	-	-	4.64
					CO	0.60	-	-	-	-	-	-	-	-	-	-	-	7.84	-	-	8.44
Wilson	97115	Marathon Oil Company	Hofferichter 1h Production Facility	No	Pop	2	-	-	-	-	-	2	4	-	-	1	-	1	1	1	10
					VOC	0.14	-	-	-	-	-	0.70	0.02	-	-	0.39	-	1.48	1.60	3.72	8.05
					NOx	0.14	-	-	-	-	-	-	-	-	-	-	-	1.80	-	-	1.94
					CO	0.12	-	-	-	-	-	-	-	-	-	-	-	3.60	-	-	3.72
Wilson	97316	Hunt Oil Company	Moczygemba 1 Facility	No	Pop	1	1	1	1	-	-	6	3	-	1	1	-	1	1	-	16
					VOC	0.03	1.60	-	2.78	-	-	-	-	-	0.46	-	-	10.18	2.81	-	17.86
					NOx	0.48	-	-	3.71	-	-	-	-	-	-	-	-	3.62	-	-	7.80
					CO	2.40	-	-	2.23	-	-	-	-	-	-	-	-	7.12	-	-	11.75
Wilson	98090	EOG Resources, Inc.	Pawelek Moy Production Facility	No	Pop	5	-	-	-	-	-	6	2	-	1	1	-	1	1	1	16
					VOC	0.05	-	-	-	-	-	-	0.57	-	2.36	-	-	0.88	6.16	13.75	23.77
					NOx	0.75	-	-	-	-	-	-	-	-	-	-	-	0.13	-	-	0.88
					CO	0.65	-	-	-	-	-	-	-	-	-	-	-	0.52	-	-	1.17
Wilson	96446	EOG Resources, Inc.	Vapor Recovery Unit	No	Pop	5	-	-	-	-	-	6	2	-	1	1	-	1	1	1	16
					VOC	0.04	-	-	-	-	-	-	0.76	-	0.61	-	-	0.57	4.82	5.65	12.45
					NOx	0.64	-	-	-	-	-	-	-	-	-	-	-	0.08	-	-	0.72
					CO	0.56	-	-	-	-	-	-	-	-	-	-	-	0.32	-	-	0.88
Wilson	95141	Hunt Oil Company	Warnken 1 Facility	No	Pop	1	1	1	1	-	-	8	3	-	1	1	-	1	1	-	18
					VOC	0.02	0.56	0.01	0.57	-	-	-	-	-	0.63	0.26	-	14.24	3.48	-	19.76
					NOx	0.32	0.02	0.16	27.72	-	-	-	-	-	-	-	-	5.23	-	-	33.46
					CO	0.27	0.02	0.13	25.17	-	-	-	-	-	-	-	-	10.35	-	-	35.94
Wilson	98122	Marathon Oil Company	Wehmeyer 1 H Production Facility	No	Pop	1	-	-	1	-	-	2	2	-	1	1	-	1	-	-	9
					VOC	0.03	-	-	0.02	-	-	-	-	-	-	-	-	0.66	-	-	0.71
					NOx	0.03	-	-	0.44	-	-	-	-	-	-	-	-	1.32	-	-	1.79
					CO	0.13	-	-	-	-	-	-	-	-	-	-	-	35.81	-	-	35.94

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APPENDIX D: SUMMARY OF EMISSION INVENTORY INPUT FACTORS

Non-Road Equipment

Stage	Equipment Type	Fuel Type	Population	HP	Activity	LF	NO_X EF (g/hp-hr)	VOC EF (g/hp-hr)	CO EF (g/hp-hr)	Eq. Type Percentage
Exploration										
	Seismic Trucks	Diesel	2	400	2 hours / Well Pad	0.59	3.71	0.24	1.22	100%
Pad Construction										
	Dozer	Diesel	1	210	40 hours/well pad	0.40	2.90	0.24	1.50	100%
	Scraper	Diesel	2	700	40 hours/well pad	0.40	2.51	0.16	1.38	100%
	Grader	Diesel	1	250	40 hours/well pad	0.40	3.10	0.30	1.44	100%
Drilling										
	Electric Drill Rig	Diesel	3.17	1,429	20.40 hours/1,000 ft drilled	0.43	4.56	0.24	2.67	86.3%
	Mechanical Drill Rig	Diesel	5.88	702	20.40 hours/1,000 ft drilled	0.43	5.13	0.48	1.99	13.7%
	Excavator	Diesel	1	197	20.40 hours/1,000 ft drilled	0.59	4.69	0.36	1.93	100%
	Crane	Diesel	1	230	20.40 hours/1,000 ft drilled	0.43	3.66	0.28	1.07	100%
	Cement Pump	Diesel	2	400	20.40 hours/1,000 ft drilled	0.43	5.00	0.63	2.70	100%
Hydraulic Fracturing/Completion										
	Pump Engines	Diesel	12	2,250	54 hours	0.30	4.56	0.24	2.67	100%
	Perf and Pump Trucks	Diesel	2	2,250	54 hours	0.30	4.56	0.24	2.67	100%
	Blender Truck	Diesel	1	634	54 hours	0.43				100%
	Water Pumps	Diesel	5	384	54 hours	0.43	5.00	0.63	2.70	100%
	Sand King	Diesel	3	78	54 hours	0.43				100%
	Blow Out Control System	Diesel	1	12.6	54 hours	0.43				100%
	Forklift	Diesel	1	110	54 hours	0.59	2.99	0.26	2.70	100%
	Generators	Diesel	5	87.4	54 hours	0.59	5.00	0.66	2.67	100%
	Generators	Diesel	1	50	54 hours	0.59	5.00	0.66	2.67	100%
	Bulldozer	Diesel	1	99	54 hours	0.59	2.90	0.24	1.50	100%
	Backhoe	Diesel	1	88	54 hours	0.59	5.04	1.25	6.15	100%
	High Pressure Water Canon	Diesel	1	200	54 hours	0.43				100%
	Crane (Large)	Diesel	1	517	54 hours	0.59	3.66	0.28	1.07	100%
	Crane (Small)	Diesel	1	230	54 hours	0.59	3.66	0.28	1.07	100%
Production										
	Compressors	Natural Gas	0.33	159	7,729 hours/year	-	10.58 tons/year	0.41 tons/year	4.63	

On-Road Vehicles

Stage	Vehicle Type	Fuel Type	Speed	Number of Trips	Distance	Idling Time	On-Road (g/mile)			Idling (g/hr)		
							NO_x EF	VOC EF	CO EF	NO_x EF	VOC EF	CO EF
Pad Construction												
	HDV	Diesel	35 mph	70	Distance to Nearest Town	0.40 hours	10.10	0.51	2.75	89.32	11.67	-
	LDV - Equipment	Diesel & Gas	35 mph	13		2.00 hours	1.33	0.28	9.18	11.11	4.09	-
	LDV - Employee	Diesel & Gas	35 mph	70		2.15 hours	1.33	0.28	9.18	11.11	4.09	-
Drilling												
	HDV	Diesel	35 mph	117	Distance to Nearest Town	0.70 hours	10.10	0.51	2.75	89.32	11.67	-
	LDV - Drill Rig	Diesel & Gas	35 mph	68		1.55 hours	1.33	0.28	9.18	11.11	4.09	-
	LDV - Employee	Diesel & Gas	35 mph	66		2.10 hours	1.33	0.28	9.18	11.11	4.09	-
Hydraulic Fracturing/Completion												
	HDV	Diesel	35 mph	807	Distance to Nearest Town	1.10 hours	10.10	0.51	2.75	89.32	11.67	-
	LDV - Eq./Supplies	Diesel & Gas	35 mph	41		2.00 hours	1.33	0.28	9.18	11.11	4.09	-
	LDV - Employee	Diesel & Gas	35 mph	87		2.10 hours	1.33	0.28	9.18	11.11	4.09	-
Production												
	HDV	Diesel	35 mph	353	Distance to Nearest Town	0.90 hours	10.10	0.51	2.75	89.32	11.67	-
	LDV - Production	Diesel & Gas	35 mph	69		2.50 hours	1.33	0.28	9.18	11.11	4.09	-
	LDV - Maintenance	Diesel & Gas	35 mph	5		2.55 hours	1.33	0.28	9.18	11.11	4.09	-

Other Sources

Stage	Process	Well Type	Amount	Molecular weight of VOC	Mass Fraction of VOC	Heat Content	Activity	Count	NO_X EF	VOC EF	CO EF	Percent
Hydraulic Fracturing/Completion												
	Completion Venting	Oil	1,200 MCF	27 g/mol	0.141	-	-	-	-	Based on Mass Fraction	-	0%
		Gas	1,200 MCF	20 g/mol	0.036	-	-	-	-		-	0%
	Flaring	Oil and Gas	1,200 MCF	-	-	1,209 BTU/scf	-	1 per well	0.068 lbs /MMBtu	-	0.37 lbs /MMBtu	100%
Production												
	Heaters	Oil	0.64 MMBtu/hr	-	-	1,209 BTU/scf	5,346 hours	0.05 per well	0.142 tons/year	0.008 tons/year	84 lbs MMscf	100%
		Gas	0.64 MMBtu/hr	-	-	1,655 BTU/scf	4,076 hours	0.91 per well	100 lbs MMscf	5.50 lbs MMscf	84 lbs MMscf	100%
	Flaring	Oil/ Condensate	0.836 MCF Flared / 1,000 bbl	-	-	1,209 BTU/scf	-	-	0.068 lbs /MMBtu	-	0.37 lbs /MMBtu	100%
		Gas	8.84 MCF Flared / 1,000 bbl	-	-	1,655 BTU/scf	-	-	0.068 lbs /MMBtu	-	0.37 lbs /MMBtu	100%
	Dehydrators	Gas	-	-	-	-	-	-	-	1.632 lbs of VOC/MMscf	-	100%
	Storage Tanks	Oil	-	-	-	-	-	3.02 per well pad	-	183 g/hr/tank	-	100%
		Condensate	-	-	-	-	-	3.02 per well pad	-	429 g/hr/tank	-	100%
	Fugitives	Oil	-	-	-	-	-	1 per well	-	104.89 g/hr	-	100%
		Gas	-	-	-	-	-	1 per well	-	368.27 lbs/year	-	100%
	Loading Loss	Oil	-	50 lb/lb-mole	-	-	-	-	-	3.88 - 4.02 lbs/1,000 gal.	-	100%
		Condensate	-	68 lb/lb-mole	-	-	-	-	-	6.73 - 7.00 lbs/1,000 gal.	-	100%
	Blowdowns	Oil	173.9 MCF	27 g/mol	0.141	-	0.71 per year	-	-	0.16 tons/ blowdown	-	100%
		Gas	173.9 MCF	20 g/mol	0.036	-	0.71 per year	-	-	0.85 tons/ blowdown	-	100%
	Pneumatic Devices	Gas	-	-	-	-	8,760 hours	-	-	3,656 lbs/year/well	-	100%

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APPENDIX E: NUMBER OF WELLS AND PRODUCTION IN THE EAGLE FORD

Number of Natural Gas Wells Drilled and Production in the Eagle Ford, 2008-2011

County	FIPS Code	Natural Gas Wells Drilled				Calculated Natural Gas Production by County (BCF)				Calculated Condensate Production by County (bbl)			
		2008	2009	2010	2011	2008	2009	2010	2011	2008	2009	2010	2011
Atascosa	48013	0	1	11	21	-	0.00	0.10	5.02	-	0.00	0.10	0.38
Bee	48025	3	1	4	3	0.00	0.01	0.07	1.67	-	0.01	0.07	0.13
Brazos	48041	4	7	13	2	0.00	0.04	0.20	3.96	0.01	0.04	0.20	0.30
Burleson	48051	2	1	5	1	0.00	0.01	0.07	1.37	0.01	0.01	0.07	0.10
DeWitt	48123	27	12	29	156	0.02	0.13	0.58	34.09	-	0.13	0.58	2.56
Dimmit	48127	3	14	41	118	0.00	0.06	0.49	26.79	0.01	0.06	0.49	2.01
Fayette	48149	2	0	2	1	0.00	0.01	0.03	0.76	0.00	0.01	0.03	0.06
Frio	48163	1	3	11	11	0.00	0.01	0.13	3.96	0.00	0.01	0.13	0.30
Gonzales	48177	1	2	10	6	0.00	0.01	0.11	2.89	-	0.01	0.11	0.22
Grimes	48185	4	8	7	4	0.00	0.04	0.16	3.50	0.00	0.04	0.16	0.26
Houston	48225	0	1	0	2	-	0.00	0.01	0.46	0.00	0.00	0.01	0.03
Karnes	48255	10	15	51	64	0.01	0.08	0.65	21.31	-	0.08	0.65	1.60
La Salle	48283	1	20	73	149	0.00	0.07	0.80	36.98	-	0.07	0.80	2.77
Lavaca	48285	6	0	1	0	0.00	0.02	0.06	1.07	-	0.02	0.06	0.08
Lee	48287	0	0	9	1	-	-	0.08	1.52	0.01	-	0.08	0.11
Leon	48289	6	7	20	18	0.00	0.04	0.28	7.76	-	0.04	0.28	0.58
Live Oak	48297	4	5	30	78	0.00	0.03	0.33	17.81	-	0.03	0.33	1.34
Madison	48313	4	1	2	2	0.00	0.02	0.06	1.37	0.00	0.02	0.06	0.10
McMullen	48311	2	3	17	1	0.00	0.02	0.19	3.50	0.02	0.02	0.19	0.26
Maverick	48323	2	15	71	115	0.00	0.06	0.75	30.90	0.00	0.06	0.75	2.32
Milam	48331	0	0	1	0	-	-	0.01	0.15	-	-	0.01	0.01
Washington	48477	2	1	5	3	0.00	0.01	0.07	1.67	-	0.01	0.07	0.13
Webb	48479	24	33	135	313	0.02	0.18	1.63	76.86	0.00	0.18	1.63	5.76
Wilson	48493	0	0	2	0	-	-	0.02	0.30	-	-	0.02	0.02
Zavala	48507	1	0	8	12	0.00	0.00	0.08	3.20	0.00	0.00	0.08	0.24
Total		109	150	558	1,081	0.08	0.84	6.96	288.87	0.08	0.84	6.96	21.66

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Number of Oil Wells Drilled and Production in the Eagle Ford, 2008-2011

County	FIPS Code	Oil Wells Drilled				Calculated Oil Production by County (MMbbl)				Calculated Casinghead Production by County (BCF)			
		2008	2009	2010	2011	2008	2009	2010	2011	2008	2009	2010	2011
Atascosa	48013	0	0	4	47	-	-	0.04	1.10	-	-	0.03	0.37
Bee	48025	0	0	1	0	-	-	0.01	0.02	-	-	0.01	0.01
Brazos	48041	7	15	19	21	0.01	0.04	0.37	1.34	-	0.18	0.32	0.45
Burleson	48051	13	3	15	12	0.02	0.03	0.28	0.93	-	0.13	0.24	0.31
DeWitt	48123	0	0	10	50	-	-	0.09	1.30	-	-	0.08	0.43
Dimmit	48127	12	9	52	209	0.02	0.04	0.65	6.11	-	0.17	0.56	2.04
Fayette	48149	3	3	6	13	0.00	0.01	0.11	0.54	-	0.05	0.09	0.18
Frio	48163	4	4	11	55	0.01	0.02	0.17	1.60	-	0.07	0.15	0.53
Gonzales	48177	0	0	29	160	-	-	0.26	4.09	-	-	0.22	1.36
Grimes	48185	1	1	6	7	0.00	0.00	0.07	0.32	-	0.02	0.06	0.11
Houston	48225	6	0	1	1	0.01	0.01	0.06	0.17	-	0.05	0.05	0.06
Karnes	48255	0	1	53	247	-	0.00	0.48	6.52	-	0.01	0.42	2.17
La Salle	48283	0	1	37	155	-	0.00	0.34	4.18	-	0.01	0.29	1.39
Lavaca	48285	0	0	0	11	-	-	-	0.24	-	-	-	0.08
Lee	48287	8	3	1	11	0.01	0.02	0.11	0.50	-	0.09	0.09	0.17
Leon	48289	0	0	4	13	-	-	0.04	0.37	-	-	0.03	0.12
Live Oak	48297	0	2	16	14	-	0.00	0.16	0.69	-	0.02	0.14	0.23
Madison	48313	5	2	5	20	0.01	0.01	0.11	0.69	-	0.06	0.09	0.23
McMullen	48311	22	7	7	10	0.03	0.06	0.32	1.00	-	0.24	0.28	0.33
Maverick	48323	1	2	6	80	0.00	0.01	0.08	1.93	-	0.02	0.07	0.64
Milam	48331	0	0	0	2	-	-	-	0.04	-	-	-	0.01
Washington	48477	0	3	0	1	-	0.01	0.03	0.09	-	0.02	0.02	0.03
Webb	48479	1	2	46	56	0.00	0.01	0.44	2.27	-	0.02	0.38	0.76
Wilson	48493	0	0	4	35	-	-	0.04	0.84	-	-	0.03	0.28
Zavala	48507	6	5	4	29	0.01	0.02	0.13	0.95	-	0.09	0.12	0.32
Total		89	63	337	1,259	0.13	0.31	4.37	37.85	0.60	1.24	3.78	12.62

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APPENDIX F: PRODUCTION PROJECTIONS IN THE EAGLE FORD BY YEAR

Spud Date	Year of Production	Low Development Total Production				Moderate Development Total Production				Aggressive Development Total Production			
		Oil (bbl)	Casinghead Gas (MCF)	Condensate (bbl)	Natural Gas (MCF)	Oil (bbl)	Casinghead Gas (MCF)	Condensate (bbl)	Natural Gas (MCF)	Oil (bbl)	Casinghead Gas (MCF)	Condensate (bbl)	Natural Gas (MCF)
2008 Wells	1st	5,391,611	1,797,204	3,301,604	44,021,389	5,391,611	1,797,204	3,301,604	44,021,389	5,391,611	1,797,204	3,301,604	44,021,389
	2nd	1,943,778	647,926	1,190,291	15,870,547	1,943,778	647,926	1,190,291	15,870,547	1,943,778	647,926	1,190,291	15,870,547
	3rd	1,064,397	354,799	651,794	8,690,585	1,064,397	354,799	651,794	8,690,585	1,064,397	354,799	651,794	8,690,585
	4th	548,205	182,735	335,699	4,475,981	548,205	182,735	335,699	4,475,981	548,205	182,735	335,699	4,475,981
	5th	176,066	58,689	107,816	1,437,545	176,066	58,689	107,816	1,437,545	176,066	58,689	107,816	1,437,545
	6th	144,103	48,034	88,243	1,176,574	144,103	48,034	88,243	1,176,574	144,103	48,034	88,243	1,176,574
	7th	121,981	40,660	74,696	995,953	121,981	40,660	74,696	995,953	121,981	40,660	74,696	995,953
	8th	105,756	35,252	64,761	863,477	105,756	35,252	64,761	863,477	105,756	35,252	64,761	863,477
	9th	93,345	31,115	57,161	762,142	93,345	31,115	57,161	762,142	93,345	31,115	57,161	762,142
	10th	83,543	27,848	51,158	682,113	83,543	27,848	51,158	682,113	83,543	27,848	51,158	682,113
	11th	75,606	25,202	46,298	617,305	75,606	25,202	46,298	617,305	75,606	25,202	46,298	617,305
2009 Wells	1st	3,816,533	1,272,178	4,543,492	60,579,894	3,816,533	1,272,178	4,543,492	60,579,894	3,816,533	1,272,178	4,543,492	60,579,894
	2nd	1,375,933	458,644	1,638,015	21,840,202	1,375,933	458,644	1,638,015	21,840,202	1,375,933	458,644	1,638,015	21,840,202
	3rd	753,450	251,150	896,964	11,959,521	753,450	251,150	896,964	11,959,521	753,450	251,150	896,964	11,959,521
	4th	388,055	129,352	461,971	6,159,607	388,055	129,352	461,971	6,159,607	388,055	129,352	461,971	6,159,607
	5th	124,631	41,544	148,370	1,978,273	124,631	41,544	148,370	1,978,273	124,631	41,544	148,370	1,978,273
	6th	102,006	34,002	121,435	1,619,138	102,006	34,002	121,435	1,619,138	102,006	34,002	121,435	1,619,138
	7th	86,346	28,782	102,793	1,370,577	86,346	28,782	102,793	1,370,577	86,346	28,782	102,793	1,370,577
	8th	74,861	24,954	89,120	1,188,272	74,861	24,954	89,120	1,188,272	74,861	24,954	89,120	1,188,272
	9th	66,076	22,025	78,661	1,048,819	66,076	22,025	78,661	1,048,819	66,076	22,025	78,661	1,048,819
	10th	59,137	19,712	70,402	938,687	59,137	19,712	70,402	938,687	59,137	19,712	70,402	938,687
2010 Wells	1st	20,415,424	6,805,141	16,901,790	225,357,204	20,415,424	6,805,141	16,901,790	225,357,204	20,415,424	6,805,141	16,901,790	225,357,204
	2nd	7,360,148	2,453,383	6,093,416	81,245,552	7,360,148	2,453,383	6,093,416	81,245,552	7,360,148	2,453,383	6,093,416	81,245,552
	3rd	4,030,358	1,343,453	3,336,706	44,489,417	4,030,358	1,343,453	3,336,706	44,489,417	4,030,358	1,343,453	3,336,706	44,489,417
	4th	2,075,788	691,929	1,718,530	22,913,739	2,075,788	691,929	1,718,530	22,913,739	2,075,788	691,929	1,718,530	22,913,739
	5th	666,678	222,226	551,938	7,359,175	666,678	222,226	551,938	7,359,175	666,678	222,226	551,938	7,359,175
	6th	545,650	181,883	451,740	6,023,195	545,650	181,883	451,740	6,023,195	545,650	181,883	451,740	6,023,195
	7th	461,885	153,962	382,391	5,098,547	461,885	153,962	382,391	5,098,547	461,885	153,962	382,391	5,098,547
	8th	400,448	133,483	331,528	4,420,371	400,448	133,483	331,528	4,420,371	400,448	133,483	331,528	4,420,371
	9th	353,452	117,817	292,621	3,901,608	353,452	117,817	292,621	3,901,608	353,452	117,817	292,621	3,901,608

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Spud Date	Year of Production	Low Development				Moderate Development				Aggressive Development			
		Oil (bbl)	Casinghead Gas (MCF)	Condensate (bbl)	Natural Gas (MCF)	Oil (bbl)	Casinghead Gas (MCF)	Condensate (bbl)	Natural Gas (MCF)	Oil (bbl)	Casinghead Gas (MCF)	Condensate (bbl)	Natural Gas (MCF)
2011 Wells	1st	76,270,086	25,423,362	32,743,432	436,579,100	76,270,086	25,423,362	32,743,432	436,579,100	76,270,086	25,423,362	32,743,432	436,579,100
	2nd	27,496,814	9,165,605	11,804,629	157,395,056	27,496,814	9,165,605	11,804,629	157,395,056	27,496,814	9,165,605	11,804,629	157,395,056
	3rd	15,057,037	5,019,012	6,464,121	86,188,279	15,057,037	5,019,012	6,464,121	86,188,279	15,057,037	5,019,012	6,464,121	86,188,279
	4th	7,754,945	2,584,982	3,329,268	44,390,236	7,754,945	2,584,982	3,329,268	44,390,236	7,754,945	2,584,982	3,329,268	44,390,236
	5th	2,490,645	830,215	1,069,256	14,256,752	2,490,645	830,215	1,069,256	14,256,752	2,490,645	830,215	1,069,256	14,256,752
	6th	2,038,495	679,498	875,144	11,668,590	2,038,495	679,498	875,144	11,668,590	2,038,495	679,498	875,144	11,668,590
	7th	1,725,557	575,186	740,797	9,877,293	1,725,557	575,186	740,797	9,877,293	1,725,557	575,186	740,797	9,877,293
	8th	1,496,034	498,678	642,261	8,563,478	1,496,034	498,678	642,261	8,563,478	1,496,034	498,678	642,261	8,563,478
2012 Wells	1st	163,071,048	54,357,016	27,504,483	331,800,116	169,232,959	56,410,986	30,684,689	370,164,504	180,322,266	60,107,422	32,145,865	387,791,385
	2nd	58,790,209	19,596,736	9,915,889	119,620,243	61,011,696	20,337,232	11,062,413	133,451,333	65,009,601	21,669,867	11,589,195	139,806,159
	3rd	32,193,050	10,731,017	5,429,862	65,503,092	33,409,519	11,136,506	6,057,689	73,076,887	35,598,740	11,866,247	6,346,151	76,556,739
	4th	16,580,643	5,526,881	2,796,585	33,736,579	17,207,170	5,735,723	3,119,940	37,637,371	18,334,702	6,111,567	3,268,509	39,429,627
	5th	5,325,183	1,775,061	898,175	10,835,132	5,526,404	1,842,135	1,002,027	12,087,944	5,888,532	1,962,844	1,049,742	12,663,560
	6th	4,358,452	1,452,817	735,121	8,868,129	4,523,144	1,507,715	820,120	9,893,506	4,819,531	1,606,510	859,173	10,364,625
	7th	3,689,367	1,229,789	622,269	7,506,743	3,828,776	1,276,259	694,219	8,374,710	4,079,664	1,359,888	727,277	8,773,506
2013 Wells	1st	155,640,890	51,880,297	23,051,376	251,469,561	186,476,205	62,158,735	28,625,127	312,274,115	249,714,025	83,238,008	31,227,412	340,662,671
	2nd	56,111,496	18,703,832	8,310,459	90,659,552	67,228,213	22,409,404	10,319,902	112,580,749	90,026,648	30,008,883	11,258,075	122,815,362
	3rd	30,726,209	10,242,070	4,550,741	49,644,449	36,813,634	12,271,211	5,651,096	61,648,321	49,297,875	16,432,625	6,164,832	67,252,714
	4th	15,825,164	5,275,055	2,343,804	25,568,776	18,960,419	6,320,140	2,910,529	31,751,226	25,390,277	8,463,426	3,175,123	34,637,701
	5th	5,082,547	1,694,182	752,757	8,211,889	6,089,492	2,029,831	934,771	10,197,498	8,154,561	2,718,187	1,019,750	11,124,544
	6th	4,159,864	1,386,621	616,102	6,721,108	4,984,010	1,661,337	765,073	8,346,251	6,674,187	2,224,729	834,625	9,105,001
2014 Wells	1st	146,115,152	48,705,051	19,279,333	189,999,224	203,114,106	67,704,702	26,593,571	262,081,571	326,310,754	108,770,251	30,062,298	296,266,124
	2nd	52,677,287	17,559,096	6,950,566	68,498,329	73,226,492	24,408,831	9,587,487	94,485,384	117,641,223	39,213,741	10,838,029	106,809,564
	3rd	28,845,663	9,615,221	3,806,074	37,509,139	40,098,244	13,366,081	5,250,032	51,739,443	64,419,397	21,473,132	5,934,819	58,488,067
	4th	14,856,611	4,952,204	1,960,273	19,318,631	20,652,118	6,884,039	2,703,966	26,647,778	33,178,435	11,059,478	3,056,657	30,123,575
	5th	4,771,478	1,590,493	629,578	6,204,539	6,632,813	2,210,938	868,429	8,558,431	10,655,873	3,551,958	981,702	9,674,748
2015 Wells	1st	134,912,951	44,970,984	16,094,052	143,058,239	219,184,235	73,061,412	24,612,878	218,781,138	385,817,791	128,605,930	28,715,024	255,244,661
	2nd	48,638,681	16,212,894	5,802,211	51,575,212	79,020,079	26,340,026	8,873,410	78,874,755	139,094,640	46,364,880	10,352,312	92,020,547
	3rd	26,634,154	8,878,051	3,177,245	28,242,175	43,270,766	14,423,589	4,859,009	43,191,188	76,167,117	25,389,039	5,668,843	50,389,719
	4th	13,717,601	4,572,534	1,636,402	14,545,792	22,286,087	7,428,696	2,502,574	22,245,101	39,228,957	13,076,319	2,919,670	25,952,618

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Spud Date	Year of Production	Low Development				Moderate Development				Aggressive Development			
		Oil (bbl)	Casinghead Gas (MCF)	Condensate (bbl)	Natural Gas (MCF)	Oil (bbl)	Casinghead Gas (MCF)	Condensate (bbl)	Natural Gas (MCF)	Oil (bbl)	Casinghead Gas (MCF)	Condensate (bbl)	Natural Gas (MCF)
2016 Wells	1st	122,369,579	40,789,860	13,411,710	107,293,680	234,726,516	78,242,172	22,700,680	181,605,437	421,067,729	140,355,910	27,240,816	217,926,524
	2nd	44,116,557	14,705,519	4,835,176	38,681,409	84,623,366	28,207,789	8,184,026	65,472,209	151,802,913	50,600,971	9,820,831	78,566,650
	3rd	24,157,875	8,052,625	2,647,704	21,181,632	46,339,081	15,446,360	4,481,508	35,852,060	83,126,066	27,708,689	5,377,809	43,022,472
2017 Wells	1st	108,408,884	36,136,295	11,158,543	80,112,614	249,781,666	83,260,555	20,870,097	149,836,592	456,112,559	152,037,520	25,686,273	184,414,267
	2nd	39,083,461	13,027,820	4,022,867	28,882,119	90,051,034	30,017,011	7,524,066	54,018,937	164,437,240	54,812,413	9,260,389	66,484,846
2018 Wells	1st	93,934,225	31,311,408	9,270,174	59,512,228	264,390,067	88,130,022	19,130,408	122,812,493	490,917,671	163,639,224	24,090,143	154,652,768

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APPENDIX G: SURVEY TEMPLATES FOR EAGLE FORD PRODUCTION

Hydraulic Fracturing Survey

2012

Company Name:

		Hydraulic Fracturing											
		Hydraulic Fracturing Dates				If Fuel Usage is Available		If Fuel Usage is Not Available					
Pad Name	Well Name	Start Date	End Date	Total Hours Hydraulic Fracturing	Controls (Tier1, Tier2, Tier4, SNCR, SCR, etc.)	Fuel Type (Diesel/NG)	Quality (gal./mcf)	Average Horsepower for Each Pump Engine	Number of Pump Engines	Actual Pump Throughput (gpm)	Discharge Pressures (psi)	Engine Make	Engine Model
-	-												
-	-												
-	-												
-	-												
-	-												
-	-												
-	-												
-	-												
-	-												
-	-												
-	-												
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-	-												
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Drilling Rig Survey

2012

Company Name:		Drilling												
Pad Name	Well Name	Drilling Dates			Well Depth (feet)	Controls (Tier1, Tier2, Tier4, SNCR, SCR, etc.)	If Fuel Usage is Available		If Fuel Usage is Not Available				
		Drilling Start Date	Drilling End Date	Total Hours Drilling			Fuel Type (Diesel)	Quality (gal.)	Horsepower for Each Engine	Number of Engines	Engine Make	Engine Model	Load Factor on each Engine
-	-												
-	-												
-	-												
-	-												
-	-												
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