**582-11-11219 Amendment Number 5**
**Task 2, Project II**

# Oil and Gas Emission Inventory, Eagle Ford Shale

## Technical Report

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**Prepared by**
**Alamo Area Council of Governments**

**Prepared in Cooperation with the**
**Texas Commission on Environmental Quality**

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**Abstract:** This assessment provides key information on the impact of increased oil and gas production in the Eagle Ford Shale region. 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. Production in the Eagle Ford emitted an estimated 66 tons of $NO_X$ and 101 tons of VOCs per ozone season day in 2011. For the 2012 photochemical model projection year, emissions increased to 111 tons of $NO_X$ and 229 tons of VOCs per ozone season day. To estimate emissions for 2018, calculations were based on three potential levels of development. $NO_X$ emissions increase slightly for the low development scenario in 2018 (113 tons per day). $NO_X$ emissions also increase under the 2018 moderate scenario (146 tons per day) and the high scenario (188 tons per day). By 2018, VOC emissions are expected to increase significantly to 338 tons per ozone season day under the low development scenario and to 872 tons per ozone season day under the high development scenario. The majority of $NO_X$ emissions in 2012 were emitted by drill rigs and well hydraulic pump engines (47%). By 2018, these sources are expected to account for only 9% of the $NO_X$ emissions as engines are replaced with models that meet TIER4 standards. In contrast, compressors and mid-stream sources only accounted for 39% of $NO_X$ emissions in 2012, but are expected to increase to 77% of total $NO_X$ emissions under the 2018 moderate scenario because of the significant increase in oil and gas production. The majority of VOC emissions in 2018 are from storage tanks (47%) and loading loss (32%).

| **Related Reports:** Oil and Gas Emission Inventory Improvement Plan, Eagle Ford | **Distribution Statement:** Alamo Area Council of Governments, Natural Resources/Transportation Department | **Permanent File:** Alamo Area Council of Governments, Natural Resources/Transportation Department |
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# EXECUTIVE SUMMARY

The compilation of the emissions inventory (EI) requires 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 citizens can work together to protect heath and the environment. This assessment provides key information on the impact of increased oil and gas production from the Eagle Ford Shale on the regional emissions inventory. A partnership between the oil and gas industry and local officials is critical for the successful development of an inventory of ozone precursor emissions. Local officials continue to work closely with oil and gas companies, drilling contractors, engine manufactures, industry representatives, and the Texas Center for Applied Technology (TCAT) to collect improved local data, conduct surveys, and get industry input.

"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."[1] Hydraulic fracturing is a technological advancement which allows producers to recover natural gas and oil resources from these shale formations. 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] 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.

Existing oil and gas production inventories in Texas and data from the Railroad Commission of Texas were used to develop the emissions inventory of the Eagle Ford. Whenever possible, local data was used to calculate emissions and project future production. 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 emissions were calculated using local industry data, emission factors from ERG's Statewide Drilling Rigs Emission Inventory,[3] TexN model, equipment manufacturers, TCEQ, and the results from TCAT surveys. Compressor engine emissions were based on TCEQ's Barnett Shale Special Inventory.

There are three different types of wells in the Eagle Ford Shale development included in the emission inventory: dry gas wells, wet gas wells that produce condensate, and oil wells that can also produce casinghead gas. Hydrocarbons are released in the Eagle Ford Shale during five main phases of well construction and production: exploration and pad construction, drilling operation, hydraulic fracturing and completion operation, production, and midstream sources. Emissions sources include drill rigs, compressors, pumps, heaters, other non-road equipment, process emissions, flares, storage tanks, fugitive, and on-road.

[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] *Ibid*.
[3] Eastern Research Group, Inc., August 15, 2011. "Development of Texas Statewide Drilling Rigs Emission Inventories for the Years 1990, 1993, 1996, and 1999 through 2040". TCEQ Contract No. 582-11-99776. 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 10/24/2013.

Production in the Eagle Ford emitted an estimated 66 tons of $NO_X$ and 101 tons of VOCs per ozone season day in 2011. For the 2012 photochemical model projection year, emissions increased to 111 tons of $NO_X$ and 229 tons of VOCs per ozone season day. To estimate emissions for 2018, calculations were based on three potential levels of development. $NO_X$ emissions increase slightly for the low development scenario in 2018 (113 tons per day). $NO_X$ emissions also increase under the 2018 moderate scenario (146 tons per day) and the high scenario (188 tons per day). By 2018, VOC emissions are expected to increase significantly to 338 tons per ozone season day under the low development scenario and to 872 tons per ozone season day under the high development scenario.

Table ES-1: Emissions Summary from the Eagle Ford, 2011, 2012, 2015, and 2018.

| Year | Low Development Scenario | | | Moderate Development Scenario | | | High Development Scenario | | |
|---|---|---|---|---|---|---|---|---|---|
| | VOC | $NO_X$ | CO | VOC | $NO_X$ | CO | VOC | $NO_X$ | CO |
| 2011 | 101 | 66 | 50 | 101 | 66 | 50 | 101 | 66 | 50 |
| 2012 | 229 | 111 | 92 | 229 | 111 | 92 | 229 | 111 | 92 |
| 2015 | 347 | 108 | 113 | 417 | 121 | 130 | 512 | 140 | 154 |
| 2018 | 338 | 113 | 113 | 544 | 146 | 160 | 872 | 188 | 226 |

The majority of $NO_X$ emissions in 2012 were emitted by drill rigs and well hydraulic pump engines (47%). By 2018, these sources are expected to account for only 9% of the $NO_X$ emissions as engines are replaced with models that meet TIER4 standards. In contrast, compressors and mid-stream sources only accounted for 39% of $NO_X$ emissions in 2012, but are expected to increase to 77% of total $NO_X$ emissions under the 2018 moderate scenario because of the significant increase in oil and gas production. The majority of VOC emissions in 2018 are from storage tanks (47%) and loading loss (32%). Other significant sources of VOC emissions are midstream sources (7%), pneumatic devices (5%), and fugitives (4%).

Over 51% of the Eagle Ford $NO_X$ emissions are produced in four counties: Webb, Dimmit, Karnes, and La Salle. Eagle Ford operations in Webb County emitted 15.7 tons of $NO_X$ per ozone season day, while operations in Dimmit emitted 14.6 tons, operations in Karnes emitted 14.2 tons, and operations in La Salle emitted 12.8 tons in 2012. Under the 2018 moderate development scenario, oil and natural gas operations are projected to emit, on an ozone season day, 26.4 tons of $NO_X$ in Webb County , 17.9 tons of $NO_X$ in Dimmit , 16.8 tons of $NO_X$ in La Salle, , and 15.1 tons of $NO_X$ in Karnes. A similar pattern occurs with VOC emissions under the 2018 moderate scenario in which ozone season daily emissions are expected to be: 84.6 tons in Webb County 71.5 tons in Dimmit , 66.1 tons in La Salle emitted, and 64.8 tons in Karnes. Emissions for each county were geo-coded based on the locations of wells and well types in each county.

Several improvements to the Eagle Ford emission inventory were not completed in time for this emission inventory. The updates for future Eagle Ford emission inventories can include: drill rig and hydraulic pump survey, projection of mid-stream sources, stack parameters of mid stream sources, TCEQ's pneumatic survey, TxDOT on-road traffic counts, Barnett shale special inventory final results, updated spatial allocation of emissions, and construction of mid-stream facilities and pipelines.

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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'."[4] 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."[5] 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.[6]

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, product is extracted by pumping "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."[7]

Locations of the Eagle Ford and other shale plays in the lower 48 states are provided in Figure 1-1.[8] 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 addressed 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 production inventories in Texas and data from the Railroad Commission of Texas were used to develop an emissions inventory of the Eagle Ford. These studies include: 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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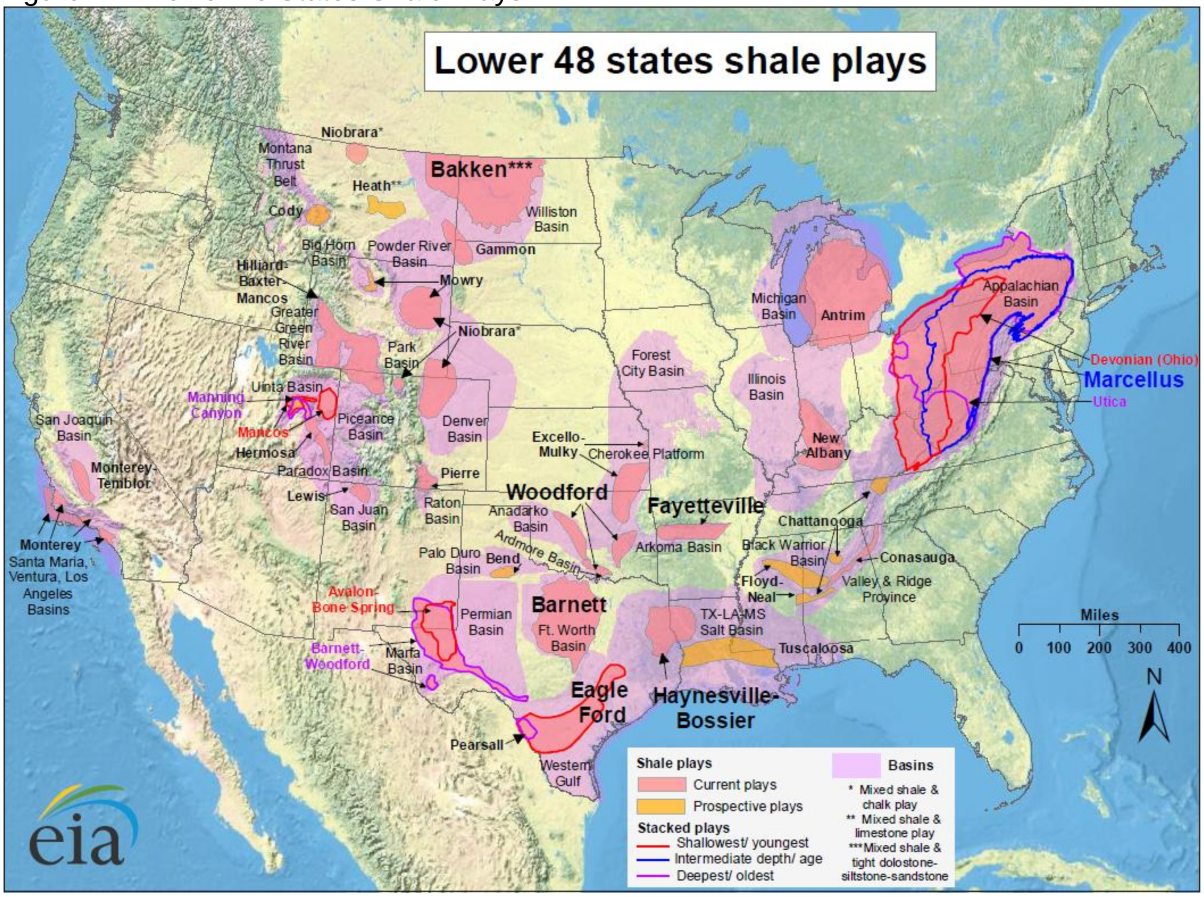
[4] Railroad Commission of Texas, May 22, 2012. "Eagle Ford Information". Austin, Texas. Available online: http://www.rrc.state.tx.us/eagleford/index.php. Accessed 05/30/2012.
[5] Chesapeake Energy, Sept. 2011. "Eagle Ford Shale Hydraulic Fracturing". Available online: http://www.chk.com/Media/Educational-Library/Fact-Sheets/EagleFord/EagleFord_Hydraulic_Fracturing_Fact_Sheet.pdf. Accessed: 04/12/2012.
[6] *Ibid*.
[7] *Ibid*.
[8] 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 conducted a mail survey through the Barnett Shale area special inventory phase two study on natural gas fracturing operations west of Dallas. Results from the Barnett Shale study were also used to calculate production and midstream emissions. Through this process, local officials worked with oil and gas companies, drilling contractors, engine manufactures, and industry representatives to refine data inputs and the emission inventory.

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.[9] 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. Although the San Antonio area has recorded ozone concentrations in violation of the 2008 ozone standard since August 2012, the timing of the violations was late enough in the NAAQS review cycle that the area was not included in EPA's designation process and the region avoided a non-attainment designation.
Ozone is produced when volatile organic compounds (VOC) and nitrogen oxides ($NO_X$) react in the presence of sunlight, especially during the summer time.[10] These ozone

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

precursors can be generated by natural processes, but the majority of chemicals that form ground-level ozone originate from anthropogenic sources.

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."[11] 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 conduct analysis that determines the emission reductions required to bring the area into compliance with the standards, local and state air quality planners need an accurate temporal and spatial account of emissions and their sources in the region. The compilation of the Eagle Ford emissions inventory (EI) required extensive research and analysis, and provided a vast database of regional pollution sources and emission rates. By understanding these varied sources that create ozone precursor pollutants, planners, political leaders, and citizens can work together to protect heath and the environment. This assessment provides key information on the impact of increased oil and gas production in the Eagle Ford Shale.

## 1.2 Inventory Pollutants

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

- Nitrogen oxides ($NO_X$)
- Volatile organic compounds (VOC)
- Carbon monoxide (CO)

Emissions were calculated for average ozone season day and aggregated to develop county totals. After the emission inventory was completed and reviewed, emissions were geo-coded to the 4km grid system used in the June 2006 region photochemical model. Photochemical modeling used to predict a region's ability to comply with the NAAQS depends, to a large degree, on accurately identifying and quantifying emission rates from these pollutants.

## 1.3 Base Year and Geographical Area Covered

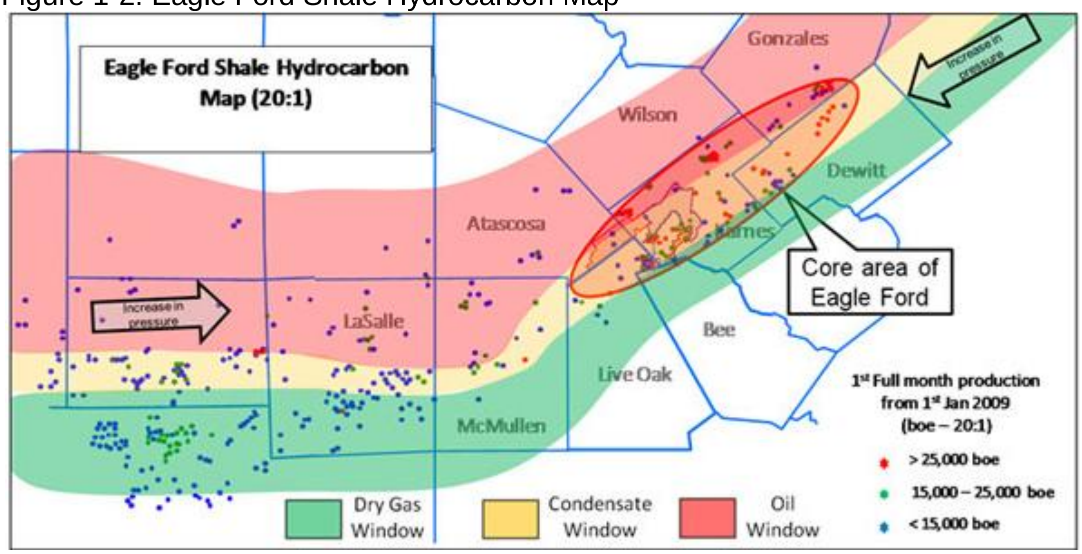
The Eagle Ford ozone precursor emission inventory includes the 25 counties listed below for the years 2011, 2012, 2015, and 2018. All 25 counties are currently in attainment of all air quality regulatory standards. Any emissions directly or indirectly associated with Eagle Ford production outside of these counties are not included in the emission inventory.

[11] 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.

- Atascosa (48013)
- Bee (48025)
- Brazos (48041)
- Burleson (48051)
- De Witt (48123)
- Dimmit (48127)
- Fayette (48149)
- Frio (48163)
- Gonzales (48177)
- Grimes (48185)
- Houston (48225)
- Karnes (48255)
- La Salle (48283)
- Lavaca (48285)
- Lee (48287)
- Leon (48289
- Live Oak (48297)
- Maverick (48323)
- McMullen (48311)
- Madison (48313)
- Milam (48331)
- Washington (48477)
- Webb (48479)
- Wilson (48493)
- Zavala (48507)

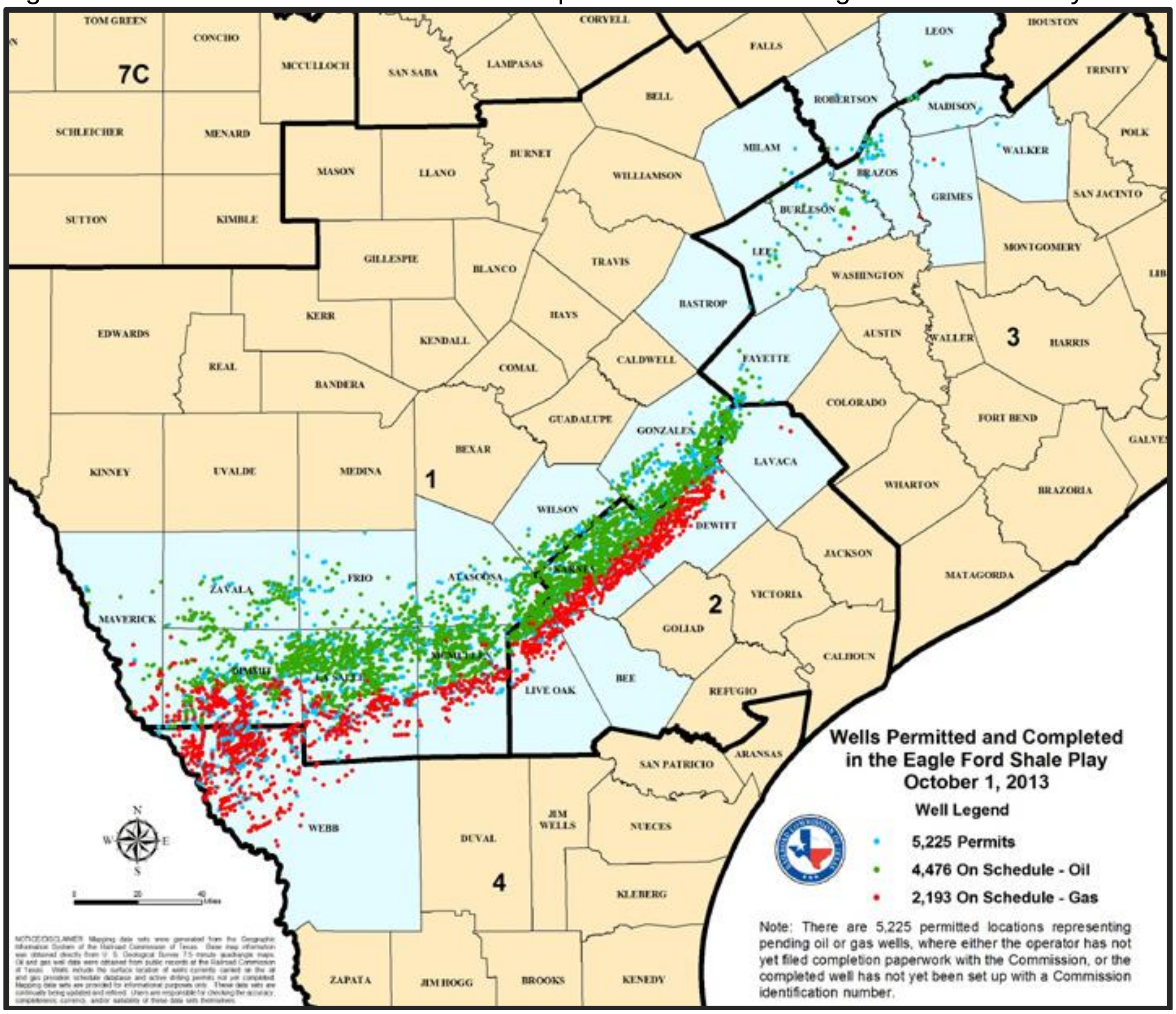
The core area of Eagle Ford production is located in Karnes County with sections of the core area in Dewitt, Gonzales, Atascosa, and Live Oak counties (Figure 1-2). This area of the Eagle Ford contains the most intensive development, and potential for future growth. Eagle Ford counties and the location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

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




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

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




There are over 200 oil and gas companies operating in the Eagle Ford counties.[14] Some of the companies that are operating in the Eagle Ford are listed below.[15]

- Abraxas Petroleum
- Acock Operating
- Alamo Operating Co.
- Ampak Oil Co.
- Anadarko Petroleum
- Apache
- Enervest
- EOG Resources
- Escondido Resources
- Espada Operating
- Express Oil
- ExxonMobil
- Redwood Operating
- Regency Energy
- Riley Exploration
- Rio Grand Exploration
- Rio Tex, Inc.
- Rock Solid Operating

[13] Railroad Commission of Texas, October 1, 2013. "Wells Permitted and Completed in the Eagle Ford Shale Play". Austin, Texas. Available online: http://www.rrc.state.tx.us/eagleford/images/EagleFordShalePlay100113-lg.jpg. Accessed: 10/22/2013.

[14] 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.

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

- 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
- 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
- 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 Modeling Domain Parameters

Development of input files and spatial surrogates for photochemical model emissions processing is 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.

## 1.5 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."[16] 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."[17] "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 1-4 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".[23]

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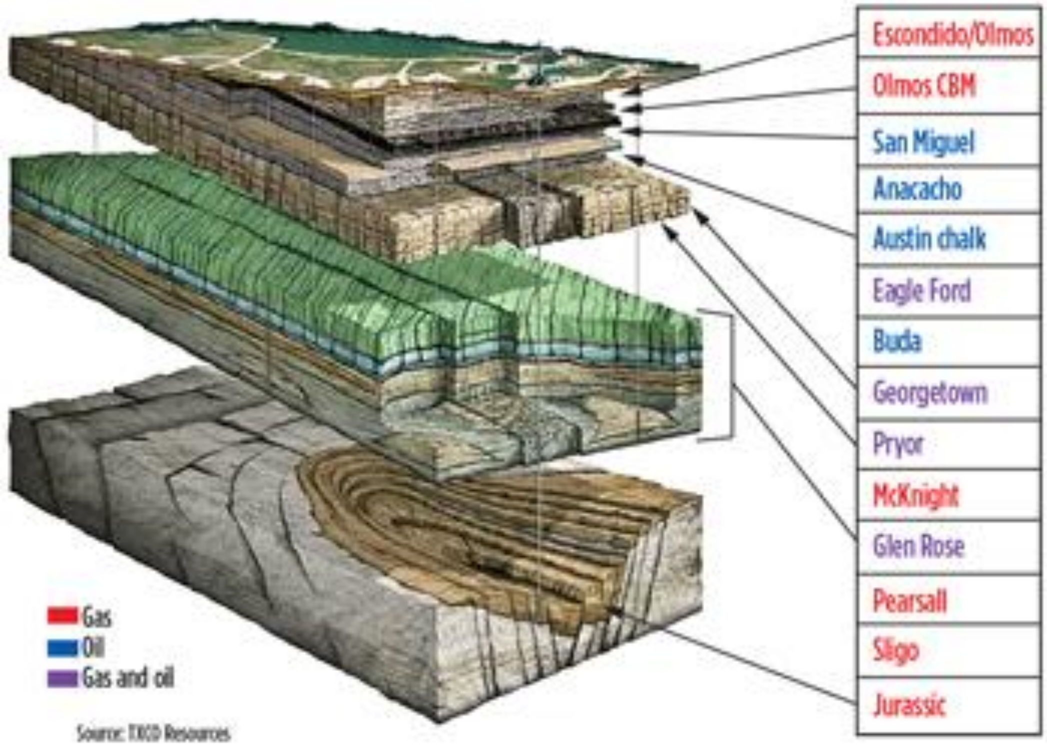
[16] Halliburton. "U.S. Shale Gas: An Unconventional Resource. Unconventional Challenges". Available online: http://www.halliburton.com/public/solutions/contents/Shale/related_docs/H063771.pdf. Accessed: 04/20/2012.
[17] *Ibid*.
[18] *Ibid*.
[19] Eagle Ford Shale Now (EFSN), Nov. 1, 2011. "Eagle Ford 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 1-4: 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 being hydraulically fractured to produce natural gas including the Austin Chalk and Pearsall formations.

### 1.6 Types of Operations in the Eagle Ford

The inventory developed for the Eagle Ford Shale includes emissions from the construction and operation of three different types of wells.

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

Hydrocarbons are produced in the Eagle Ford during five main phases that of activity.

- Exploration and Pad Construction: During exploration, vibrator trucks produce sound waves beneath the surface to help determine subsurface geologic features. 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

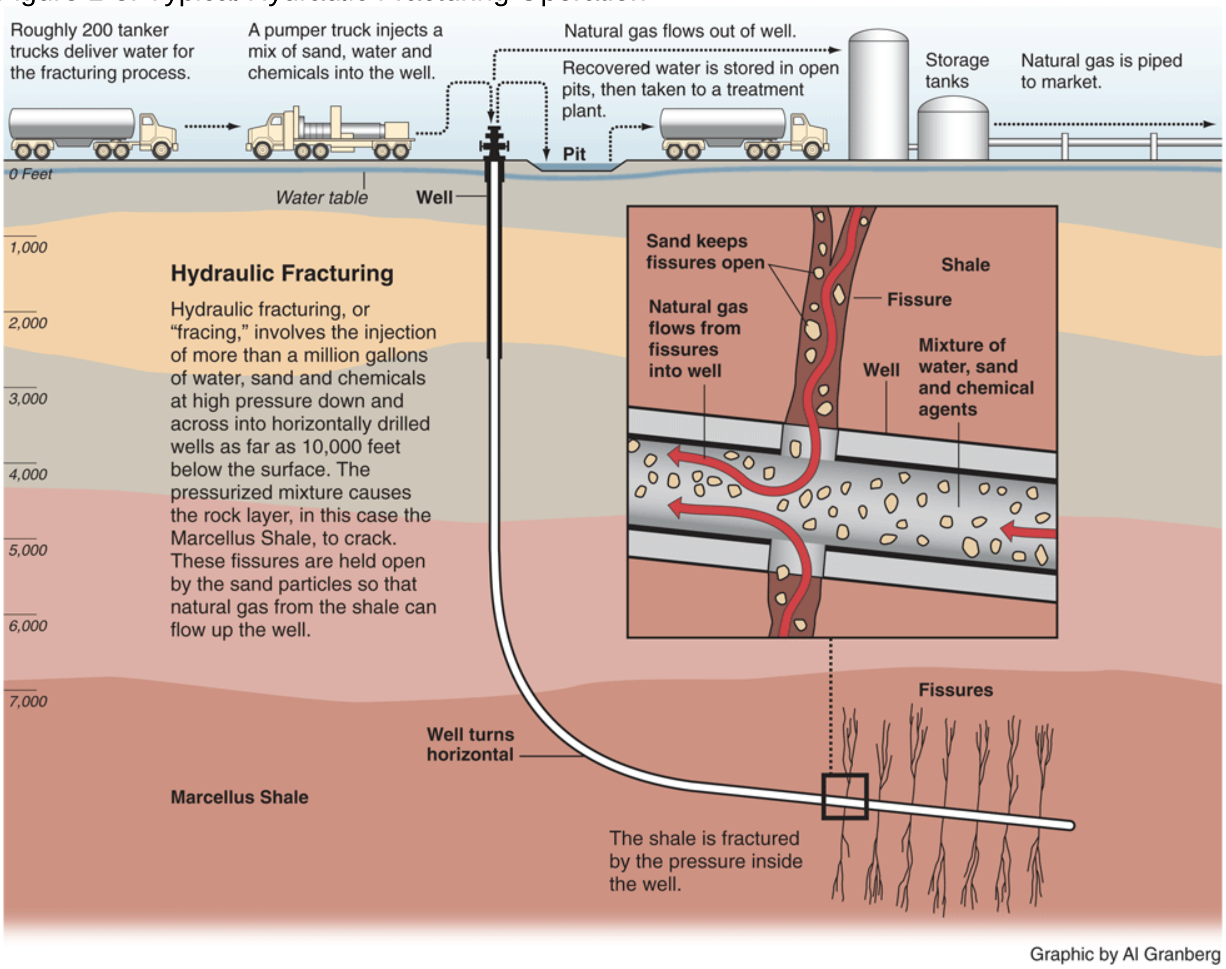
[24] *Ibid*.

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 include construction equipment and trucks to haul supplies, equipment, fluids, and employees.
- Hydraulic Fracturing and Completion Operation: As shown in Figure 1-5, 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, gas vented during the completion process is usually flared.
- Production: Once the product is collected from the well, emissions can be released 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 1-5: Typical Hydraulic Fracturing Operation[29]




Below is a list of emission sources for each phase of operation. Emission sources include non-road equipment, generators, drill rigs, on-road vehicles, compressors, fugitive emissions, and flare combustion. However, actual equipment used in the Eagle Ford for drilling, hydraulic fracturing, and production varies by company. Table 1-1 shows the assignment of SCC codes for each emission source listed below.

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

Table 1-1: Assignment of SCCs to Eagle Ford Oil and Gas Sources

| Phase | Source | SCC |
|---|---|---|
| Exploration and Pad Construction | Diesel Seismic Trucks | 2270002051 |
| | Diesel Dozer | 2270002069 |
| | Diesel Excavator | 2270002018 |
| | Diesel Scraper | 2270002036 |
| | Diesel Grader | 2270002048 |
| | Diesel Tractors | 2270002066 |
| | Diesel Loader | 2270002060 |
| | Diesel Roller | 2270002015 |
| | Heavy Duty Trucks Exhaust | MVDSCS21RX |
| | Heavy Duty Trucks Idling | MVDSCLOFIX |
| | Light Duty Trucks Exhaust | MVDSLC21RX |
| | Light Duty Trucks Idling | MVDSLC21RX |

| Phase | Source | SCC |
|---|---|---|
| Drilling Operation | Diesel Mechanical Drill Rigs | 2270002033 |
| | Diesel Electric Drill Rigs | 2270006005 |
| | Diesel Cranes | 2270002045 |
| | Diesel Pumps | 2270006010 |
| | Diesel Excavators | 2270002036 |
| | Heavy Duty Trucks Exhaust | MVDSCS21RX |
| | Heavy Duty Trucks Idling | MVDSCLOFIX |
| | Light Duty Trucks Exhaust | MVDSLC21RX |
| | Light Duty Trucks Idling | MVDSLC21RX |
| Hydraulic Fracturing and Completion Operation | Diesel Pump Engines | 2270006005 |
| | Diesel Cranes | 2270002045 |
| | Diesel Backhoe | 2270002066 |
| | Diesel Bulldozer | 2270002069 |
| | Diesel Forklift | 2270003020 |
| | Diesel Generator Sets | 2270006005 |
| | Diesel Water Pumps | 2270006010 |
| | Diesel Blender Truck | 2270010010 |
| | Diesel Sand Kings | 2270010010 |
| | Diesel Blow Out Control Systems | 2270010010 |
| | Heavy Duty Trucks Exhaust | MVDSCS21RX |
| | Heavy Duty Trucks Idling | MVDSCLOFIX |
| | Light Duty Trucks Exhaust | MVDSLC21RX |
| | Light Duty Trucks Idling | MVDSLC21RX |
| | Completion Flares – Oil Wells | 2310021600 |
| | Completion Flares – Natural Gas Wells | 2310010700 |
| Production | Natural Gas, Lean - 2 Cycle Compressors | 20200252 |
| | Natural Gas, Lean - 4 Cycle Compressors | 20200251 |
| | Natural Gas, Rich - 2 Cycle Compressors | 20200251 |
| | Natural Gas, Rich - 4 Cycle Compressors | 20200253 |
| | Diesel Compressors | 2265006015 |
| | Wellhead Heaters | 2310011100 |
| | Flares - Natural Gas Wells | 31000204 |
| | Flares - Oil Wells | 31000160 |
| | Wellhead Dehydrators - Natural Gas Wells | 2310021400 |
| | Wellhead Dehydrators - Oil Wells | 2310021400 |
| | Condensate Tanks | 2310011010 |
| | Oil Tanks | 2310011020 |
| | Fugitives - Natural Gas Wells | 2310021501 |
| | Fugitives - Oil Wells | 2310011501 |
| | Loading Loss - Condensate | 2310011201 |
| | Loading Loss - Oil | 2310011202 |
| | Blowdowns - Gas Wells | 2310021600 |
| | Blowdowns - Oil Wells | 2310010700 |
| | Pneumatic Devices | 2310020700 |
| | Heavy Duty Trucks Exhaust | MVDSCS21RX |
| | Heavy Duty Trucks Idling | MVDSCLOFIX |
| | Light Duty Trucks Exhaust | MVDSLC21RX |
| | Light Duty Trucks Idling | MVDSLC21RX |

TCEQ's point source database was checked to avoid double counting emissions from mid-stream sources or large wellhead compressor facilities. AACOG's Eagle Ford emissions inventory also omits some infrequent, ancillary, and indirect sources. Non-routine emissions, such as those generated during upsets or from maintenance, startup, and shutdown activities, were excluded from the emission inventory, with the exception of blowdowns from gas wells. The emission inventory 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. Emission sources outside of the Eagle Ford shale region that are directly or indirectly affected by the shale development are not included. The emission inventory 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 excludes emissions from railroad activity related to Eagle Ford development. Railroads carry fracturing sands, pipelines, petroleum products, equipment, building materials, and other supplies to production sites in the Eagle Ford. 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] "BNSF is investing heavily in southwest Bexar County, with intentions to construct a rail yard or a larger shipping facility. Union Pacific, encouraged by the thriving Eagle Ford petroleum find, has hired an additional 300 people in the area, increasing their south Texas workforce to 1,400. The company also reactivated the South Side Rail Yard, which had been idled due to lack of activity. Union Pacific invested $100 million in an intermodal transportation terminal in San Antonio that can switch cargo containers from trains onto tractor-trailers fanning out from the terminal. Additionally, the Port of San Antonio, which operates a rail yard that connects both Union Pacific and BNSF lines, experienced a 53 percent increase in traffic in 2011. More than half of the current rail activity at the privatized air base is now related to Eagle Ford activity."[31]

## 1.7 Eagle Ford Emissions Inventory Group Workshop

### 1.7.1 May 21st, 2012 Meeting

A partnership between the oil and gas industry and local officials is critical for the successful development of an ozone precursor emissions inventory. Local officials continue to work closely with local oil and gas industry, equipment manufacturers, and the 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 21, 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 was attended by 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 developing an accurate emissions inventory of ozone precursors produced by oil and gas activities in the Eagle Ford. The industry was provided an overview

[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] GoRail. "Railroads Continue Hiring to Meet Eagle Ford Shale Demand". Available online: http://gorail.org/community/freight-rail-helps-franklin-county-load-up-on-jobs/. Accessed 10/29/2013.

of the region's regulatory ozone challenge, the purpose of the AIR Committees, 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 was provided to industry representatives.

Local industry representatives recommended surveying targeted companies for each phase of the operation. Each survey focused on a specific aspect of the operations, such as drilling or hydraulic fracturing operations. Draft surveys were reviewed by industry representatives for accuracy and comprehensiveness.

The Eagle Ford group suggested collecting data for a variety of activities including fuel usage or activity data, 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[32] could be useful for the ozone precursor emission inventory.

Recommendations put forth in the meeting by industry included using Wyoming[33] and Pennsylvania[34] surveys of oil and gas operations as templates for conducting surveys in the 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)[35] could be used as a "data aggregator" to work proprietary data into a public format. AACOG involved the industry in all aspects of the emission inventory development.

#### 1.7.2 January 8, 2013 Meeting

The second meeting of the Eagle Ford Emissions Inventory Group occurred on January 8, 2013. Topics at the meeting included a review of ozone values for San Antonio, draft estimations of the Eagle Ford Shale inventory, status of the June 2006 photochemical modeling episode, and the results from other oil and gas studies. Oil and gas industry representatives recommended looking at performance test engine data for large oil and gas emission sources. Oil and gas companies have to report this data for larger engines to TCEQ. For pneumatic devices, industry representatives recommended using the results from TCEQ's statewide pneumatic devices survey. A review of state and federal regulations, and potential control measures were presented at the end of the meeting.

Initial draft survey forms for drill rigs and well pad hydraulic pump engines were presented to the oil and gas industry representatives. Several oil and gas industry trade groups offered to distribute the survey to members to help increase response rates. Industry recommendations for the survey letter included adding to the survey the model year, total

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[32] 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.

[33] 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.

[34] 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.

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

depth drilled, total annual hours, and number of wells drilled. Industry representatives suggested distributing the survey after the reporting deadline for EPA's greenhouse gas subpart W – petroleum and natural gas systems. It would be too difficult for companies to complete reporting for subpart W and the Eagle Ford emission inventory survey at the same time. Industry also noted that the survey did not need to collect data on individual well sites and it would be easier to fill out the survey using boxes on the forms.

Industry representatives mentioned that emissions could be projected in the future based on engine wear data collected by companies. In addition, North Central Texas Council of Governments (NCTCOG) collected data on projections for operators in the Barnett Shale. Any projections should take into account faster drill times as drill rigs are getting significantly more powerful and faster.

#### 1.7.3 July 2, 2013 meeting

Industry representatives were provided updated draft results of the Eagle Ford Emission Inventory and projections at the third meeting of the Eagle Ford Emissions Inventory Group. Results from the initial photochemical model run for each projection scenario were provided to stakeholders. Final drill rig and well pad hydraulic pump engines survey forms were reviewed by the committee at the meeting.

At the end of the meeting, HoltCAT staff presented on the Texas Emission Reduction Plan (TERP) and SB 1727. The bill text for the oil and gas industry reads "reduction of emissions from the operation of drilling, production, completions, and related heavy-duty on-road vehicles or non-road equipment in oil and gas production fields where the commission determines that the programs can help prevent that area or an adjacent area from being in violation of national ambient air quality standards."[36] The committee recommended sending a letter to the state recommending the following changes to the TERP program: requiring a 2-3 year contract, raising default hours and mileage to realistic oil and gas operations, including the entire state for TERP funding, setting aside funds for oil and gas grants, and raising cost per ton limits.

## 1.8 Data Sources

A variety of data sources were used to estimate emissions from Eagle Ford oil and gas production. Whenever possible, local data was used to calculate emissions and project future production. Counts of drill rigs operating in the Eagle Ford and number of wells drilled were provided by Schlumberger. Similarly, well characteristics and production amounts were collected from Schlumberger and the Railroad Commission of Texas. Non-road equipment emissions were calculated using local industry data, emission factors from ERG's Statewide Drilling Rigs Emission Inventories for the Years 1990, 1993, 1996, and 1999 through 2040,[37] TexN model, equipment manufacturers, TCEQ, and the results from TCAT surveys. Compressor engine emissions were based on TCEQ's Barnett Shale Special Inventory (Table 1-2).

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[36] Texas Legislature, 06/14/2013. "S.B. No. 1727". Austin, Texas. Available online: http://www.legis.state.tx.us/BillLookup/Text.aspx?LegSess=83R&Bill=SB1727. Accessed 10/24/2013.
[37] Eastern Research Group, Inc., August 15, 2011. "Development of Texas Statewide Drilling Rigs Emission Inventories for the Years 1990, 1993, 1996, and 1999 through 2040". TCEQ Contract No. 582-11-99776. 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 10/24/2013.

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 from Marathon Oil Corporation | Equipment Manufactures | Local Industry Data from Marathon Oil Corporation | 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 in Appendix A | Local Industry Data in Appendix A | Local Industry Data from Schlumberger Limited, Global Hunter Securities, Energy Strategy Partners, and Railroad Commission of Texas | Local Industry Data/ TexN Model | TCEQ |
| Mechanical Drill Rigs | Local Industry Data in Appendix A | Local Industry Data in Appendix A | Local Industry Data from Schlumberger Limited, Global Hunter Securities, Energy Strategy Partners, and Railroad Commission of Texas | ERG Drill Rig EI | ERG Drill Rig EI |
| 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 Eagle Ford Survey, ERG's Fort Worth Natural Gas Study, local data, and aerial imagery | TCAT Eagle Ford Survey, ERG's Drilling Rig Emission Inventory for the State of Texas, industry stakeholders | 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, ENVIRON CENRAP EI (Western Gulf), and TexN Model |
| Compressor Stations, Production facilities, etc. | Emissions from TCEQ Permit Data and Barnett Shale Special Inventory | | | | |

Production emission calculations relied on data produced for TCEQ's Barnett Shale special inventory. Other sources for production emissions included local industry data, ERG's Texas emission inventory, ENVIRON's CENRAP emission inventory, and AP42 emission factors for flares (Table 1-3). On-road data sources, as listed in Table 1-4, are from NCTCOG's study in the Barnett Shale, TxDOT's study also in the Barnett Shale, and ENVIRON's Colorado report. Emission factors for heavy duty and light duty trucks were produced by the MOVES model and provided by the EPA.

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 and ENVIRON CENRAP EI (Western Gulf) |
| Dehydrators | - | - | ERG Texas EI |
| Storage Tanks | - | - | ERG Texas EI and ERG's condensate tank study |
| Fugitives from Natural Gas Wells | - | - | Barnett Shale Special Inventory |
| Fugitives from Oil Wells | | - | 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 | NCTCOG (Barnett) | Railroad Commission of Texas | MOVES Model |
| | Idling | NCTCOG (Barnett) | ENVIRON Colorado Report | MOVES Model |
| Light Duty Trucks | On-Road | ENVIRON Colorado Report | Railroad Commission of Texas | MOVES Model |
| | Idling | ENVIRON Colorado Report | ENVIRON Colorado Report | EPA based on MOVES model |

### 1.9 TxLED

$NO_X$ emission estimates for all diesel equipment were reduced to account for Texas Low Emission Diesel (TxLED) supplied in the following 19 counties in the Eagle Ford[38].

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

### 1.10 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."[39]

Equations, data sources, and methodology were checked 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"[40]

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

When errors and omissions were identified, they were corrected and all documentation was updated with the corrections. All emission inventory calculation methodologies were documented and described in detail so external officials and other interested parties can replicate the results. For every emission inventory source, documentation was consistent and contained data sources, methodology, formulas, and results. When the emission inventory was completed, documentation and spreadsheets were sent to local industry, TCEQ, and other interested parties for review.

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[38] 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.

[39] 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.

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

# 2 PREVIOUS STUDIES

Several oil and gas emissions inventories were review for data sources, methodologies, and calculation methodologies.

## 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."[41]

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."[42] The survey was sent to all companies that conducted operations in the Barnett Shale formation during 2009, including such activities as oil and gas production, transmission, processing, and related activities such as saltwater disposal.[43]

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 fugitives, heaters, and other sources. The special inventory provided the parameters for calculating emissions from compressor engines, storage tanks, heaters, and fugitive emissions and it was these parameters on which AACOG based emission estimates for similar activities in the Eagle Ford. Since the Barnett study was based on dry gas shale, operations, however, there are significant differences with Eagle Ford operations that produce condensate and oil. The Barnett survey did not collect data for pad construction, drilling, hydraulic fracturing, completion, and on-road vehicles. These sources can emit significant amounts of ozone precursor emissions. The special inventory relied on companies to report all sources and emissions from production. Also, the results from the Barnett survey were based on calendar year 2009. Since that time, development, processes, and operations may have changed since the industry is rapidly developing to increase production from shale plays across the United States.

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[41] 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.
[42] *Ibid*.
[43] 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.

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

The Eagle Ford emission inventory development process included a review of data gathered from a limited on-site survey conducted by the Texas Center for Applied Technology (TCAT) at Texas A&M University System. The study was conducted 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 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."[44]

Graduate students observed and recorded 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 were 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. The activity data and engine characteristics from hydraulic fracturing collected during this survey were 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's 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."[45] The study found that the main sources of $NO_X$ emissions from oil and gas production are compressor engines, while the main sources of VOC emissions are oil and condensate storage tanks.[46]

"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."[47] ERG's emission inventory included only emission sources from production such as lifts, storage tanks, fugitives, loading fugitives, heaters, compressors, well completion, and pneumatic pumps. The ERG report was used to estimate the percentage of oil wells serviced by wellhead heaters, the average heater rating, the emission factors for dehydrators, and VOC emission factor for fugitives from oil wells. The report was also used to estimate the molecular

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[44] 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.

[45] 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.

[46] *Ibid*., pp. v-vi.

[47] *Ibid*.. p. v.

weight of the gas, the mass fraction of VOC emissions in the vented gas from blowdowns, and the volumetric bleed rate from pneumatic devices.

### 2.4 Drilling Rig Emission Inventory for the State of Texas

ERG developed statewide drilling rig emission inventories for 1990, 1993, 1996, and 1999 through 2040. "The purpose of this study was to develop comprehensive statewide controlled and uncontrolled emissions inventories for drilling rig engines associated with onshore oil and gas exploration activities occurring in Texas. Oil and gas exploration and production facilities are considered some of the largest sources of area source emissions in certain geographical areas, dictating the need for continuing studies and surveys to more accurately depict these activities. The current inventory effort builds off of the previous 2009 study prepared for the TCEQ, 2009 Drilling Rig Emission Inventory for the State of Texas (July 15, 2009, prepared by ERG), which focused exclusively on drilling activities. The previous effort is expanded upon by improving the activity data (well counts, types, and depths) used to estimate emissions, and uses the drilling rig engine emission profiles developed in the 2009 study. The improved well activity data was obtained through acquisition of the 'Drilling Permit Master and Trailer' database from the Texas Railroad Commission (TRC). The activity data and emissions characterization data were then used to develop controlled and uncontrolled drilling rig engine emissions inventories for the years 1990, 1993, 1996, and 1999 through 2040."[48]

ERG states "drilling activity is estimated to remain relatively constant across the state from 2011 through 2035."[49] According to the study, "the preponderance of the high $NO_X$ emitting counties were predominantly in West and North-Central Texas."[50] ERG projects that drill rig emissions in Texas will decrease from 22,920 tons of $NO_X$ per year in 2012 to 7,311 tons of $NO_X$ per year in 2040.[51] ERG's emission inventory did not take into account the improvements in efficiency, increased activity, and rapid turnover rates of drill rigs in the Eagle Ford. Most of the mechanical drill rigs in the Eagle Ford are being removed from service and there is a significant expansion of production in the Eagle Ford. Electrical horizontal drill rigs in the Eagle Ford have more engines (3.17 engines compared 2.03 in the ERG report for electric drill rigs), higher horsepower (1,429 hp compared 1,346 in the ERG report), and lower load factors (0.35 compared to 0.525 in the ERG report) compared to what was used to calculate emissions in ERG's report.

### 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 was used in a photochemical model simulation was described in 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."[52] Emission inventory categories included drill rigs,

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[48] Eastern Research Group, Inc., August 15, 2011. "Development of Texas Statewide Drilling Rigs Emission Inventories for the Years 1990, 1993, 1996, and 1999 through 2040". TCEQ Contract No. 582-11-99776. Austin, Texas. p. 1-1. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5821199776FY1105-20110815-ergi-drilling_rig_ei.pdf. Accessed 10/24/2013.

[49] *Ibid*. p. 1-5.

[50] *Ibid*.

[51] *Ibid*. pp. 1-2 – 1-3.

[52] 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.

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."[53] When entered in 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.[54]

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 may be over estimated and the horsepower required for hydraulic fracturing is under estimated. In contrast to the future projection developed by ENVIRON, drilling and hydraulic fracturing activities have declined 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

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

[53] *Ibid*.

[54] 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 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.

proposals submitted in response to a solicitation for conducting this study, and to ultimately choose a qualified organization to conduct the study."[55]

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."[56] 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.[57]

FLIR™ infrared cameras were used to survey all equipment in natural gas service at each point source site visited.[58] "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."[59] 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.[60] 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".[61] 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."[62]

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[55] 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.

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

[57] *Ibid*. pp. 3-3 – 3-4.

[58] *Ibid*. pp. 3-7 – 3-9.

[59] *Ibid*. p. 3-23.

[60] 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.

[61] *Ibid*.

[62] *Ibid*.

An oil and gas mobile sources pilot study was also conducted by ENVIRON to provide "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."[63] "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".[64]

Other on-road mobile emission inventories include NCTCOG's "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 contractors. NCTCOG study on trucking emission in the Barnett is schedule to be completed August 2012."[65]

An evaluation of upstream oil and gas storage tank project flash emission 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 sites in West Texas and thirteen sites in North Texas.[66]

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."[67]

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[63] 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.

[64] *Ibid*.

[65] 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.

[66] 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.

[67] ENVIRON International Corporation, August 2010. "Upstream Oil and Gas Tank Emission Measurements TCEQ Project 2010 – 39". Prepared for: Texas Commission on Environmental Quality,

Al Armendariz from department of environmental and civil engineering at Southern Methodist University 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."[68]

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".[69] The report calculates "all GHG emissions from land clearing, resource consumption, and diesel consumed in internal-combustion engines (mobile and stationary) during well development."[70] The report gives 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."[71] 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."[72] Other emission inventories of oil and gas production include "Tumbleweed II Exploratory Natural Gas Drilling Project" in Utah[73] and "Pinedale Anticline Project" in Wyoming.[74] TCEQ developed a "2007 Southeast Texas Compressor and

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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.

[68] 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.

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

[70] *Ibid*.

[71] 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.

[72] *Ibid.*

[73] 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.

[74] 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.

Dehydrator Survey"[75] and DFW Compressor Engine Project that provided ambient measurements downwind of gas compressor engines.

[75] 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, seismic exploration is “an investment in subsurface information, lowers risk, provides confident geologic information, and leads to greater drilling accuracy”[76] “Seismic exploration helps scientist pinpoint ideal drilling locations within oil and natural gas reservoirs.”[77] “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.”[78]

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”.[79] 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.[80]

Figure 3-1: Seismic Survey Vibration Truck or Vibroseis Vehicle in the Eagle Ford shale play[81]

[76] 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.
[77] *Ibid*.
[78] *Ibid*.
[79] Chesapeake Energy, 2012. “Seismic Exploration”. Available online: http://www.askchesapeake.com/Eagle-Ford-Shale/About/Pages/Seismic-Exploration.aspx. Accessed: 03/27/2012.
[80] 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.
[81] 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.

Existing data in the TexN Model was used to calculate emission factors for non-road equipment used in the Eagle Ford. The TexN model was modified to match the horsepower of equipment used in the Eagle Ford and the updated inputs provided in Appendix C. The TexN Model run specifications were:

- Analysis Year = 2011
- Max Tech. Year = 2011
- Met Year = Typical Year
- Period = Annual
- Summation Type = Annual
- Post Processing Adjustments = All
- Rules Enabled = All including TxLED[82]
- 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

Equation 3-1 was used to calculate emissions from seismic trucks operating in the Eagle Ford.

Equation 3-1, Ozone season day seismic trucks emissions

$E_{Seismic.BC}$ = $(NUM_{BC} / WPAD_B) \times POP \times HP \times HRS \times LF_{TexN} \times EF_{TexN}$ / 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 type C wells (gas or oil)
$NUM_{BC}$ = Annual number of wells drilled in county B for Eagle Ford development type C wells, from Table 4-1 (Schlumberger Limited)
$WPAD_B$ = Number of wells per pad for county B, Table 3-5 (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)
$LF_{TexN}$ = Load factor for off road trucks, 0.59 (from TexN Model)
$EF_{TexN}$ = Emission factor for off road trucks, 2.510 g/hp-hr for $NO_X$, 0.183 g/hp-hr for VOC, or 1.285 g/hp-hr for CO (from TexN Model)

[82] Texas Administrative Code, Sept. 13, 2012. "Low Emission Diesel: RULE §114.319 Affected Counties and Compliance Dates". Austin, Texas. http://info.sos.state.tx.us/pls/pub/readtac$ext.TacPage?sl=R&app=9&p_dir=&p_rloc=&p_tloc=&p_ploc=&pg=1&p_tac=&ti=30&pt=1&ch=114&rl=319. Accessed 09/17/13.

Sample Equation: $NO_X$ emissions from seismic trucks in Wilson County for oil wells, 2011

$E_{Pad.ABC}$ = (35 oil wells /1.1 wells per well pad) x 3 trucks x 400 hp x 2 hours x 0.59 x 2.510 grams of $NO_X$/hp-hr / 907,184.74 grams per ton / 365 days/year
= 0.0004 tons of $NO_X$/ozone season day from seismic trucks in Wilson County for oil wells, 2011

Table 3-1: $NO_X$ and VOC Emissions from Seismic Trucks Operating in the Eagle Ford, 2011

| County | FIPS Code | SCC 2270002051 | |
|---|---|---|---|
| | | VOC | $NO_X$ |
| Atascosa | 48013 | 0.0000 | 0.0001 |
| Bee | 48025 | 0.0000 | 0.0000 |
| Brazos | 48041 | 0.0000 | 0.0000 |
| Burleson | 48051 | 0.0000 | 0.0000 |
| DeWitt | 48123 | 0.0000 | 0.0002 |
| Dimmit | 48127 | 0.0000 | 0.0003 |
| Fayette | 48149 | 0.0000 | 0.0000 |
| Frio | 48163 | 0.0000 | 0.0001 |
| Gonzales | 48177 | 0.0000 | 0.0002 |
| Grimes | 48185 | 0.0000 | 0.0000 |
| Houston | 48225 | 0.0000 | 0.0000 |
| Karnes | 48255 | 0.0000 | 0.0004 |
| La Salle | 48283 | 0.0000 | 0.0003 |
| Lavaca | 48285 | 0.0000 | 0.0000 |
| Lee | 48287 | 0.0000 | 0.0000 |
| Leon | 48289 | 0.0000 | 0.0000 |
| Live Oak | 48297 | 0.0000 | 0.0001 |
| Madison | 48313 | 0.0000 | 0.0000 |
| McMullen | 48311 | 0.0000 | 0.0002 |
| Maverick | 48323 | 0.0000 | 0.0000 |
| Milam | 48331 | 0.0000 | 0.0000 |
| Washington | 48477 | 0.0000 | 0.0000 |
| Webb | 48479 | 0.0000 | 0.0004 |
| Wilson | 48493 | 0.0000 | 0.0000 |
| Zavala | 48507 | 0.0000 | 0.0001 |
| Total | | 0.0002 | 0.0028 |

## 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."[83] "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

[83] 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.

typically requires clearing, grubbing, and grading, followed by placement of a base material (e.g., crushed stone)."[84]

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."[85] "The pit can be about 200 yards wide and about 20-40 feet deep, may be dug to hold waste from the digging and later from the hydrofracturing."[86]

Heavy equipment, such as bulldozers, gravel trucks, and rollers, is used to build the pad sites and remove trees. Chesapeake Energy states that the "typical horizontal well pad requires ~5 acres to construct (not including fresh water impoundments and access roads)"[87] and takes 4-6 weeks to complete[88]. 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."[89] In the Marcellus Shale Play, pads average 7.4 acres in size including roads and utility corridors based on 1,108 horizontal well pads and 8,197 acres of total land disturbance for horizontal drilling.[90] Site construction includes:

- Land clearing
- Excavating and grading
- Road construction
- Pipeline and utilities installation
- Pad construction
- Sump hole excavation

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[84] 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.

[85] 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.

[86] 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.

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

[88] 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.

[89] 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.

[90] 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.

### 3.2.2 Non-Road Equipment Used During Well Pad Construction

The methodology used to estimate emissions from non-road equipment used during well pad construction incorporated information on equipment type, equipment population, horsepower, and activity data from local sources and previous studies. Several studies have estimated the amount, size, and time it takes to construct well pads (Table 3-2). A Cornell University study of the Marcellus determined that 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.[91] San Juan Public Lands Center documented similar results for the activity hours associated with pad construction, but the equipment types were different.

In ENVIRON's report for the Piceance Basin of Northwestern Colorado, they only provided total equipment population, total horsepower, and average activity rates per piece of equipment. The horsepower and activity rate to clear the pad was a little lower than the other two studies, but the results were similar.[92] Other studies on non-road equipment used during well pad construction included Tumbleweed II in Utah[93], Buys & Associates in Utah[94], and Pinedale Anticline Project in Wyoming.[95] These studies found higher activity rates, between 57 to 140 hours per piece of equipment, to clear well pads.

The sizes of twenty randomly selected well pads were measured in the Eagle Ford including the pad, water impoundment, and road areas (Table 3-3). [96] The average well pad was 5.2 acres with a standard deviation of 2.1 acres and a confidence level of 0.9 acres. Since the well pad sizes of the Eagle Ford match other studies, equipment types and activity rates used to construct the well pads should be similar.

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[91] 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.

[92] 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.

[93] 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.

[94] 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.

[95] 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.

[96] April 20, 2012. "Google Earth". Available online: http://www.google.com/earth/index.html. Accessed 07/23/2012.

Table 3-2: 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[97] | Jonah Infill, Wyoming | Tumble-weed II, Utah | Buys & Associates, Utah | Pinedale Anticline Project, Wyoming |
|---|---|---|---|---|---|---|---|---|---|---|
| | Dozer | | 6 | 1 | | 1 | 1 | 1 | 1 | 1 |
| | Excavator | | 1 | - | | - | - | - | - | - |
| | Scraper | | - | 2 | | - | 2 | - | - | 2 |
| | Grader | | - | 1 | | 1 | 1 | 1 | 1 | 1 |
| Count per Site | Backhoe | | - | - | 4 | 1 | - | 1 | 1 | 1 |
| | Loader | | - | - | | - | - | - | 1 | 1 |
| | Roller | | - | - | | - | - | - | - | 1 |
| | Water Truck | | - | - | | - | - | - | - | 1 |
| | Dump Truck | | - | - | | - | - | - | - | 1 |
| | Dozer | 248 | 335 | **210** | | 150 | 210 | 686 | 150 | 300 |
| | Excavator | **197** | 159 | - | | - | - | - | - | - |
| | Scraper | 591 | - | **700** | | - | 700 | - | - | 600 |
| | Grader | 170 | - | **250** | | 135 | 250 | 158 | 135 | 300 |
| Horse-power | Backhoe | **67** | - | - | 764.3 total HP | 70 | - | 129 | 100 | 100 |
| | Loader | **152** | - | - | | - | - | - | 150 | 200 |
| | Roller | **87** | - | - | | - | - | - | - | 200 |
| | Water Truck | 908 | - | - | | - | - | - | - | 210 |
| | Dump Truck | 908 | - | - | | - | - | - | - | 330 |
| | Dozer | | 36 | **40** | | 24 | 40 | 100 | 140 | 104 |
| | Excavator | | 36 | - | | - | - | - | - | - |
| | Scraper | | - | **40** | | - | 40 | - | - | 104 |
| | Grader | | - | **40** | | 24 | 40 | 100 | 140 | 114 |
| Hours | Backhoe | | - | - | 21.2 / equipment | 24 | - | 100 | 140 | 76 |
| | Loader | | - | - | | - | - | - | 140 | 76 |
| | Roller | | - | - | | - | - | - | - | 95 |
| | Water Truck | | - | - | | - | - | - | - | 114 |
| | Dump Truck | | - | - | | - | - | - | - | 57 |

[97] 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.

| 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[98] | 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 |

[98] 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.

Table 3-3: Sample of Well Pad Sizes from Aerial Imagery, Acres

| Well Pad Sample | County | Pad | Water Impoundment | Road | Total Acres |
|---|---|---|---|---|---|
| 1 | Atascosa | 4.8 | - | 0.0 | 4.9 |
| 2 | McMullen | 3.0 | 0.8 | 0.0 | 3.9 |
| 3 | Live Oak | 5.8 | - | 0.8 | 6.7 |
| 4 | Karnes | 2.7 | - | 0.1 | 2.7 |
| 5 | Live Oak | 3.3 | 1.4 | 0.2 | 4.9 |
| 6 | Wilson | 3.0 | 0.4 | 0.1 | 3.5 |
| 7 | McMullen | 3.6 | 0.9 | 0.1 | 4.6 |
| 8 | McMullen | 6.9 | 4.1 | 0.5 | 11.5 |
| 9 | McMullen | 6.1 | 1.0 | 0.3 | 7.4 |
| 10 | Atascosa | 5.7 | - | 0.1 | 5.8 |
| 11 | Karnes | 4.7 | - | 0.3 | 5.0 |
| 12 | Karnes | 3.9 | 4.6 | 0.5 | 9.0 |
| 13 | Wilson | 4.6 | - | 0.2 | 4.8 |
| 14 | Gonzales | 2.6 | - | 0.2 | 2.8 |
| 15 | Gonzales | 2.6 | 0.8 | 0.2 | 3.7 |
| 16 | Dewitt | 3.5 | 1.6 | 0.1 | 5.2 |
| 17 | Bee | 4.1 | - | 0.4 | 4.4 |
| 18 | Karnes | 3.7 | 0.3 | 0.2 | 4.2 |
| 19 | Karnes | 3.8 | - | 0.1 | 3.9 |
| 20 | Wilson | 3.1 | 0.8 | 0.2 | 4.1 |
| | Average | 4.1 | 0.8 | 0.2 | 5.2 |

Construction equipment used to construct well pads was counted using aerial imagery of randomly selected pads in the Eagle Ford.[99] As shown in Table 3-4, construction of most well pads in the Eagle Ford was accomplished using dozers, graders, and rollers, although loaders and excavators were used at a few of the pads studied. In the Eagle Ford, tractors are sometimes used to spread gravel instead of loaders or aggregate trucks.

Other types of equipment may be used for well pad construction in the Eagle Ford than the sample sites listed in table 3-4, but data is not available for each site. The equipment counts for pad construction determined for Eagle Ford development are higher compared to those documented by other studies except Cornell University's study in Marcellus and the Pinedale Anticline Project in Wyoming.[100] Figure 3-2 shows examples of Eagle Ford well pads under construction and the equipment used at those pads in Wilson and Karnes counties

### 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

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[99] *Ibid*.

[100] 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.

Statoil constructs 4-8 horizontal wells at each multi- well pad in the Eagle Ford,[101] Rosetta Resources typically drills threewells/pad,[102] Chesapeake Energy drills multiple wells on a single pad[103], and Plains Exploration & Production Company (PXP) typically drills 2 wells per pad,[104] Dave Burnett of the Texas A & M University found that current practice is to drill only 1 well per pad.[105] By examining the Railroad Commission's data on wells located in the Eagle Ford, it was determined there are an average of 1.4 wells per pad and the average distance to the nearest town from the pad was 13 miles in 2012 (Table 3-5).[106]

Table 3-4: Non-Road Pad Construction Population Counts from Aerial Imagery, 2012

| Sample Site | County | Dozer | Excavator | Scraper | Grader | Tractors | Loader | Roller | total |
|---|---|---|---|---|---|---|---|---|---|
| 1 | McMullen | 1 | 1 | - | 1 | - | - | 2 | 5 |
| 2 | Live Oak | 1 | - | 1 | 1 | - | - | 2 | 5 |
| 3 | Atascosa | 3 | - | 1 | 2 | - | - | 3 | 9 |
| 4 | Atascosa | 2 | - | - | 2 | - | - | 2 | 6 |
| 5 | Wilson | - | 1 | 2 | - | - | - | - | 3 |
| 6 | Wilson | 1 | - | 1 | 1 | - | - | 1 | 4 |
| 7 | Gonzales | 4 | 1 | - | - | - | - | 2 | 7 |
| 8 | Karnes | 2 | - | - | 1 | - | 1 | 2 | 6 |
| 9 | Karnes | - | - | - | 1 | - | - | 2 | 3 |
| 10 | Karnes | - | - | 1 | 1 | - | - | 2 | 4 |
| 11 | Karnes | 4 | - | 1 | 1 | - | - | - | 6 |
| 12 | Dewitt | 1 | - | - | 1 | 3 | - | 1 | 6 |
| 13 | Dewitt | 1 | - | - | 1 | 3 | - | 1 | 6 |
| Average | | 1.5 | 0.2 | 0.5 | 1.0 | 0.5 | 0.1 | 1.5 | 5.4 |
| Standard Deviation | | 1.4 | - | 0.7 | 0.6 | 1.1 | - | 0.6 | 1.7 |
| Confidence Level | | 0.8 | - | 0.4 | 0.3 | 0.6 | - | 0.3 | 0.9 |

Note: Standard deviation and confidence level are only calculated if there are more than 4 pieces of equipment in the sample

[101] 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.

[102] 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.

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

[104] 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.

[105] 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.

[106] Data files provided by the Railroad Commission of Texas, Austin, Texas.

Figure 3-2: Well Pad Construction Aerial Imagery

Wilson County - 28.7656°, -98.1712°

Karnes County - 28.9848, -97.8863

Table 3-5: Distance to the Nearest Town and Number of Permitted Wells per Pad and Disposal Wells per Well Pad in the Eagle Ford by County, 2012

| 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, was used for counties without data.

Jonah Infill's results in Wyoming[107] were used to estimate horsepower and hours to construct each pad (Table 3-6) and emission factors from the TexN 1.6 model was used to calculate emissions (Table 3-7). All applicable control strategies including TxLED were included in the TexN 1.6 model runs.

[107] 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.

Table 3-6: Non-Road Parameters Used to calculate Pad Construction

| Eq. Type | Fuel Type | SCC | Population[#] | HP | Hours* | Load Factor** |
|---|---|---|---|---|---|---|
| Roller | Diesel | 2270002015 | 1.5 | 107** | 40 | 0.59 |
| Scraper | Diesel | 2270002018 | 0.5 | 700* | 40 | 0.59 |
| Excavator | Diesel | 2270002036 | 0.2 | 241** | 40 | 0.59 |
| Grader | Diesel | 2270002048 | 1.0 | 250* | 40 | 0.59 |
| Loader | Diesel | 2270002060 | 0.1 | 196** | 40 | 0.59 |
| Tractors | Diesel | 2270002066 | 0.5 | 68** | 40 | 0.21 |
| Dozer | Diesel | 2270002069 | 1.5 | 210* | 40 | 0.59 |

[#] From aerial imagery

* from San Juan Public Lands Center, Colorado

** Existing data in the TexN model

Table 3-7: TexN 2011 Emission Factors and Parameters for Non-Road Equipment used during Pad Construction

| Equipment Type | SCC | VOC EF (g/hp-hr) | $NO_X$ EF (g/hp-hr) | CO EF (g/hp-hr) |
|---|---|---|---|---|
| Rollers | 2270002015 | 0.436 | 4.123 | 2.492 |
| Scrapers | 2270002018 | 0.203 | 3.161 | 2.109 |
| Excavators | 2270002036 | 0.294 | 3.823 | 1.581 |
| Graders | 2270002048 | 0.399 | 3.900 | 1.766 |
| Loaders | 2270002060 | 0.267 | 3.129 | 1.486 |
| Tractors | 2270002066 | 1.247 | 5.018 | 6.128 |
| Dozers | 2270002069 | 0.204 | 2.076 | 1.017 |

VOC, $NO_X$, and CO emissions from non-road equipment used for well pad construction was calculated using the formula provided below based on data from the Railroad Commission of Texas, local equipment population 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 $LF_{A.TexN}$ x $EF_{A.TexN}$ / $WPAD_B$ / 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 type C wells (gas or oil)

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

$POP_A$ = Number of non-road equipment type A, from Table 3-7 (from aerial imagery)

$HP_A$ = Average horsepower for non-road equipment type A, from Table 3-7 (from San Juan Public Lands Center, Colorado and TexN model)

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

$LF_{A.TexN}$ = Load factor non-road equipment type A, from Table 3-7 (from TexN Model)

$EF_{A.TexN}$ = $NO_X$, VOC, or CO emission factor non-road equipment type A, from Table 3-7 (from TexN Model)

$WPAD_B$ = Number of wells per pad for county B, from Table 3-5 (calculated from data provided by the Railroad Commission of Texas)

Sample Equation: $NO_X$ emissions from graders in Wilson County used to construct oil well pads

$E_{Pad.ABC}$ = 35 oil wells x 1.0 x 250 hp x 40 hours x 0.59 x 3.900 g of $NO_X$/hp-hr / 1.1 wells per well pad / 907,184.74 grams per ton / 365 days/year
= 0.0022 tons of $NO_X$/ozone season day from graders in Wilson County used to construct oil well pads, 2011

### 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 truck trips made during pad construction (Table 3-9). ENVIRON's report for the Piceance Basin of Northwestern Colorado provided detailed information on activity rates, speeds, and idling hours for each heavy duty truck trip. On average, there were 22.86 trips by heavy duty vehicles and 82.46 trips by light duty trucks during construction of the well pads. The study found that idling times by heavy duty trucks was 0.40 hours for each trip and the amount of time spent idling in light duty trucks varied between 2.00 and 2.15 hours per trip.[108] In the Barnett shale development, TxDOT reported an average of 70 heavy duty truck trips were made during pad construction.[109]

[108] 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.

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

Table 3-8: $NO_X$ and VOC Emissions from Non-Road Equipment used during Pad Construction in the Eagle Ford, 2011

| County | FIPS Code | Dozer | | Excavator | | Scraper | | Grader | | Tractors | | Loader | | Roller | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2270002069 | | 2270002036 | | 2270002018 | | 2270002048 | | 2270002066 | | 2270002060 | | 2270002015 | |
| | | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ |
| Atascosa | 48013 | 0.000 | 0.003 | 0.000 | 0.001 | 0.000 | 0.005 | 0.000 | 0.004 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.003 |
| Bee | 48025 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Brazos | 48041 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 |
| Burleson | 48051 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 |
| DeWitt | 48123 | 0.001 | 0.007 | 0.000 | 0.002 | 0.001 | 0.013 | 0.001 | 0.010 | 0.000 | 0.001 | 0.000 | 0.001 | 0.001 | 0.007 |
| Dimmit | 48127 | 0.001 | 0.009 | 0.000 | 0.003 | 0.001 | 0.015 | 0.001 | 0.012 | 0.000 | 0.001 | 0.000 | 0.001 | 0.001 | 0.009 |
| Fayette | 48149 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 |
| Frio | 48163 | 0.000 | 0.003 | 0.000 | 0.001 | 0.000 | 0.006 | 0.000 | 0.005 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.003 |
| Gonzales | 48177 | 0.001 | 0.007 | 0.000 | 0.002 | 0.001 | 0.012 | 0.001 | 0.010 | 0.000 | 0.001 | 0.000 | 0.000 | 0.001 | 0.007 |
| Grimes | 48185 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 |
| Houston | 48225 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Karnes | 48255 | 0.001 | 0.012 | 0.000 | 0.004 | 0.001 | 0.022 | 0.002 | 0.018 | 0.000 | 0.001 | 0.000 | 0.001 | 0.001 | 0.012 |
| La Salle | 48283 | 0.001 | 0.011 | 0.000 | 0.003 | 0.001 | 0.019 | 0.002 | 0.015 | 0.000 | 0.001 | 0.000 | 0.001 | 0.001 | 0.011 |
| Lavaca | 48285 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Lee | 48287 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 |
| Leon | 48289 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.002 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 |
| Live Oak | 48297 | 0.000 | 0.004 | 0.000 | 0.001 | 0.000 | 0.007 | 0.001 | 0.006 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.004 |
| Madison | 48313 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 |
| McMullen | 48311 | 0.001 | 0.007 | 0.000 | 0.002 | 0.001 | 0.013 | 0.001 | 0.011 | 0.000 | 0.001 | 0.000 | 0.001 | 0.001 | 0.007 |
| Maverick | 48323 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 |
| Milam | 48331 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Washington | 48477 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Webb | 48479 | 0.001 | 0.012 | 0.000 | 0.004 | 0.001 | 0.022 | 0.002 | 0.018 | 0.000 | 0.001 | 0.000 | 0.001 | 0.001 | 0.013 |
| Wilson | 48493 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.003 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 |
| Zavala | 48507 | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.003 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 |
| Total | | 0.008 | 0.086 | 0.002 | 0.027 | 0.010 | 0.152 | 0.013 | 0.125 | 0.002 | 0.007 | 0.001 | 0.006 | 0.009 | 0.087 |

Table 3-9: Parameters for On-Road Vehicles operated during Pad Construction based on 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** | | | | | | | | | |

The New York City Department of Environmental Protection's study of the Marcellus that found 20 to 40 heavy duty diesel trucks were needed for pad construction was similar to ENVIRON's survey.[110] Other studies of the Marcellus by Cornell University,[111] the National Park Service,[112] and All Consulting Marcellus,[113] provided similar results for the number of trips by heavy duty trucks. The ENVIRON study for the southern Ute reported slightly more heavy duty trucks: 56 heavy duty truck loads.[114]

For light duty vehicle use, the Pinedale Anticline Project in Wyoming[115] had significantly more trips[116] than ENVIRON's survey, while the San Juan Public Lands Center in Colorado,[117] Tumbleweed II in Utah,[118] Jonah Infill in Wyoming,[119] and Buys & Associates in Utah[120] studies

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[110] 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.

[111] 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.

[112] 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.

[113] 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.

[114] 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.

[115] 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.

[116] 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.

[117] 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.

[118] 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.

found less light duty trucks compared to ENVIRON's report in the Piceance Basin of Colorado. Since local data was not available for Eagle Ford activities, the number of trips by vehicle type and the idling time per vehicle trip were taken from TxDOT's findings in the Barnett shale and ENVIRON's report in the Piceance Basin of Colorado. These reports were selected because the TxDOT report provided data from well pad construction in a similar area in Texas and ENVIRON's report is the only one with specific data on idling rates.

EPA's MOVES2010b model was used to estimate emissions from vehicles while idling or transporting employees, equipment, and materials to the oil fields for 2011, 2012, 2015, and 2018. Since the contiguous Eagle Ford counties experience similar meteorological conditions, MOVES2010b was run only for Webb County and the results were applied to the rest of the counties. For climate and transportation inputs, all MOVES's default data was used with the exception of the vehicle speed table which had been modified for an average speed of 35 miles per an hour.

Light duty truck emission factors were based on MOVES2010b categories of gasoline and diesel passenger trucks and light commercial trucks (Table 3-10).[121] For heavy duty trucks, emissions factors from MOVES were calculated using local data and diesel short haul combination trucks. Combination short-haul trucks are classified in MOVES2010b as trucks that are operated within 200 miles of home base for the majority of time.[122] Similar to the Pinedale Anticline Project in Wyoming, an average speed of 35 miles per hour was used for both vehicle types because the 25 miles per hour used in other studies are too slow for rural areas typical of the Eagle Ford. A complete list of all on-road emission factors are provided in Appendix B for 2011, 2012, 2015, and 2018. Idling emission factors for heavy duty trucks and light duty trucks were provided by EPA.[123]

Table 3-10 MOVES2010b Ozone Season Day Emission Factors for On-Road Vehicles in Eagle Ford Counties, 2011

| Vehicle Type | Fuel Type | Location | Speed | VOC EF | $NO_X$ EF | CO EF |
|---|---|---|---|---|---|---|
| Light Duty Trucks | Diesel and Gasoline | On-Road | 35 mph | 1.08 g/mile | 1.71 g/mile | 13.72 g/mile |
| | | Idling | - | 4.09 g/hr | 11.11 g/hr | N/A |
| Heavy Duty Trucks | Diesel | On-Road | 35 mph | 0.58 g/mile | 9.55 g/mile | 2.94 g/mile |
| | | Idling | - | 43.00 g/hr | 178.42 g/hr | 88.65 g/hr |

N/A – not calculated and not provided by EPA

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[119] 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.
[120] 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.
[121] 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.
[122] 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.
[123] Brzezinski, Office of Transportation and Air Quality, U.S. Environmental Protection Agency, Washington, DC, e-mail dated 05/19/2012.

On-road VOC, $NO_X$, and CO emission factors for vehicles were calculated using the formula provided below, while idling emissions were calculated using Equation 3-4. The formula inputs are based on local data, MOVES output emission factors, TxDOT in the Barnett Shale, and data from ENVIRON's survey in Colorado. For heavy duty vehicles, 50 miles was used for each round trip based on data from NCTCOG.[124] Although NCTCOG used this value for the drilling and completion phases instead of well pad construction, this is the best available data. The Railroad Commission of Texas' data on average distance to the nearest town was used as an approximation of the traveling distance for light duty vehicles trip by county because resources and housing are usually centrally located in towns.

$NO_X$ emission reductions from the use of TxLED in affected counties were included in the calculations of on-road emissions. According to TCEQ, "TxLED requirements are intended to result in reductions in $NO_X$ emissions from diesel engines. Currently, reduction factors of 5.7% (0.057) for on-road use and 7.0% (0.07) for non-road use have been accepted as a $NO_X$ reduction estimate resulting from use of TxLED fuel. However, this reduction estimate is subject to change, based on the standards accepted by the EPA for use in the Texas State Implementation Plan (SIP)."[125]

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

$$E_{pad.road.ABC} = NUM_{BC} \times TRIPS_{A.TXDOT} \times (DIST_{B.RCC} \times 2) \times (1 - TxLED_{TCEQ}) \times OEF_{A.MOVES} / WPAD_{B.RCC} / 907{,}184.74 \text{ grams per ton} / 365 \text{ days/year}$$

Where,

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

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

$TRIPS_{A.TXDOT}$ = Annual number of trips per pad for vehicle type A, 70 for heavy duty trucks (from TxDOT 's Barnett report) and 82.46 for light duty trucks in Table 3-9 (from ENVIRON's Colorado report)

$DIST_{B.RCC}$ = Distance, 25 miles (25 miles one way, 50 miles per round trip) for heavy duty trucks and to the nearest town for light duty vehicles in county B, Table 3-5 (from Railroad Commission of Texas)

$TxLED_{TCEQ}$ = On-road emission reductions from TxLED, 0.057 for $NO_X$ from Heavy Duty Diesel Trucks, 0.0 for VOC, 0.0 for CO, and 0.0 for Gasoline Light Duty Vehicles (from TCEQ)

$OEF_{A.MOVES}$ = $NO_X$, VOC, or CO on-road emission factor for vehicle type A in Table 3-10 (from MOVES2010b Model)

$WPAD_{B.RCC}$ = Number of wells per pad for county B, Table 3-5 (calculated from data provided by the Railroad Commission of Texas)

[124] Lori Clark, Shannon Stevenson, and Chris Klaus North Central Texas Council of Governments, August 2012. "Development of Oil and Gas Mobile Source Inventory in the Barnett Shale in the 12-County Dallas-Fort Worth Area". Arlington, Texas. Texas Commission on Environmental Quality Grant Number: 582-11-13174. pp. 11, 13. Available online: http://www.nctcog.org/trans/air/barnettshale.asp. Accessed 01/23/2013.

[125] TCEQ, July 24, 2012. "Texas Emissions Reduction Plan (TERP) Emissions Reduction Incentive Grants Program". Austin, Texas. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/terp/techsup/2012onvehicle_ts.pdf. Accessed 8/27/13.

Sample Equation: $NO_X$ emissions from heavy duty truck exhaust in Wilson County during the construction of oil well pads

$E_{pad.road.ABC}$ = 35 oil wells x 70 trips x (25 miles x 2) x (1 - 0.057) x 9.548 g/mile / 1.1 wells per well pad / 907,184.74 grams per ton / 365 days/year

= 0.0030 tons of $NO_X$ per ozone season day from heavy duty truck exhaust in Wilson County during the construction of oil well pads

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

$E_{pad.idling.ABC}$ = $NUM_{BC}$ x $TRIPS_{A.TXDOT}$ x $IDLE_A$ x (1 - $TxLED_{TCEQ}$) x $IEF_{A.EPA}$ / $WPAD_{B.RCC}$ / 907,184.74 grams per ton / 365 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 type C wells (Gas or Oil)

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

$TRIPS_{A.TXDOT}$ = Annual number of trips per pad for vehicle type A, 70 for heavy duty trucks (from TxDOT 's Barnett report), 12.86 for light duty trucks for equipment, and 69.6 light duty trucks for employees in Table 3-9 (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)

$TxLED_{TCEQ}$ = On-road emission reductions from TxLED, 0.057 for $NO_X$ from Heavy Duty Diesel Trucks, 0.0 for VOC, 0.0 for CO, and 0.0 for Gasoline Light Duty Vehicles (from TCEQ)

$IEF_{A.EPA}$ = $NO_X$, VOC, or CO idling emission factor for vehicle type A in Table 3-10 (from EPA based on the MOVES model)

$WPAD_{B.RCC}$ = Number of wells per pad for county B, Table 3-5 (calculated from data provided by the Railroad Commission of Texas)

Sample Equation: $NO_X$ emissions from heavy duty truck idling in Wilson County during the construction of oil well pads

$E_{pad.road.ABC}$ = 35 oil wells x 70 trips x 0.4 hours idling x (1 - 0.057) x 178.42 g/hour / 1.1 wells per well pad / 907,184.74 grams per ton / 365 days/year

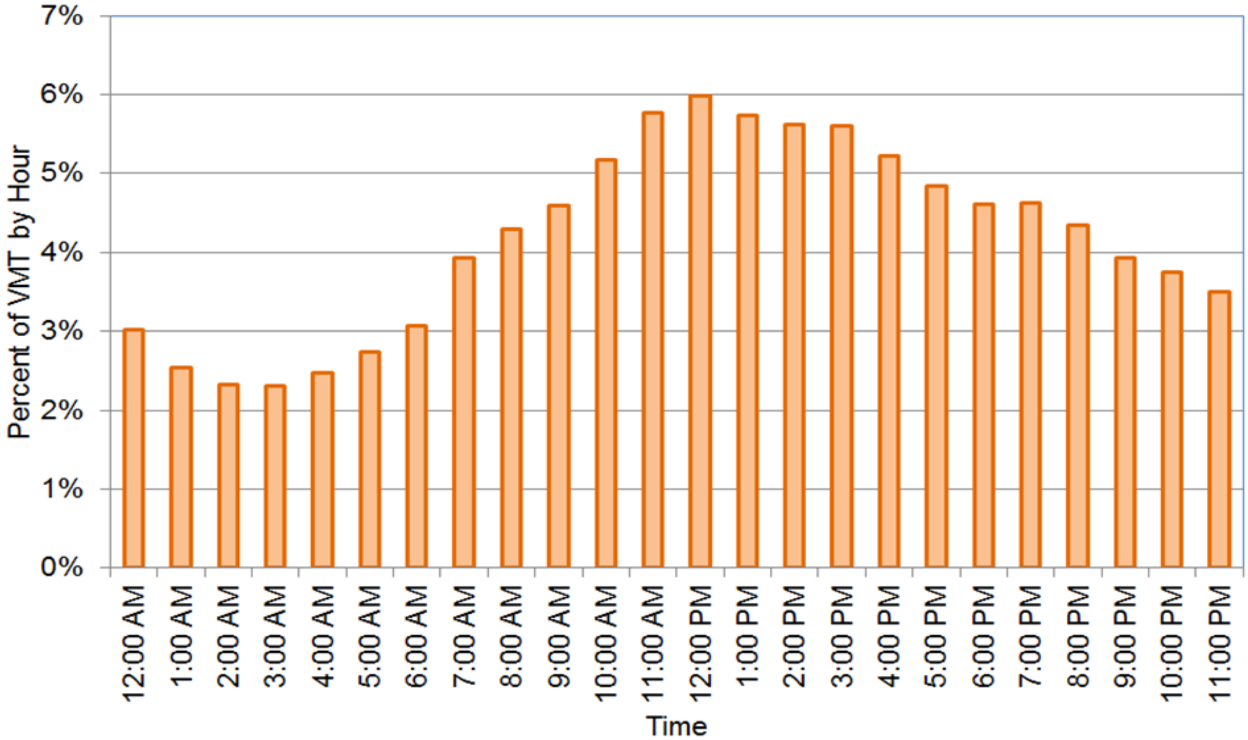
= 0.00045 tons of $NO_X$ per ozone season day from heavy duty truck idling in Wilson County during the construction of oil well pads

Table 3-11: $NO_X$ and VOC Emissions from On-Road vehicles used during Pad Construction in the Eagle Ford, 2011

| County | FIPS Code | Heavy Duty Trucks Exhaust | | Heavy Duty Trucks Idling | | Light Duty Trucks Exhaust (Equipment) | | Light Duty Trucks Idling (Equipment) | | Light Duty Trucks Exhaust (Employees) | | Light Duty Trucks Idling (Employees) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MVDSCS21RX | | MVDSCLOFIX | | MVDSLC21RX | | MVDSLC21RX | | MVDSLC21RX | | MVDSLC21RX | |
| | | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ |
| Atascosa | 48013 | 0.000 | 0.005 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 |
| Bee | 48025 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Brazos | 48041 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Burleson | 48051 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| DeWitt | 48123 | 0.001 | 0.014 | 0.001 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.001 |
| Dimmit | 48127 | 0.001 | 0.017 | 0.001 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.001 |
| Fayette | 48149 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Frio | 48163 | 0.000 | 0.006 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 |
| Gonzales | 48177 | 0.001 | 0.013 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.001 |
| Grimes | 48185 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Houston | 48225 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Karnes | 48255 | 0.002 | 0.024 | 0.001 | 0.004 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.001 |
| La Salle | 48283 | 0.001 | 0.022 | 0.001 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.002 | 0.000 | 0.001 |
| Lavaca | 48285 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Lee | 48287 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Leon | 48289 | 0.000 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Live Oak | 48297 | 0.001 | 0.008 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 |
| Madison | 48313 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| McMullen | 48311 | 0.001 | 0.015 | 0.001 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.001 |
| Maverick | 48323 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Milam | 48331 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Washington | 48477 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Webb | 48479 | 0.002 | 0.026 | 0.001 | 0.004 | 0.001 | 0.001 | 0.000 | 0.000 | 0.004 | 0.006 | 0.000 | 0.001 |
| Wilson | 48493 | 0.000 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Zavala | 48507 | 0.000 | 0.003 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Total | | 0.011 | 0.171 | 0.006 | 0.025 | 0.002 | 0.003 | 0.001 | 0.001 | 0.010 | 0.016 | 0.003 | 0.009 |

Temporal distribution of on-road vehicles in the photochemical model was based on North Central Texas Council of Governments' work on a heavy duty truck mobile source inventory in the Barnett Shale. "To develop a diurnal distribution of emissions, NCTCOG staff utilized automatic traffic recorder (ATR) data which distributes volume of trips across 24 hours in a day. Use of this data is standard NCTCOG process for travel demand modeling. NCTCOG staff did not expect industry operating patterns to vary depending on school or summer seasons. Indeed, survey results did not indicate any seasonal variation in operation. Therefore, annual average daily adjustment factors were applied with no seasonal adjustment. The diurnal distribution is derived from vehicle classification counts of multi-unit trucks from year 2004."[126] Figure 1-13-3 shows the hourly distribution for multi-unit trucks from NCTCOG's inventory of the Barnett Shale used to adjust hourly on-road emissions.

Figure 3-3: Distribution of Multi-Unit Trucks by Time of Day in the Barnett Shale




[126] Lori Clark, Shannon Stevenson, and Chris Klaus North Central Texas Council of Governments, August 2012. "Development of Oil and Gas Mobile Source Inventory in the Barnett Shale in the 12-County Dallas-Fort Worth Area". Arlington, Texas. Texas Commission on Environmental Quality Grant Number: 582-11-13174. pp. 34-35. Available online: http://www.nctcog.org/trans/air/barnettshale.asp. Accessed 01/23/2013.

# 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.”[127] A picture of an Eagle Ford drill rig near Tilden is provided in Figure 4-1[128], while a picture of a Magnum Hunter Resources drilling rig is shown in Figure 4-2.[129]

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

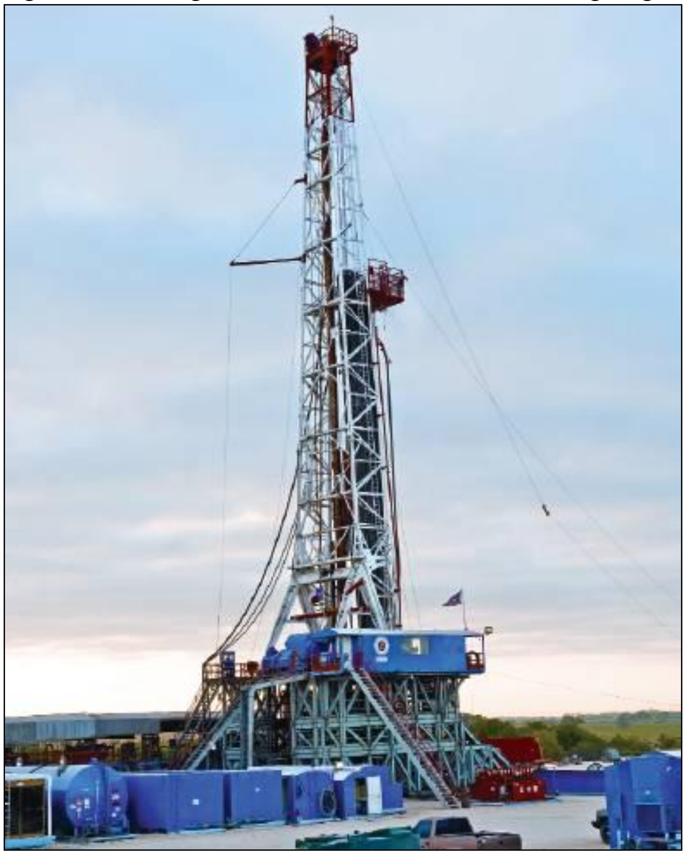
[127] Eastern Research Group, Inc. July 15, 2009. “Drilling Rig Emission Inventory for the State of Texas”. Prepared for: Texas Commission on Environmental Quality. Austin, Texas. p. 3-3 – 3.5. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820783985FY0901-20090715-ergi-Drilling_Rig_EI.pdf.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

[128] 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.

[129] 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."[130]

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



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."[131]

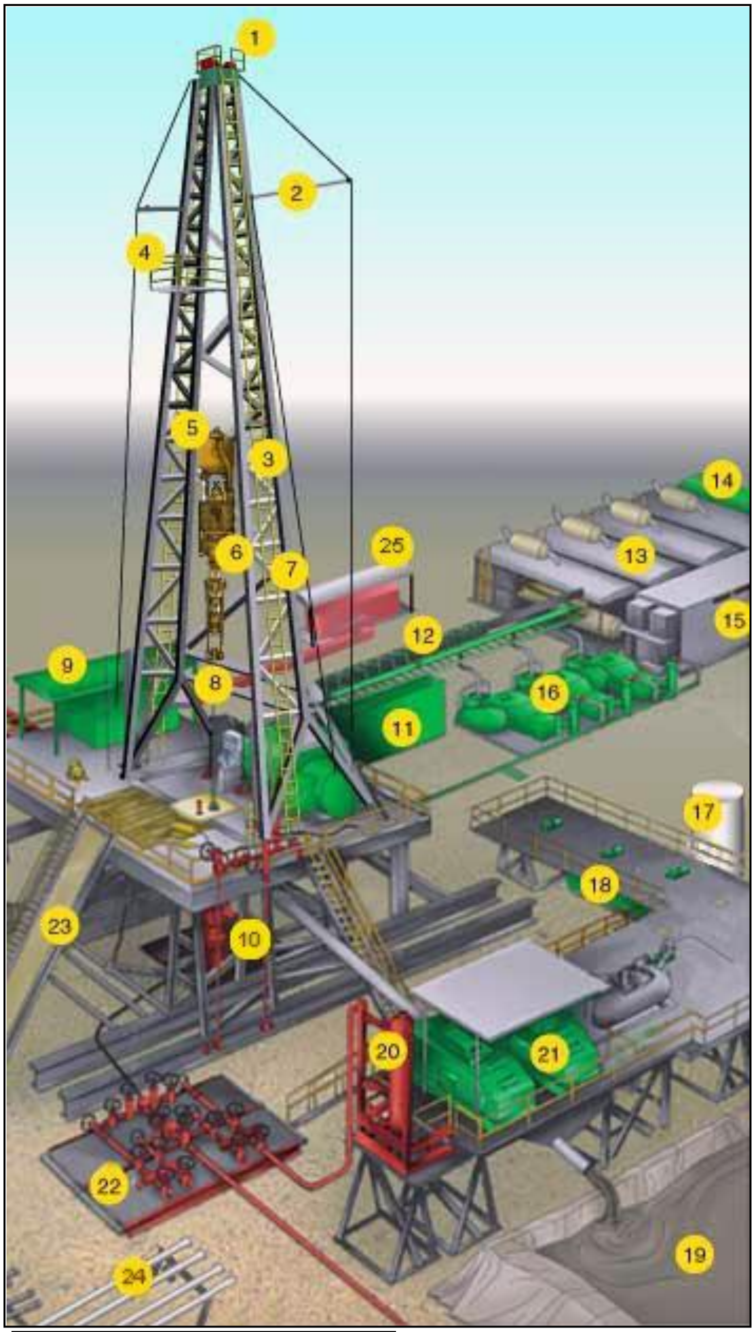
Drilling is "stopped at certain depths to place steel casing into the ground to protect the hole as well as surrounding rock layers and underground aquifers. The casing is fixed in place by pumping cement down the inside of the casing and up the outside between the steel

[130] 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.

[131] 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.[132] "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."[133] The Occupational Safety and Health Administration provided the typical drill rig components shown in Figure 4-3.[134] The main sources of ozone precursor emissions are 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

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132 *Ibid*.
133 *Ibid*.
134 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."[135] Drill rigs are not permanently kept at an individual pad site; when the operation is completed the drill rig is typically moved to a nearby pad site to drill another well and the rig will often remain in the Eagle Ford.

The number of production wells drilled in the Eagle Ford Shale during 2011 were obtained from Schlumberger Limited including county, spud date, well type, well direction, proposed depth, and purpose[136], 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. Within the counties of the San Antonio MSA that have active drill rigs in the Eagle Ford, Atascosa and Wilson counties, a total of 110 wells were 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."[137]

"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."[138]

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[135] 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.
[136] Schlumberger Limited. "STATS Rig Count History". Available online: http://stats.smith.com/new/history/statshistory.htm. Accessed: 04/21/2012.
[137] 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.
[138] *Ibid*.

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

| County | FIPS Code | Type of well | Number of Wells | 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 | - | - | - | - | - | - |

| 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

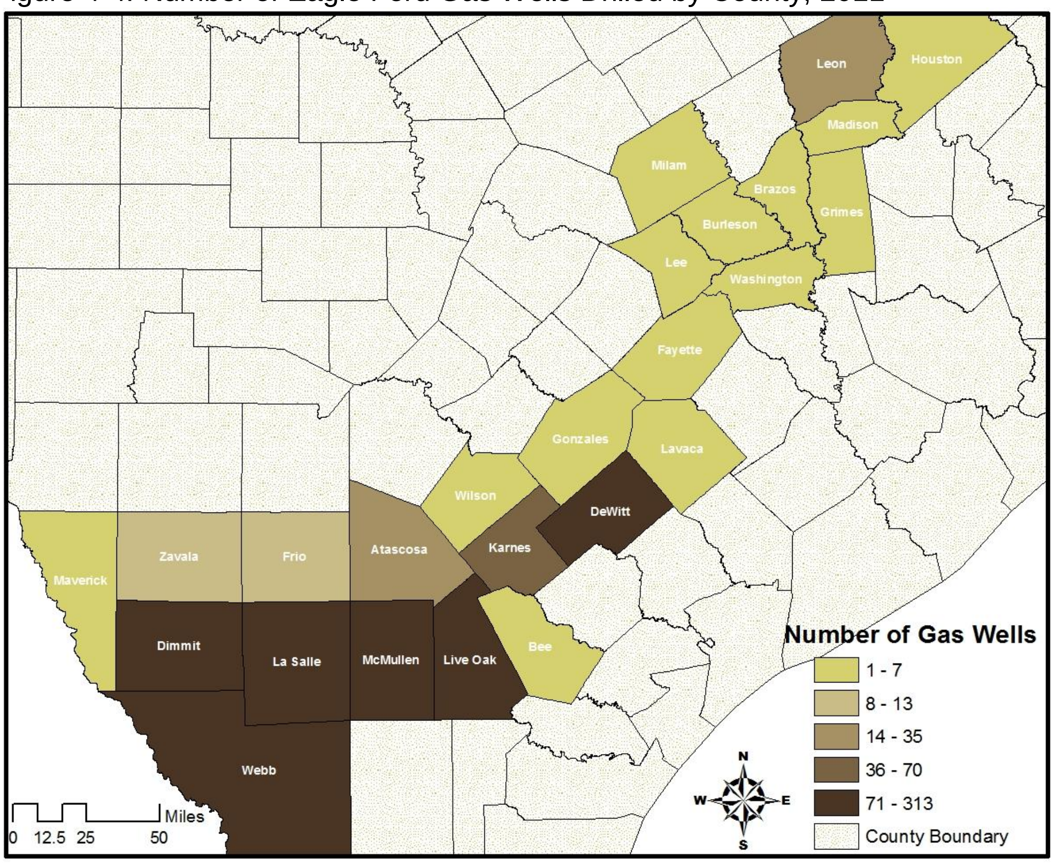
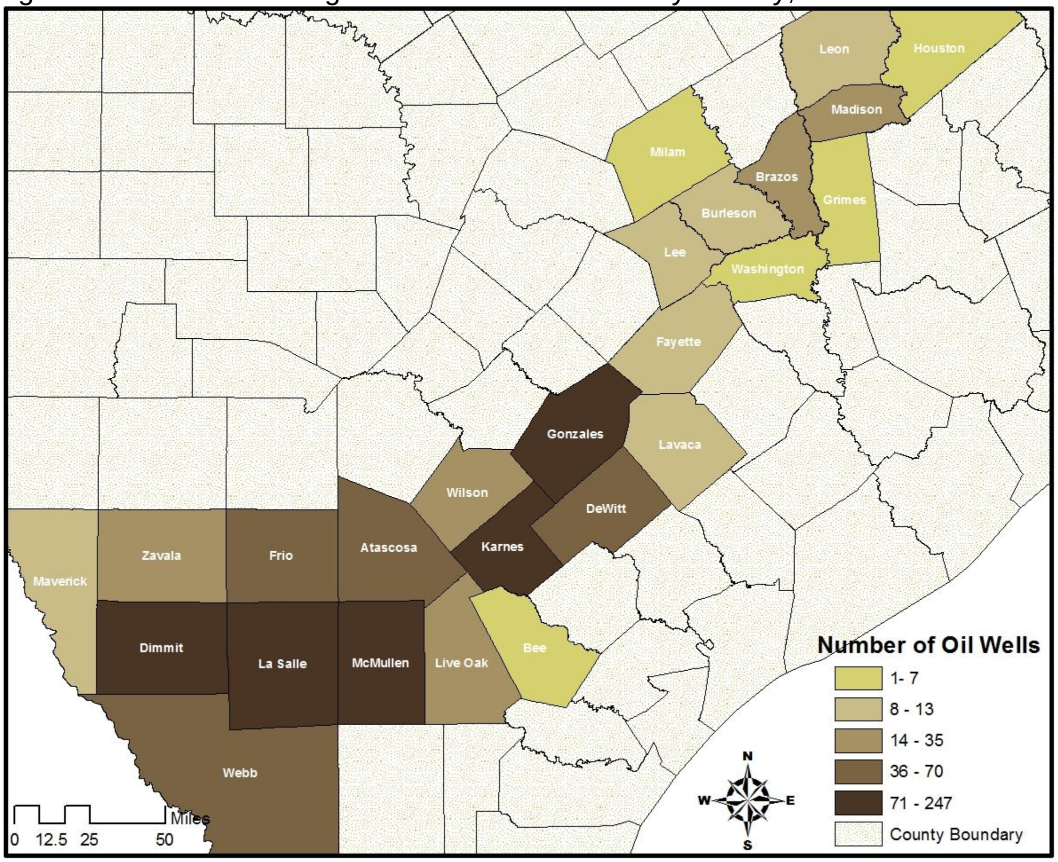


Figure 4-5: Number of Eagle Ford Oil Wells Drilled by County, 2011




"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)."[139] 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."[140] "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."[141]

Data collected for 205 drill rigs operating in the Eagle Ford indicated that 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.[142] Of the 14 rigs operated by Pioneer drilling in the Eagle Ford development, there are 4 mechanical

[139] *Ibid*.
[140] 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.
[141] *Ibid*.
[142] Nabors Industries Ltd. http://www.nabors.com/Public/Index.asp?Page_ID=419. Accessed: 04/20/2012.

and 10 electrical drill rigs.[143] Patterson-UTI operated 10 mechanical rigs and 21 electric rigs during 2011 in the Eagle Ford.[144] Other companies, such as Helmerich & Payne,[145] ENSIGN,[146] Precision Drilling[147] and Trinidad Drilling[148] only operated electric rigs in the Eagle Ford. Below is the number of drill rigs used in Eagle Ford by drilling contractor during 2011.[149]

- 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, and hours required to drill a well, used to calculate emissions for previous studies. The drill rig horsepower data collected from previous studies varied greatly: 1,000 total hp in the Armendariz Barnett study,[150] 4,428 hp in ERG's Fort Worth survey for the Barnett,[151] 4,500 hp in Carnegie Mellon University's research of the Marcellus,[152] and 5,139 hp in ENVIRON's

[143] Pioneer Drilling Company. "Drilling Service Rig Fleet". Available online: http://www.pioneerdrlg.com/rig-fleet.aspx?id=1. Accessed: 04/24/11.
[144] Patterson-UTI Drilling Company LLC. "Rig Locator System". Available online: http://patdrilling.com/rigs. Accessed: 04/19/2012.
[145] Helmerich & Payne."Rig Fleet". Available online: http://www.hpinc.com/RigFleet.html. Accessed: 04/18/2012.
[146] Ensign Energy Services Inc., 2012. "Ensign RigFinder". Available online: http://www.ensignenergy.com/_layouts/ensign.rigfinder/rigfinder.aspx. Accessed: 04/26/2012.
[147] Precision Drilling. "Find Rig by Location". Available online: http://rigs.precisiondrilling.com/rig_search_combo.asp. Accessed: 04/19/2012.
[148] Trinidad Drilling, 2012. Rig Fleet". Available online: http://www.trinidaddrilling.com/Services/RigFleet.aspx. Accessed: 04/25/2012.
[149] Schlumberger Limited. "STATS Rig Count History". Available online: http://stats.smith.com/new/history/statshistory.htm. Accessed: 04/21/2012
[150] 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.
[151] 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.
[152] 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.

CENRAP emission inventory.[153] 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.[154] ERG's drill rig emission inventory estimated the hours needed to complete the drilling based on the hours it takes each engine to drill 1,000 feet.[155] Other studies on drill rigs include Tumbleweed II in Utah[156], San Juan Public Lands Center in Colorado[157], ENVIRON's Southern Ute emission inventory[158] and Cornell University's report about the Marcellus[159].

Drill rig operations, capacity, technology, engine, horsepower, and activity rates have significantly changed in the last 2 years, so parameters determined by previous studies are not necessarily applicable to the Eagle Ford and were updated with local data. Drill rigs in the Eagle Ford are often powered by 3 electrical diesel engines including ORION Drilling Company's drill rigs.[160] For example, their latest drill rig, the Gemini 550, uses 3 engines to power a 1,200 hp ALTA Rig Drawworks, two 1,500 hp mud pumps, and other mud system engines.[161] The average hp of rigs operated by Nabors is approximately 1,500 hp including the Pace F-series and Pace 1500.[162] Goodrich Petroleum uses Drawworks that can deliver

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

[154] 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.

[155] 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.

[156] 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.

[157] 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.

[158] 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.

[159] 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.

[160] 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.

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

[162] 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.

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."[163] Companies prefer "to have at least 1,600-horsepower 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."[164]

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."[165] 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 an average of 5.88 engines with 702 horsepower each for mechanical drill rigs. The number of engines, horsepower, and engine types used at 102 drill rigs in the Eagle Ford 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 are one of the reasons Unit Drilling has been able to reduce 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."[166] "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".[167] 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."[168]

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[163] 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.

[164] *Ibid*.

[165] 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.

[166] 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.

[167] 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.

[168] *Ibid*.

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 the typical duration for drilling a horizontal well is 20 to 24 days in the Eagle Ford.[169] The drill rig runs 24 hours 7 days a week to maintain the integrity of the drill hole.[170] In 2011, one of the fastest Eagle Ford shale drilling operations took 13 days to drill 15,467 feet or 20.17 hours/1,000 feet by EOG.[171] 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."[172] Other companies have experienced similar drill times including Swift Energy Co. at 21 days per well.[173] Marathon's"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."[174] H&P Drilling Company averaged 9 days to drill approximately 13,500 feet based on the last 10 wells drilled in the Eagle Ford in 2011.[175]

*Rigzone* found that the majority of wells being drilled in the Eagle Ford are targeting horizontal laterals ranging from 5,000 to 7,000 feet.[176] Swift Energy Co. found that 5,000-6,000 feet laterals are the most economic[177], Rosetta Resources' wells have 5,300-5,500 foot laterals[178], Magnum Hunter Resources Corporation is drilling average lateral lengths of 5,753 feet[179], and ConocoPhillips has lateral lengths of 4,000 to 6,000 feet in the Eagle Ford.[180] Goodrich Petroleum averaged 5,679-foot laterals[181] and is targeting 9,000-foot long

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

[170] 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

[171] 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.

[172] 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.

[173] 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.

[174] 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.

[175] 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.

[176] 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.

[177] 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.

[178] 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.

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

[180] 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.

[181] 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.[182] Laterals for other companies range from Statoil's 3,000 – 5,500 feet,[183] Chesapeake Energy's 5,000 – 8,000 feet,[184] and BHP Billiton Petroleum's 5,000 to 6,000 feet lateral lengths.[185] Diane Langley of *Drilling Contractor* reported "lateral sections are generally 3,000-9,000 ft but average 6,000-7,000 ft in length."[186] Helmerich & Payne found that horizontal laterals have increased in length an average of 30% to 50% between 2009 and 2011.[187] Table 4-3 shows that the average lateral is 5,490 feet for the top 10 drilling contractors in the Eagle Ford.[188] GIS databases provided by the Railroad Commission of Texas shows that almost all permitted Eagle Ford wells only had one lateral per well.[189]

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 |

By using the following formula, the average time to drill a 17,645 foot Eagle Ford well is 20.40 hours/1,000 feet. As drilling efficiencies increase from improved technology, the time to drill 1,000 feet will decrease. The equation below is based on drilling time being similar for all areas in the Eagle Ford. Improved data on average time to drill in the Eagle Ford is not available for other counties in the formation.

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[182] 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.

[183] 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.

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

[185] 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.

[186] 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.

[187] 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.

[188] 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.

[189] Data provided by the Railroad Commission of Texas. Austin, Texas.

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

$HRS_{drill}$ = (DAY x 24 hours/day) / [DEP + (LENGTH x $LNUM_{RCC}$)] 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)
$LNUM_{RCC}$ = Number of Laterals per well, 1 (from Railroad Commission of Texas)

Sample Equation: Average time to drill 1,000 feet in the Eagle Ford

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

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. Emission factors for mechanical drill rigs are based on ERG's Statewide Drilling Rigs Emission Inventories for the Years 1990, 1993, 1996, and 1999 through 2040.[190] TCEQ TERP program emissions factors for generators ≥ 750 hp[191] was used to estimate emissions from electric drill rigs, while existing data in the TexN Model was used to calculate emission factors for mechanical drill rigs (Table 4-4). The emission factors highlighted in bold on Table 4-4 was used to estimate emissions from drill rigs. $NO_X$ emission reductions of 0.062 from the ERG report for TxLED were included in the calculations of drill rig emissions

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 local industry for load factor, 0.35, was 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.

[190] Eastern Research Group, Inc., August 15, 2011. "Development of Texas Statewide Drilling Rigs Emission Inventories for the Years 1990, 1993, 1996, and 1999 through 2040". TCEQ Contract No. 582-11-99776. 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 10/24/2013.

[191] 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.

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 (Horizontal/ Directional) | ENVIRON, Haynesville Shale | ENVIRON Southern Ute (Tier 2)[192] | Caterpillar Inc.[193] | | 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 | **0.362 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 | **0.016 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 | **0.067 tons/ 1,000 ft** | 5.0 g/bhp-hr | 0.00570 lbs/hp-hr | 2.3 g /kw-hr | 0.5 g /kw-hr | - | - |

[192] 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.
[193] California Environmental Protection Agency Air Resources Board, March 30, 2011. “New Off-Road Compression-Ignition Engines: Caterpillar Inc.”.

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 were 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."[194] Engines emission estimates in the report were reduced by 25% "to account for the number of wells being drilled without diesel-engine power."[195] Drill rig emissions in the Eagle Ford did not include these reductions because none of the drill rigs located in the Eagle Ford operated off the electrical grid. VOC, $NO_X$, and CO emissions for electrical and mechanical drill rigs were calculated using Equation 4-3 provided below.

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

$E_{RIG.ABC}$ = $PER_A$ x $NUM_{BC}$ x [($DEP_{BC}$ + (LENGTH x $LNUM_{RCC}$)] / 1,000 feet x (1 - $TxLED_{ERG}$) x $EF_{ERG}$ / 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 type C wells (Gas, Oil, or Disposal)
- $PER_A$ = Percentage of Drill rigs type A, 13.7 percent mechanical drill rigs in the Eagle Ford, 2011 (from local data in Appendix A)
- $NUM_{BC}$ = Annual number of wells drilled in county B for Eagle Ford development type C wells, from Table 4-1 (from Schlumberger Limited)
- $DEP_{BC}$ = Average depth of the well for county B for Eagle Ford development type C wells, 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)
- $LNUM_{RCC}$ = Number of Laterals per well, 1 (from Railroad Commission of Texas)
- $TxLED_{ERG}$ = On-road emission reductions from TxLED, 0.062 for $NO_X$, 1.0 for VOC, and 1.0 for CO (from ERG)
- $EF_{ERG}$ = $NO_X$, VOC, or CO emission factor, Table 4-4 (from ERG's Drilling Rigs Emission Inventories for Horizontal/ Directional drill rigs)

Sample Equation: $NO_X$ emissions from mechanical drill rigs operating in Wilson County for oil wells

$E_{RIG.ABC}$ = 13.7% of drill rigs are electric x 35 oil wells x [(11,307 feet + (5,490 feet x 1)] / 1,000 feet x (1 – 0.062) x 0.362 tons/1,000 feet / 365 days/year

= 0.075 tons of $NO_X$/day from mechanical drill rigs operating in Wilson County for oil wells

Equation 4-3, Ozone season day electric drill rig emissions for each well

$E_{RIG.ABC}$ = $PER_A$ x $NUM_{BC}$ x [$DEP_{BC}$ + (LENGTH x $LNUM_{RCC}$)] x $ENG_A$ x $HP_A$ x $HRS_{dril}$ / 1,000 feet x $LF_A$ x (1 – $TxLED_{ERG}$) x $EF_{TERP}$ x (1 – $PER_{Electric}$) / 907,184.74 grams per ton / 365 days/year

[194] 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.

[195] *Ibid*.

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 type C wells (Gas, Oil, or Disposal)
$PER_A$ = Percentage of Drill rigs type A, 86.3 percent electrical drill rigs in the Eagle Ford, 2011 (from local data in Appendix A)
$NUM_{BC}$ = Annual number of wells drilled in county B for Eagle Ford development type C wells, from Table 4-1 (from Schlumberger Limited)
$DEP_{BC}$ = Average depth of the well for county B for Eagle Ford development type C wells, 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)
$LNUM_{RCC}$ = 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 drill rigs (from local data in Appendix A)
$HP_A$ = Drill rig type A average horsepower, 1,429 hp for electrical 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)
$TxLED_{ERG}$ = On-road emission reductions from TxLED, 0.062 for $NO_X$, 1.0 for VOC, and 1.0 for CO (from ERG)
$EF_{TERP}$ = $NO_X$, VOC, or CO emission factor, Table 4-4 (from TCEQ TERP program for electric rigs)
$PER_{Electric}$ = Percent of electric drill rigs using electricity from the power grid, 0%

Sample Equation: $NO_X$ emissions from electric drill rigs operating in Wilson County for oil wells

$E_{RIG.ABC}$ = 86.3% of drill rigs are electric x 35 oil wells x [(11,307 feet + (5,490 feet x 1)] x 3.17 engines per drill rig x 1,429 hp for electric drill rigs x 20.40 hours/1,000 feet / 1,000 feet x 0.35 x (1 – 0.062) x 4.56 g/bhp-hr x (1 - 0.00) / 907,184.74 grams per ton / 365 days/year
= 0.199 tons of $NO_X$/day from electric drill rigs operating in Wilson County for oil wells

## 4.2 Other Drilling Non-Road Equipment

Other nonroad equipment used at drill sites includes cement pumps, excavator, and cranes. Local industry representatives confirmed this equipment counts and the results were cross compared with aerial imagery. The data available was limited, but it was the best data available to estimate other equipment used at drill rig sites. According to Caterpillar, "cementing is the process of pumping cement down a well bore to anchor the casing".[196] Cementing is usually done with trucks that have "two engines of approximately 400 hp (300 kW) each".[197] 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

[196] 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.
[197] *Ibid*.

applications.[198] Cornell University report in the Marcellus also found that well sites need cement pumps with a total horsepower of 750.[199]

Table 4-5: $NO_X$ and VOC Emissions from Drill Rigs Operating in the Eagle Ford, 2011

| County | FIPS Code | Mechanical Drill Rigs 2270002033 | | Electric Drill Rigs 2270006005 | |
|---|---|---|---|---|---|
| | | VOC | $NO_X$ | VOC | $NO_X$ |
| Atascosa | 48013 | 0.008 | 0.161 | 0.026 | 0.429 |
| Bee | 48025 | 0.000 | 0.010 | 0.002 | 0.027 |
| Brazos | 48041 | 0.002 | 0.043 | 0.007 | 0.114 |
| Burleson | 48051 | 0.001 | 0.022 | 0.004 | 0.059 |
| DeWitt | 48123 | 0.026 | 0.545 | 0.087 | 1.450 |
| Dimmit | 48127 | 0.030 | 0.656 | 0.098 | 1.747 |
| Fayette | 48149 | 0.002 | 0.035 | 0.006 | 0.093 |
| Frio | 48163 | 0.006 | 0.142 | 0.021 | 0.377 |
| Gonzales | 48177 | 0.019 | 0.386 | 0.062 | 1.029 |
| Grimes | 48185 | 0.001 | 0.023 | 0.004 | 0.061 |
| Houston | 48225 | 0.000 | 0.008 | 0.001 | 0.022 |
| Karnes | 48255 | 0.036 | 0.750 | 0.120 | 1.998 |
| La Salle | 48283 | 0.033 | 0.731 | 0.109 | 1.948 |
| Lavaca | 48285 | 0.001 | 0.026 | 0.004 | 0.069 |
| Lee | 48287 | 0.001 | 0.022 | 0.004 | 0.059 |
| Leon | 48289 | 0.004 | 0.081 | 0.013 | 0.215 |
| Live Oak | 48297 | 0.012 | 0.246 | 0.039 | 0.656 |
| Madison | 48313 | 0.002 | 0.044 | 0.007 | 0.118 |
| McMullen | 48311 | 0.022 | 0.484 | 0.072 | 1.288 |
| Maverick | 48323 | 0.001 | 0.017 | 0.003 | 0.045 |
| Milam | 48331 | 0.000 | 0.004 | 0.001 | 0.012 |
| Washington | 48477 | 0.000 | 0.009 | 0.001 | 0.024 |
| Webb | 48479 | 0.040 | 0.899 | 0.134 | 2.395 |
| Wilson | 48493 | 0.004 | 0.075 | 0.012 | 0.199 |
| Zavala | 48507 | 0.004 | 0.081 | 0.012 | 0.215 |
| Total | | 0.255 | 5.501 | 0.846 | 14.647 |

Existing data in the TexN Model was used to calculate emission factors for other non-road equipment used during the drilling process (Table 4-6). Existing horsepower data in the TexN model was 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 were calculated using Equation 4-4. $NO_X$ emission reductions from the use of TxLED in affect counties were included in the calculations.

[198] 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.

[199] 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 4-6: TexN 2011 Emission Factors and Parameters for other Non-Road Equipment used during Drilling

| Parameters | Excavator | Crane | Cement Pump |
|---|---|---|---|
| SCC | 2270002036 | 2270002045 | 2270006010 |
| Count per Site | 1 | 1 | 2 |
| Horsepower | 241 | 230 | 400 |
| Fuel Type | Diesel | Diesel | Diesel |
| Load Factor | 0.59 | 0.43 | 0.43 |
| $NO_X$ EF (g/hp-hr) | 3.823 | 3.657 | 4.408 |
| VOC EF (g/hp-hr) | 0.294 | 0.283 | 0.412 |
| CO EF (g/hp-hr) | 1.581 | 1.067 | 1.799 |

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

$E_{Nonroad.ABC}$ = $NUM_{BC}$ x $POP_A$ x $HP_A$ x $HRS_{drill}$ x [$DEP_{BC}$ + (LENGTH x $LNUM_{RCC}$)] / 1,000 feet x $LF_{A.TexN}$ x $EF_{TexN}$ / 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 type C wells (Gas or Oil)
$NUM_{BC}$ = Annual 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 4-6 (local data)
$HP_A$ = Non-road equipment type A average horsepower, from Table 4-6 (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 type C wells, from Table 4-1 (from Schlumberger Limited)
LENGTH = Average length for a lateral distance, 5,490 feet, Table 4-3 (from Energy Strategy Partners)
$LNUM_{RCC}$ = Number of Laterals per well, 1 (from Railroad Commission of Texas)
$LF_{A.TexN}$ = Load factor for non-road equipment type A, from Table 4-6 (from TexN Model)
$EF_{TexN}$ = $NO_X$, VOC, or CO emission factor non-road equipment type A, from Table 4-6 (from TexN model)

Sample Equation: $NO_X$ emissions from cement pumps used to drill oil wells in Karnes County

$E_{Nonroad.ABC}$ = 247 x 2 x 400 x 20.40 hours/1,000 feet x [12,537 feet + (5,490 feet x 1)] / 1,000 feet x 0.43 x 4.408 g/hp-hr / 907,184.74 grams per ton / 365 days/year
= 0.416 tons of $NO_X$/ozone season day from cement pump for oil wells in Karnes County

Table 4-7: $NO_X$ and VOC Emissions from Non-Road Equipment used during Drilling in the Eagle Ford, 2011

| County | FIPS Code | Diesel Cranes | | Diesel Pumps | | Diesel Excavators | |
|---|---|---|---|---|---|---|---|
| | | 2270002045 | | 2270006010 | | 2270002036 | |
| | | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ |
| Atascosa | 48013 | 0.000 | 0.003 | 0.001 | 0.010 | 0.000 | 0.005 |
| Bee | 48025 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 |
| Brazos | 48041 | 0.000 | 0.001 | 0.000 | 0.003 | 0.000 | 0.001 |
| Burleson | 48051 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.001 |
| DeWitt | 48123 | 0.001 | 0.010 | 0.003 | 0.035 | 0.002 | 0.017 |
| Dimmit | 48127 | 0.001 | 0.011 | 0.003 | 0.039 | 0.002 | 0.019 |
| Fayette | 48149 | 0.000 | 0.001 | 0.000 | 0.002 | 0.000 | 0.001 |
| Frio | 48163 | 0.000 | 0.002 | 0.001 | 0.008 | 0.000 | 0.004 |
| Gonzales | 48177 | 0.001 | 0.007 | 0.002 | 0.025 | 0.001 | 0.012 |
| Grimes | 48185 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.001 |
| Houston | 48225 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 |
| Karnes | 48255 | 0.001 | 0.013 | 0.004 | 0.048 | 0.002 | 0.023 |
| La Salle | 48283 | 0.001 | 0.012 | 0.003 | 0.044 | 0.002 | 0.021 |
| Lavaca | 48285 | 0.000 | 0.000 | 0.000 | 0.002 | 0.000 | 0.001 |
| Lee | 48287 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.001 |
| Leon | 48289 | 0.000 | 0.001 | 0.000 | 0.005 | 0.000 | 0.002 |
| Live Oak | 48297 | 0.000 | 0.004 | 0.001 | 0.016 | 0.001 | 0.007 |
| Madison | 48313 | 0.000 | 0.001 | 0.000 | 0.003 | 0.000 | 0.001 |
| McMullen | 48311 | 0.001 | 0.008 | 0.002 | 0.029 | 0.001 | 0.014 |
| Maverick | 48323 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 |
| Milam | 48331 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Washington | 48477 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 |
| Webb | 48479 | 0.001 | 0.015 | 0.004 | 0.054 | 0.002 | 0.026 |
| Wilson | 48493 | 0.000 | 0.001 | 0.000 | 0.005 | 0.000 | 0.002 |
| Zavala | 48507 | 0.000 | 0.001 | 0.000 | 0.005 | 0.000 | 0.002 |
| Total | | 0.007 | 0.093 | 0.026 | 0.339 | 0.015 | 0.162 |

## 4.3 Fugitive emissions from Drilling Operations

Fugitive emissions from drilling operations are not included in the emission inventory because no fugitive emissions associated with drilling activities were detected by Eastern Research Group study in Fort Worth.[200] Although only one natural gas well drilling operation was surveyed by Eastern Research Group, 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 emission data is not available from storage ponds used during the drilling process.

[200] 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.

## 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 4-8).[201] This result is very similar to TxDOT findings that 44 heavy duty trucks are needed to move a rig in the Barnett Shale.[202] 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[203], Buys & Associates research in Utah[204], and Jonah Infill field study in Wyoming.[205]

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.[206] Data from NCTCOG of governments on the number of heavy duty truck trips, 187, in the Barnett was used to estimate emission in the Eagle Ford.[207] Heavy duty truck counts from NCTCOG report was used to calculate emissions because it contains data in Texas from a comparable area.

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[201] 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.

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

[203] 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.

[204] 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.

[205] 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.

[206] 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.

[207] Lori Clark, Shannon Stevenson, and Chris Klaus North Central Texas Council of Governments, August 2012. "Development of Oil and Gas Mobile Source Inventory in the Barnett Shale in the 12-County Dallas-Fort Worth Area". Arlington, Texas. Texas Commission on Environmental Quality Grant Number: 582-11-13174. p. 11. Available online: http://www.nctcog.org/trans/air/barnettshale.asp. Accessed 01/23/2013.

Table 4-8: 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[208] | 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 | **187** | 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 | - | - | - | **50** | - |
| | | 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** | - | - | - | - | - | - | - | 6 | - |
| | | Drilling Eq. | | | | | | | | | | | | | |
| | | Employee | | | | **2.1** | | | | | | | | - | |

[208] 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[209] was used to calculate emissions from light duty trucks. The results are lower than ENVIRON findings of 213 light duty vehicles in Southern Ute [210], All Consulting vehicle count of 280 light duty vehicles in the Marcellus[211], and Pinedale Anticline Project determination of 548.8 light duty trucks in Wyoming[212]. On the other hand, San Juan Public Lands Center in Colorado[213] and Tumble-weed II in Utah[214] predicted fewer light duty vehicles.

VOC, $NO_X$, and CO emissions for heavy duty trucks and light duty trucks used during drilling were calculated in Equation 4-5 for on-road emissions and Equation 4-6 for idling emissions. The inputs into the formula are based on local data, MOVES output emission factors, NCTCOG truck counts, and data from ENVIRON's survey in Piceance Basin of Northwestern Colorado. $NO_X$ emission reductions of 0.057 from the use of TxLED in affect counties were included in the calculations of on-road emissions.[215]

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

$$E_{Drill.road.ABC} = NUM_{BC} \times TRIPS_{A} \times (DIST_{B.RCC} \times 2) \times (1 - TxLED_{TCEQ}) / WPAD_{B.RCC} \times OEF_{A.MOVES} / 907{,}184.74 \text{ grams per ton} / 365 \text{ days/year}$$

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 type C wells (Gas or Oil)

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[209] 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.

[210] 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.

[211] 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.

[212] 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.

[213] 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.

[214] 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.

[215] TCEQ, July 24, 2012. "Texas Emissions Reduction Plan (TERP) Emissions Reduction Incentive Grants Program". Austin, Texas. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/terp/techsup/2012onvehicle_ts.pdf. Accessed 8/27/13.

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

$TRIPS_A$ = Number of trips for vehicle type A, 187 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 4-8 (from ENVIRON's Colorado report)

$DIST_{B.RCC}$ = Distance, 25 miles (25 miles one way, 50 miles per round trip) for heavy duty trucks and to the nearest town for light duty vehicles in county B (from Railroad Commission of Texas)

$TxLED_{TCEQ}$ = On-road emission reductions from TxLED, 0.057 for $NO_X$ from Heavy Duty Diesel Trucks, 0.0 for VOC, 0.0 for CO, and 0.0 for Gasoline Light Duty Vehicles (from TCEQ)

$WPAD_{B.RCC}$ = Number of Wells per Pad for county B (calculated from data provided by the Railroad Commission of Texas)

$OEF_{A.MOVES}$ = $NO_X$, VOC, or CO on-road emission factor for vehicle type A in Table 3-10 (from MOVES2010b Model)

Sample Equation: $NO_X$ emissions from heavy duty truck exhaust for oil wells in Karnes County

$E_{Drill.road.ABC}$ = 247 oil wells drilled in Karnes County x 187 trips x (25 miles x 2) x (1 – 0.057) / 1.3 wells per oil pad in Karnes County x 9.548 grams of $NO_X$ per mile / 907,184.74 grams per ton / 365 days/year

= 0.0502 tons of $NO_X$ per ozone season day for heavy duty truck on-road emissions from drilling oil wells in Karnes County, 2011

Equation 4-6, Ozone season day idling emissions during drilling operations

$E_{Drill.Idling.ABC}$ = $NUM_{BC}$ x $TRIPS_A$ x $IDLE_A$ / $WPAD_B$ x (1 - $TxLED_{TCEQ}$) x $IEF_{A.EPA}$ / 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 type C wells (Gas or Oil)

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

$TRIPS_A$ = Number of trips for vehicle type A, 187 for heavy duty trucks (from TxDOT in the Barnett), 68.1 for light duty trucks for equipment, and 66 light duty trucks in Table 4-8 (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 4-8 (from ENVIRON's Colorado report)

$WPAD_{B.RCC}$ = Number of Wells per Pad for county B (calculated from data provided by the Railroad Commission of Texas)

$TxLED_{TCEQ}$ = On-road emission reductions from TxLED, 0.057 for $NO_X$ from Heavy Duty Diesel Trucks, 0.0 for VOC, 0.0 for CO, and 0.0 for Gasoline Light Duty Vehicles (from TCEQ)

$IEF_{A.EPA}$ = $NO_X$, VOC, or CO idling emission factor for vehicle type A in Table 3-10 (from EPA based on the MOVES model)

Sample Equation: $NO_X$ emissions from heavy duty truck idling for oil wells in Karnes County

$E_{Drill.Idling.ABC}$ = 247 oil wells drilled in Karnes County x 187 trips x 0.7 hours idling / 1.3 wells per well pad in Karnes County x (1 - 0.057) x 178.424 g/hour / 907,184.74 grams per ton / 365 days/year

= 0.0131 tons of $NO_X$ per ozone season day for heavy duty truck idling emissions from drilling oil wells in Karnes County, 2011

Table 4-9: $NO_X$ and VOC Emissions from On-Road Vehicles used during Drilling in the Eagle Ford, 2011

| County | FIPS Code | Heavy Duty Trucks Exhaust | | Heavy Duty Trucks Idling | | Light Duty Trucks Exhaust (Equipment) | | Light Duty Trucks Idling (Equipment) | | Light Duty Trucks Exhaust (Employee) | | Light Duty Trucks Idling (Employee) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MVDSCS21RX | | MVDSCLOFIX | | MVDSLC21RX | | MVDSLC21RX | | MVDSLC21RX | | MVDSLC21RX | |
| | | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ |
| Atascosa | 48013 | 0.001 | 0.014 | 0.001 | 0.004 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 |
| Bee | 48025 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Brazos | 48041 | 0.000 | 0.005 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Burleson | 48051 | 0.000 | 0.003 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| DeWitt | 48123 | 0.002 | 0.037 | 0.002 | 0.010 | 0.000 | 0.001 | 0.000 | 0.001 | 0.000 | 0.001 | 0.000 | 0.001 |
| Dimmit | 48127 | 0.003 | 0.046 | 0.003 | 0.012 | 0.001 | 0.001 | 0.000 | 0.001 | 0.001 | 0.001 | 0.000 | 0.001 |
| Fayette | 48149 | 0.000 | 0.003 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Frio | 48163 | 0.001 | 0.016 | 0.001 | 0.004 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 |
| Gonzales | 48177 | 0.002 | 0.035 | 0.002 | 0.009 | 0.001 | 0.001 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.001 |
| Grimes | 48185 | 0.000 | 0.003 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Houston | 48225 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Karnes | 48255 | 0.004 | 0.063 | 0.004 | 0.017 | 0.001 | 0.001 | 0.000 | 0.001 | 0.001 | 0.001 | 0.000 | 0.001 |
| La Salle | 48283 | 0.003 | 0.057 | 0.004 | 0.015 | 0.001 | 0.002 | 0.000 | 0.001 | 0.001 | 0.002 | 0.000 | 0.001 |
| Lavaca | 48285 | 0.000 | 0.003 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Lee | 48287 | 0.000 | 0.003 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Leon | 48289 | 0.000 | 0.007 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Live Oak | 48297 | 0.001 | 0.022 | 0.001 | 0.006 | 0.001 | 0.001 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 |
| Madison | 48313 | 0.000 | 0.005 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| McMullen | 48311 | 0.002 | 0.040 | 0.003 | 0.011 | 0.001 | 0.001 | 0.000 | 0.001 | 0.001 | 0.001 | 0.000 | 0.001 |
| Maverick | 48323 | 0.000 | 0.003 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Milam | 48331 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Washington | 48477 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Webb | 48479 | 0.004 | 0.070 | 0.004 | 0.018 | 0.004 | 0.006 | 0.000 | 0.001 | 0.004 | 0.006 | 0.000 | 0.001 |
| Wilson | 48493 | 0.001 | 0.008 | 0.001 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Zavala | 48507 | 0.001 | 0.009 | 0.001 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Total | | 0.028 | 0.456 | 0.030 | 0.119 | 0.010 | 0.015 | 0.002 | 0.006 | 0.010 | 0.015 | 0.003 | 0.008 |

# 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."[216] "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."[217]

"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.[218] According to Chesapeake Energy, "normally a hydraulic fracturing operation is only performed once during the life of a well".[219]

"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."[220] "This process description describes one stage of the multi-stage hydraulic fracturing and perforating process. Additional stages simply repeat these steps."[221]

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[216] 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.
[217] 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.
[218] 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.
[219] 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.
[220] 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.
[221] *Ibid*.

### 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."[222]

### 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

[222] *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."[223] 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[224]

### 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

[223] *Ibid*.

[224] 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."[225] 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.[226] 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 Well Pad Hydraulic 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[227] to 120 hours from ERG's drill rig emission inventory in Texas.[228] All Consulting estimated that it takes 48 hours to hydraulic fracture a well with 8 frac stages in the Marcellus Shale Play[229], while Armendariz emission inventory in the Barnett Shale[230] and ENVIRON's Haynesville study both lists 54 hours (Table 5-1).[231]

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[225] 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.

[226] 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.

[227] 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.

[228] 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.

[229] 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.

[230] 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.

[231] 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

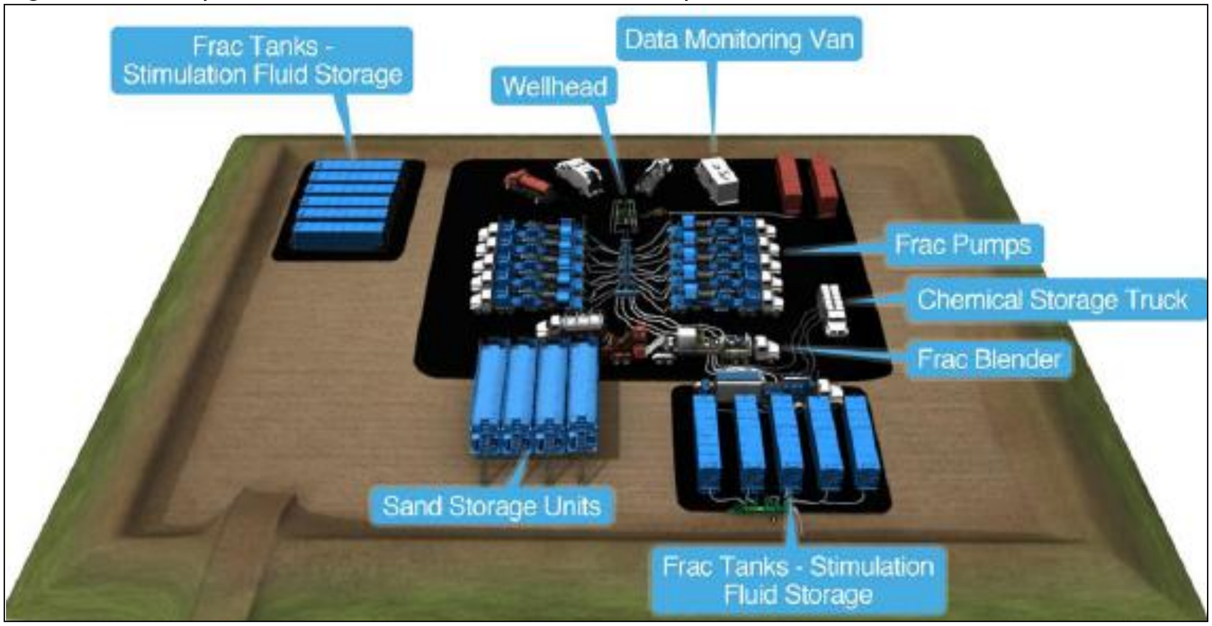

Haliburton Well Frac Site, Christine, Texas[232]

Epley well site in McMullen County, Texas[233]

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

[233] 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.[234] This result is similar to Chesapeake Energy's standard operating practice to complete fracturing within 3-5 days during daylight hours.[235] 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.[236] 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.[237] This activity rate would average just 28 hours per well based on a 12 hour work day. Halliburton stated on average that they run 3 Stages during the day and 2-3 stages at night with a total of 15 stages to frac a well.[238] Using these numbers, a frac job on a single well would take between 60 and 72 hours to complete.

[234] 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.
[235] 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
[236] 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.
[237] 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.
[238] Halliburton, Jan 30th, 2013. San Antonio, Texas.

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[239] | Pioneer Drilling, Eagle Ford[240] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | | - | |

[239] 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.

[240] 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.[241] Swift Energy 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,"[242] Since the company is using gel and slick water, they can pump the jobs at 65-80 barrels a minute.

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.[243] Similarly, All Consulting in the Marcellus Shale Play found an average of 97,649 bbl of frac fluid used per well.[244] Chesapeake Energy uses approximately 6 million gallons of water (190,476 bbls) per well[245]. To estimate emissions from pump engines, a conservative estimation of 54 hours from ENVIRON's study was used. Also, the number of hours it takes to complete hydraulic fracturing per well is decreasing as technology is improved.

#### 5.2.2 Well Pad Hydraulic 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[246] and Ohio EPA stated 1,125 hp[247], while Cornell University report in the Marcellus listed 9,300 hp[248]. Other studies had even higher horsepower estimations: average horsepower needed per frac job was 34,125 according to Raymond James &

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[241] 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.

[242] 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.

[243] 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.

[244] 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.

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

[246] 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.

[247] 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.

[248] 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.

Associates.[249] 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.[250]

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).[251] Weir, a leading supplier of pump engines, estimates that 17,000 – 30,000 frack hp is needed in the Bakken and Marcellus shale plays.[252] ERG drill rig emission inventory in Texas[253] and the TCAT's survey[254] 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.

Observations of aerial imagery of 14 hydraulic fracturing operations in the Eagle Ford found that on average there were 13.9 hydraulic fracturing pump trucks per operation with a standard deviation of 1.8 pump trucks (Table 5-2). None of the sites observed had less than 11 pump trucks. These results are similar to the sites visited by TCAT Eagle Ford Survey and ERG's Fort Worth Natural Gas Study. Total engine hp of 27,000 was used to calculate pump engine emissions based on 12 pump trucks at 2,250 hp each.

### 5.2.1 Pump Engine Emission Calculation Methodology

Pump engines emission factors from previous studies are provided in Table 5-3. 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,[255] 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.[256] The emission factors from TERP was used to calculate pump engine emissions. Through local industry contacts, engine load of 30% was used to calculate VOC, $NO_X$, and CO emissions. Load factor was based on data collected by hydraulic pump operators in the Eagle Ford. The weighted average load factor was calculated from multiple stages at 10 different hydraulic fracturing operations (Table

[249] 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.

[250] 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.

[251] 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.

[252] 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.

[253] 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.

[254] 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.

[255] 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.

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

5-4). $NO_X$ emission reductions of 0.070 in counties included in the TCEQ's TxLED rule[257] was used to calculate well pad hydraulic pump engine emissions.

Table 5-2: Aerial Imagery Results for Hydraulic Pump Engines Counts.

| Site | County | Latitude | Longitude | Number of Pumps |
|---|---|---|---|---|
| 1 | McMullen | 8°38'12.99"N | 98°34'40.88"W | 19 |
| 2 | McMullen | 8°30'13.11"N | 98°31'52.31"W | 16 |
| 3 | McMullen | 8°25'43.64"N | 98°23'18.12"W | 12 |
| 4 | Karnes | 28°46'3.55"N | 7°53'33.49"W | 16 |
| 5 | Karnes | 28°51'7.38"N | 98° 5'51.25"W | 12 |
| 6 | Karnes | 28°51'24.18"N | 97°58'12.71"W | 14 |
| 7 | Karnes | 28°53'17.74"N | 7°59'32.96"W | 14 |
| 8 | Karnes | 28°55'46.91"N | 98° 0'36.25"W | 14 |
| 9 | Karnes | 29° 6'38.80"N | 97°46'13.95"W | 11 |
| 10 | Gonzales | 29°19'7.90"N | 97°28'56.89"W | 11 |
| 11 | Gonzales | 9°17'25.36"N | 97°23'46.06"W | 11 |
| 12 | DeWitt | 29° 5'42.41"N | 97°35'12.86"W | 13 |
| 13 | DeWitt | 29° 7'28.80"N | 97°33'5.53"W | 18 |
| 14 | DeWitt | 29°18'6.59"N | 97°15'40.81"W | 14 |
| Average | | | | 13.9 |

Equation 5-1, Ozone season day pump engine emissions for each well

$E_{Pump.BC}$ = $NWEL_{BC}$ x PUMP x HP x HRS x LF x (1 – $TxLED_{TCEQ}$) x $EF_{TCEQ}$ / 907,184.74 grams per ton / 365 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 type C wells (Gas or Oil)
- $NWEL_{BC}$ = Annual number of production wells drilled in county B for Eagle Ford development type C wells, Table 4-1 (from Schlumberger Limited)
- PUMP = Number of pump trucks per fracking operation, 12 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, 0.30, Table 5-1 (from local industry provided in the TCAT Eagle Ford survey)
- $TxLED_{TCEQ}$ = On-road emission reductions from TxLED, 0.070 for $NO_X$, 0.0 for VOC, and 0.0 for CO (from TCEQ)
- $EF_{TCEQ}$ = $NO_X$, VOC, or CO emission factor for generators, Table 5-3 (from TCEQ TERP program for Engines ≥ 750 hp and TexN model)

[257] TCEQ, July 24, 2012. "Texas Emissions Reduction Plan (TERP) Emissions Reduction Incentive Grants Program". Austin, Texas. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/terp/techsup/2012onvehicle_ts.pdf. Accessed 8/27/13.

Table 5-3: Pump Engines 2011 Emission Factors from Previous Studies

<table>
<tr><th rowspan="2">Pollutant</th><th rowspan="2">TexN Model. Generators Eagle Ford Counties</th><th rowspan="2">ERG's Fort Worth Natural Gas Study, Barnett</th><th rowspan="2">TCAT Survey, Eagle Ford</th><th rowspan="2">ENVIRON, Haynesville Shale EI</th><th colspan="4">EPA (kW > 900)[258]</th><th colspan="2">Caterpillar Inc.[259]</th><th colspan="2">TCEQ</th></tr>
<tr><th>Tier 1</th><th>Tier 2</th><th>Tier 4 Interim</th><th>Tier 4</th><th>(Tier 2)</th><th>(Tier 4 Interim 2011 Model Year)</th><th>Tier 2, (Engines ≥ 750 hp)</th><th>Tier 4 (gensets > 1,200 hp)</th></tr>
<tr><td>$NO_X$ EF</td><td>5.00 g/hp-hr</td><td>4.77 g/hp-hr</td><td>1.34E-02 lb/hp-hr</td><td>8.0 g/bhp-hr</td><td>9.2</td><td rowspan="2">6.4</td><td>0.67</td><td>0.67</td><td rowspan="2">6.1 g $NO_X$ + HC/kw-hr</td><td>3.1 g/kw-hr</td><td>4.56 g/bhp-hr</td><td>0.50 g/bhp-hr</td></tr>
<tr><td>VOC EF</td><td>0.66 g/hp-hr</td><td></td><td>7.07E-04 lb/hp-hr</td><td>1.0 g/bhp-hr</td><td>1.3</td><td>0.40</td><td>0.19</td><td>0.17 g of HC/kw-hr</td><td>0.24 g/bhp-hr</td><td>-</td></tr>
<tr><td>CO EF</td><td>2.67 g/hp-hr</td><td>2.61 g/hp-hr</td><td>2.47E-03 lb/hp-hr</td><td>5.0 g/bhp-hr</td><td>11.4</td><td>3.5</td><td>3.5</td><td>3.5</td><td>2.3 g /kw-hr</td><td>0.5 g /kw-hr</td><td>-</td><td>-</td></tr>
</table>

258 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.

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

Table 5-4: Average Load Factors for Hydraulic Pump Engines.

| Site Number | Load Factor |
|---|---|
| 1A | 0.18 |
| 2A | 0.11 |
| 3A | 0.33 |
| 4A | 0.21 |
| 1B | 0.25 |
| 2B | 0.36 |
| 3B | 0.20 |
| 4B | 0.40 |
| 5B | 0.29 |
| 1C | 0.30 |
| Weighted Average* | 0.30 |

*note: The average is a little higher because not all sites contained the same number of stages

Sample Equation: Well pad hydraulic pump engines $NO_X$ emissions from oil wells in Karnes County, 2011

$E_{Pump.BC}$ = 247 oil wells x 12 pump trucks x 2,250 hp x 54 hours x 0.30 x (1 – 0.070) x 4.56 g/bhp-hr / 907,184.74 grams per ton / 365 days/year
= 1.39 tons of $NO_X$/day from well pad hydraulic pump engines in Karnes County, 2011

Table 5-5: $NO_X$ and VOC Emissions from Hydraulic Pump Engines Operating in the Eagle Ford, 2011

| County | FIPS Code | 2270006005 Pump Engines VOC | 2270006005 Pump Engines $NO_X$ |
|---|---|---|---|
| Atascosa | 48013 | 0.022 | 0.383 |
| Bee | 48025 | 0.001 | 0.017 |
| Brazos | 48041 | 0.007 | 0.129 |
| Burleson | 48051 | 0.004 | 0.073 |
| DeWitt | 48123 | 0.066 | 1.159 |
| Dimmit | 48127 | 0.104 | 1.978 |
| Fayette | 48149 | 0.004 | 0.079 |
| Frio | 48163 | 0.021 | 0.399 |
| Gonzales | 48177 | 0.053 | 0.934 |
| Grimes | 48185 | 0.004 | 0.062 |
| Houston | 48225 | 0.001 | 0.017 |
| Karnes | 48255 | 0.099 | 1.749 |
| La Salle | 48283 | 0.097 | 1.839 |
| Lavaca | 48285 | 0.004 | 0.062 |
| Lee | 48287 | 0.004 | 0.068 |
| Leon | 48289 | 0.010 | 0.174 |
| Live Oak | 48297 | 0.029 | 0.518 |
| Madison | 48313 | 0.007 | 0.124 |
| McMullen | 48311 | 0.062 | 1.179 |
| Maverick | 48323 | 0.004 | 0.067 |
| Milam | 48331 | 0.001 | 0.011 |
| Washington | 48477 | 0.001 | 0.023 |
| Webb | 48479 | 0.117 | 2.232 |
| Wilson | 48493 | 0.011 | 0.197 |
| Zavala | 48507 | 0.013 | 0.248 |
| Total | | 0.745 | 13.719 |

## 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."[260] Sand kings deliver proppant "to location and delivers it to the blender for mixing with the fracturing fluid".[261]

Data from the TCAT Eagle Ford survey, located in Table 5-6, was 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 were not included in the emission inventory because no activity data is available. Although the data is limited, it is the best data available and was used to calculate emissions.

Existing data in the TexN Model was used to calculate emission factors for other non-road equipment used during the hydraulic fracturing process (Table 5-7). Existing horsepower data in the TexN model was used to calculate emissions from the small generator and small crane because local data is not available. Industrial data on blenders was 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 was calculated using Equation 5-2. $NO_X$ emission reductions from the use of TxLED in affect counties were included in the calculations.

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[260] 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.

[261] 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[262]

Figure 5-5: A Blender Truck used during Hydraulic Fracturing[263]


[262] 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.
[263] *Ibid*. p. 35.

Table 5-6: Hydraulic Fracturing Other Non-Road Equipment Parameters from TCAT Survey

| Equipment Type | SCC | Population | Horsepower |
|---|---|---|---|
| Blender Truck | 2270010010 | 1 | 634 (Industry Data) [264] |
| 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) |

[264] 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

Table 5-7: 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) |
|---|---|---|---|---|---|---|
| Diesel Cranes (Large) | Diesel | 2270002045 | 0.43 | 3.783 | 0.266 | 1.227 |
| Diesel Cranes (Small) | Diesel | 2270002045 | 0.43 | 3.657 | 0.283 | 1.067 |
| Backhoe | Diesel | 2270002066 | 0.21 | 5.408 | 1.529 | 7.222 |
| Bulldozer | Diesel | 2270002069 | 0.59 | 2.946 | 0.272 | 3.940 |
| Forklift | Diesel | 2270003020 | 0.59 | 2.386 | 0.233 | 1.449 |
| Generator Sets | Diesel | 2270006005 | 0.43 | 4.653 | 0.684 | 3.137 |
| Generator Sets | Diesel | 2270006005 | 0.43 | 4.781 | 1.042 | 3.323 |
| Generator Sets | Diesel | 2270006005 | 0.43 | 4.653 | 0.684 | 3.137 |
| Water Pumps | Diesel | 2270006010 | 0.43 | 4.408 | 0.412 | 1.799 |
| Blender Truck | Diesel | 2270010010 | 0.43 | 3.524 | 0.221 | 1.465 |
| Sand Kings | Diesel | 2270010010 | 0.43 | 3.626 | 0.382 | 2.558 |
| Blow Out Control Systems | Diesel | 2270010010 | 0.43 | 3.729 | 0.530 | 3.134 |

Equation 5-2, 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 $LF_{A.TexN}$ x $EF_{A.TexN}$ / 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 type C wells (Gas or Oil)
- $NUM_{BC}$ = Annual number of production wells drilled in county B for Eagle Ford development type C wells, from Table 4-1 (from Schlumberger Limited)
- $POP_A$ = Number of non-road equipment type A, from Table 5-6 (TCAT Survey, Eagle Ford)
- $HP_A$ = Non-road equipment type A average horsepower, from Table 5-6 (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)
- $LF_{A.TexN}$ = Load factor non-road equipment type A, from Table 5-7 (from TexN Model)
- $EF_{A.TexN}$ = $NO_X$, VOC, or CO emission factor non-road equipment type A, from Table 5-7 (from TexN Model)

Sample Equation: Backhoes used during hydraulic fracturing $NO_X$ emissions from oil wells in Karnes County, 2011

$E_{Nonroad.ABC}$ = 247 oil wells x 1 x 88 HP x 54 hours x 0.21 x 5.408 g/bhp-hr / 907,184.74 grams per ton / 365 days/year

=0.004 tons of $NO_X$/day from backhoes used during hydraulic fracturing in Karnes County, 2011

### 5.4 Hydraulic Fracturing Fugitive Emissions

Fugitive emissions from hydraulic fracturing are not included in the emission inventory because no emissions associated with hydraulic fracturing activities were detected by Eastern Research Group study in Fort Worth.[265] 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.

[265] 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.

Table 5-8: $NO_X$ and VOC Emissions from Non-Road Equipment used during Hydraulic Fracturing in the Eagle Ford, 2011

| County | FIPS Code | Diesel Cranes (Large) 2270002045 | | Diesel Cranes (Small) 2270002045 | | Backhoe 2270002066 | | Bulldozer 2270002069 | | Forklift 2270003020 | | Generator Sets (87.4 hp) 2270006005 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ |
| Atascosa | 48013 | 0.001 | 0.009 | 0.000 | 0.004 | 0.000 | 0.001 | 0.000 | 0.002 | 0.000 | 0.002 | 0.001 | 0.010 |
| Bee | 48025 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Brazos | 48041 | 0.000 | 0.003 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.001 | 0.000 | 0.003 |
| Burleson | 48051 | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 |
| DeWitt | 48123 | 0.002 | 0.028 | 0.001 | 0.012 | 0.001 | 0.003 | 0.001 | 0.006 | 0.001 | 0.005 | 0.004 | 0.029 |
| Dimmit | 48127 | 0.003 | 0.045 | 0.001 | 0.019 | 0.002 | 0.005 | 0.001 | 0.009 | 0.001 | 0.008 | 0.007 | 0.047 |
| Fayette | 48149 | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 |
| Frio | 48163 | 0.001 | 0.009 | 0.000 | 0.004 | 0.000 | 0.001 | 0.000 | 0.002 | 0.000 | 0.002 | 0.001 | 0.009 |
| Gonzales | 48177 | 0.002 | 0.023 | 0.001 | 0.010 | 0.001 | 0.003 | 0.000 | 0.005 | 0.000 | 0.004 | 0.003 | 0.024 |
| Grimes | 48185 | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 |
| Houston | 48225 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Karnes | 48255 | 0.003 | 0.043 | 0.001 | 0.018 | 0.001 | 0.005 | 0.001 | 0.009 | 0.001 | 0.008 | 0.007 | 0.044 |
| La Salle | 48283 | 0.003 | 0.042 | 0.001 | 0.018 | 0.001 | 0.005 | 0.001 | 0.009 | 0.001 | 0.008 | 0.006 | 0.043 |
| Lavaca | 48285 | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 |
| Lee | 48287 | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 |
| Leon | 48289 | 0.000 | 0.004 | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.001 | 0.000 | 0.001 | 0.001 | 0.004 |
| Live Oak | 48297 | 0.001 | 0.013 | 0.000 | 0.005 | 0.000 | 0.001 | 0.000 | 0.003 | 0.000 | 0.002 | 0.002 | 0.013 |
| Madison | 48313 | 0.000 | 0.003 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.001 | 0.000 | 0.003 |
| McMullen | 48311 | 0.002 | 0.027 | 0.001 | 0.012 | 0.001 | 0.003 | 0.001 | 0.005 | 0.000 | 0.005 | 0.004 | 0.028 |
| Maverick | 48323 | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 |
| Milam | 48331 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Washington | 48477 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 |
| Webb | 48479 | 0.004 | 0.051 | 0.002 | 0.022 | 0.002 | 0.006 | 0.001 | 0.010 | 0.001 | 0.009 | 0.008 | 0.053 |
| Wilson | 48493 | 0.000 | 0.005 | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.001 | 0.000 | 0.001 | 0.001 | 0.005 |
| Zavala | 48507 | 0.000 | 0.006 | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.001 | 0.000 | 0.001 | 0.001 | 0.006 |
| Total | | 0.023 | 0.321 | 0.011 | 0.138 | 0.011 | 0.038 | 0.006 | 0.066 | 0.006 | 0.059 | 0.049 | 0.334 |

| County | FIPS Code | Generator Set (50hp) | | Generator Sets (384 hp) | | Water Pumps | | Blender Truck | | Sand Kings | | Blow Out Control Systems | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2270006005 | | 2270006005 | | 2270006010 | | 2270010010 | | 2270010010 | | 2270010010 | |
| | | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ |
| Atascosa | 48013 | 0.000 | 0.001 | 0.006 | 0.043 | 0.002 | 0.014 | 0.000 | 0.004 | 0.000 | 0.000 | 0.001 | 0.004 |
| Bee | 48025 | 0.000 | 0.000 | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Brazos | 48041 | 0.000 | 0.000 | 0.002 | 0.014 | 0.001 | 0.005 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 |
| Burleson | 48051 | 0.000 | 0.000 | 0.001 | 0.008 | 0.000 | 0.003 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 |
| DeWitt | 48123 | 0.001 | 0.003 | 0.019 | 0.129 | 0.006 | 0.043 | 0.001 | 0.012 | 0.000 | 0.001 | 0.002 | 0.011 |
| Dimmit | 48127 | 0.001 | 0.005 | 0.030 | 0.205 | 0.010 | 0.068 | 0.001 | 0.019 | 0.000 | 0.001 | 0.002 | 0.017 |
| Fayette | 48149 | 0.000 | 0.000 | 0.001 | 0.009 | 0.000 | 0.003 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 |
| Frio | 48163 | 0.000 | 0.001 | 0.006 | 0.041 | 0.002 | 0.014 | 0.000 | 0.004 | 0.000 | 0.000 | 0.000 | 0.003 |
| Gonzales | 48177 | 0.001 | 0.003 | 0.015 | 0.104 | 0.005 | 0.034 | 0.001 | 0.010 | 0.000 | 0.001 | 0.001 | 0.009 |
| Grimes | 48185 | 0.000 | 0.000 | 0.001 | 0.007 | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 |
| Houston | 48225 | 0.000 | 0.000 | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Karnes | 48255 | 0.001 | 0.005 | 0.029 | 0.195 | 0.009 | 0.064 | 0.001 | 0.018 | 0.000 | 0.001 | 0.002 | 0.016 |
| La Salle | 48283 | 0.001 | 0.005 | 0.028 | 0.190 | 0.009 | 0.063 | 0.001 | 0.018 | 0.000 | 0.001 | 0.002 | 0.016 |
| Lavaca | 48285 | 0.000 | 0.000 | 0.001 | 0.007 | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 |
| Lee | 48287 | 0.000 | 0.000 | 0.001 | 0.008 | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 |
| Leon | 48289 | 0.000 | 0.001 | 0.003 | 0.019 | 0.001 | 0.006 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.002 |
| Live Oak | 48297 | 0.000 | 0.002 | 0.008 | 0.058 | 0.003 | 0.019 | 0.000 | 0.005 | 0.000 | 0.000 | 0.001 | 0.005 |
| Madison | 48313 | 0.000 | 0.000 | 0.002 | 0.014 | 0.001 | 0.005 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 |
| McMullen | 48311 | 0.001 | 0.003 | 0.018 | 0.122 | 0.006 | 0.040 | 0.001 | 0.011 | 0.000 | 0.001 | 0.001 | 0.010 |
| Maverick | 48323 | 0.000 | 0.000 | 0.001 | 0.007 | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 |
| Milam | 48331 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Washington | 48477 | 0.000 | 0.000 | 0.000 | 0.003 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Webb | 48479 | 0.001 | 0.006 | 0.034 | 0.231 | 0.011 | 0.076 | 0.001 | 0.021 | 0.000 | 0.001 | 0.003 | 0.019 |
| Wilson | 48493 | 0.000 | 0.001 | 0.003 | 0.022 | 0.001 | 0.007 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.002 |
| Zavala | 48507 | 0.000 | 0.001 | 0.004 | 0.026 | 0.001 | 0.008 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.002 |
| Total | | 0.009 | 0.039 | 0.215 | 1.466 | 0.071 | 0.484 | 0.008 | 0.135 | 0.001 | 0.007 | 0.017 | 0.122 |

## 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 5-9, found between 15 and 2,100 trucks are needed during the hydraulic fracturing and completion of the well site. Jonah Infill in Wyoming[266] and NCTCOG[267] 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.[268] These results are similar to All Consulting vehicle count of 868 heavy duty trucks[269] and Park Service average of 695 heavy duty trucks in the Marcellus.[270] NCTCOG of governments estimated the number of heavy duty truck trips used during drilling was 440.[271]

Data from TxDOT in the Barnett Shale, 807 heavy duty trucks, was used for calculating emissions. TxDOT data represents the best data from a region in Texas similar to the development in the Eagle Ford. 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". [272]

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268 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.

269 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.

270 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.

271 Lori Clark, Shannon Stevenson, and Chris Klaus North Central Texas Council of Governments, August 2012. "Development of Oil and Gas Mobile Source Inventory in the Barnett Shale in the 12-County Dallas-Fort Worth Area". Arlington, Texas. Texas Commission on Environmental Quality Grant Number: 582-11-13174. p. 11. Available online: http://www.nctcog.org/trans/air/barnettshale.asp. Accessed 01/23/2013.

272 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.

Table 5-9: 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 | | | 5 | | | | 5 | 10 | 5 | | **4** |
| | | Fracture Eq. | 150 | | | 94 | | | | 100-150 | 40 | 220 | | **94** |
| | | Water/Sand Truck | 440 | 15 | 148.6 | 21 | 400 | 300 | 238 | 100-1,000 | 350-1,000 | 523 | 440 | **685** |
| | | Chemical Truck | 5 | | | 1 | | | | 10-20 | 5-50 | 20 | | **-** |
| | | Flowback Trucks | 190 | | | - | | | | - | 350-1,000 | 100 | | **24** |
| | Distance (miles) | Completion Eq. | 200 | | | 10 | | | | | | | | |
| | | Fracture Eq. | 200 | | | 10 | | | | | | | | |
| | | Water/Sand Truck | 125 | 12.5 | 40.2 | 10 | 9.5 | 10 | 168 | - | - | - | - | - |
| | | Chemical Truck | 125 | | | 10 | | | | | | | | |
| | | Flowback Trucks | 125 | | | 10 | | | | | | | | |
| | Speed (mph) | Completion Eq. | | | | 20 | | | | | | | | |
| | | Fracture Eq. | | | | 20 | | | | | | | | |
| | | Water/Sand Truck | - | 20 (road) | 16.85 | 20 | 20 (road) | 35 | - | - | - | - | - | - |
| | | Chemical Truck | | | | 20 | | | | | | | | |
| | | Flowback Trucks | | | | 20 | | | | | | | | |
| | Idling Hours/trip | Completion Eq. | | | | | | | | | | | | |
| | | Fracture Eq. | | | | | | | | | | | | |
| | | Water/Sand Truck | - | - | **1.1** | - | - | - | - | - | - | - | - | - |
| | | 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** | | | | | | | | | |

The number trips by light duty vehicles ranged from 30 found in the San Juan Public Lands Center study in Colorado[273] 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[274], and Buys & Associates research in Utah[275]. To calculate on-road vehicle emissions, the number of light duty vehicles and idling rates was based on ENVIRON's survey in Colorado.[276] This report contains the most comprehensive data on vehicles used for hydraulic fracturing and there was very little data available in Texas.

Hydraulic fracturing on-road VOC, $NO_X$, and CO emissions for heavy duty trucks and light duty trucks were calculated using Equation 5-3 and Equation 5-4. $NO_X$ emission reductions of 0.057 from the use of TxLED in affect counties were included in the calculations of on-road emissions.

Equation 5-3, Ozone season day on-road emissions during hydraulic fracturing

$$E_{Onroad.ABC} = NUM_{BC} \times TRIPS_A \times (DIST_{B.RCC} \times 2) \times (1 - TxLED_{TCEQ}) \times OEF_{A.MOVES} / WPAD_{B.RCC} / 907{,}184.74 \text{ grams per ton} / 365 \text{ days/year}$$

Where,

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

$NUM_{BC}$ = Annual number of production wells drilled in county B for Eagle Ford development type C wells, 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 5-9 (from ENVIRON's Colorado report)

$DIST_{B.RCC}$ = Distance, 25 miles (25 miles one way, 50 miles per round trip) for heavy duty trucks and to the nearest town for light duty vehicles in county B, Table 3-5 (from Railroad Commission of Texas)

$TxLED_{TCEQ}$ = On-road emission reductions from TxLED, 0.057 for $NO_X$ from Heavy Duty Diesel Trucks, 0.0 for VOC, 0.0 for CO, and 0.0 for Gasoline Light Duty Vehicles (from TCEQ)

$OEF_{A.MOVES}$ = $NO_X$, VOC, or CO on-road emission factor for vehicle type A in Table 3-10 (from MOVES Model)

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[273] 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.

[274] 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.

[275] 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.

[276] 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.

$WPAD_{B.RCC}$ = Number of wells per pad for county B, Table 3-5 (calculated from data provided by the Railroad Commission of Texas)

Sample Equation: $NO_X$ emissions from Heavy Duty Truck Exhaust in Karnes County for hydraulic fracturing Oil Wells in Karnes County

$E_{Drill.road.ABC}$ = 247 oil wells drilled in Karnes County x 807 trips x (25 miles x 2) x (1 – 0.057) x 9.548 grams of $NO_X$ per mile / 1.3 wells per well pad in Karnes County / 907,184.74 grams per ton / 365 days/year

= 0.217 tons of $NO_X$ per day for heavy duty truck on-road emissions from hydraulic fracturing oil wells in Karnes County, 2011

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

$$E_{Idling.ABC} = NUM_{BC} \times TRIPS_A \times IDLE_A \times (1 - TxLED_{TCEQ}) \times IEF_{A,EPA} / WPAD_{B.RCC} / 907{,}184.74 \text{ grams per ton} / 365 \text{ days/year}$$

Where,

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

$NUM_{BC}$ = Annual number of production wells drilled in county B for Eagle Ford development type C wells, 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 5-9 (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 5-9 (from ENVIRON's Colorado report)

$TxLED_{TCEQ}$ = On-road emission reductions from TxLED, 0.057 for $NO_X$ from Heavy Duty Diesel Trucks, 0.0 for VOC, 0.0 for CO, and 0.0 for Gasoline Light Duty Vehicles (from TCEQ)

$IEF_{A.EPA}$ = $NO_X$, VOC, or CO idling emission factor for vehicle type A in Table 3-10 (from EPA based on the MOVES model)

$WPAD_{B.RCC}$ = Number of wells per pad for county B, Table 3-5 (calculated from data provided by the Railroad Commission of Texas)

Sample Equation: $NO_X$ emissions from Heavy Duty Truck Idling in Karnes County for hydraulic fracturing Oil Wells in Karnes County

$E_{Drill.Idling.ABC}$ = 247 oil wells drilled in Karnes County x 807 trips x 1.1 hours idling x (1 - 0.057) x 178.42 g/hour / 1.3 wells per well pad in Karnes County / 907,184.74 grams per ton / 365 days/year

= 0.089 tons of $NO_X$ per day for heavy duty truck idling emissions from hydraulic fracturing oil wells in Karnes County, 2011

Table 5-10: $NO_X$ and VOC Emissions from On-Road Vehicles used during Hydraulic Fracturing in the Eagle Ford, 2011

| County | FIPS Code | Heavy Duty Trucks Exhaust | | Heavy Duty Trucks Idling | | Light Duty Trucks Exhaust (Equipment) | | Light Duty Trucks Idling (Equipment) | | Light Duty Trucks Exhaust (Employee) | | Light Duty Trucks Idling (Employee) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MVDSCS21RX | | MVDSCLOFIX | | MVDSLC21RX | | MVDSLC21RX | | MVDSLC21RX | | MVDSLC21RX | |
| | | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ |
| Atascosa | 48013 | 0.004 | 0.059 | 0.006 | 0.024 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 |
| Bee | 48025 | 0.000 | 0.003 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Brazos | 48041 | 0.001 | 0.023 | 0.002 | 0.010 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Burleson | 48051 | 0.001 | 0.014 | 0.001 | 0.006 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| DeWitt | 48123 | 0.010 | 0.160 | 0.017 | 0.066 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.001 |
| Dimmit | 48127 | 0.012 | 0.200 | 0.020 | 0.082 | 0.000 | 0.001 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.001 |
| Fayette | 48149 | 0.001 | 0.014 | 0.001 | 0.006 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Frio | 48163 | 0.004 | 0.069 | 0.007 | 0.028 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 |
| Gonzales | 48177 | 0.010 | 0.149 | 0.016 | 0.061 | 0.000 | 0.001 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.001 |
| Grimes | 48185 | 0.001 | 0.012 | 0.001 | 0.005 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Houston | 48225 | 0.000 | 0.003 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Karnes | 48255 | 0.017 | 0.273 | 0.029 | 0.112 | 0.000 | 0.001 | 0.000 | 0.001 | 0.001 | 0.001 | 0.001 | 0.002 |
| La Salle | 48283 | 0.015 | 0.248 | 0.025 | 0.102 | 0.001 | 0.001 | 0.000 | 0.001 | 0.001 | 0.002 | 0.000 | 0.001 |
| Lavaca | 48285 | 0.001 | 0.011 | 0.001 | 0.005 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Lee | 48287 | 0.001 | 0.013 | 0.001 | 0.005 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Leon | 48289 | 0.002 | 0.030 | 0.003 | 0.012 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Live Oak | 48297 | 0.006 | 0.094 | 0.010 | 0.039 | 0.000 | 0.001 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.001 |
| Madison | 48313 | 0.001 | 0.022 | 0.002 | 0.009 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| McMullen | 48311 | 0.011 | 0.175 | 0.017 | 0.072 | 0.000 | 0.001 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.001 |
| Maverick | 48323 | 0.001 | 0.012 | 0.001 | 0.005 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Milam | 48331 | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Washington | 48477 | 0.000 | 0.004 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Webb | 48479 | 0.018 | 0.301 | 0.030 | 0.124 | 0.002 | 0.003 | 0.000 | 0.001 | 0.005 | 0.007 | 0.001 | 0.002 |
| Wilson | 48493 | 0.002 | 0.034 | 0.004 | 0.014 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Zavala | 48507 | 0.002 | 0.040 | 0.004 | 0.016 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Total | | 0.122 | 1.966 | 0.200 | 0.808 | 0.006 | 0.009 | 0.002 | 0.005 | 0.013 | 0.020 | 0.004 | 0.011 |

### 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”. [277] “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”.[278]

ENVIRON[279] and ERG[280] 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 5-11). 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.[281] Interviews with local companies operating in the Eagle Ford found that 100% of the completions are now flared. Industry representatives at the May 21st, 2012 meeting of the Eagle Ford Emissions Inventory Group Workshop confirm the all completion venting is now controlled by flares. Although it is preferable to have detailed data, but it is not available and the information provided by the industry is the best data available. The amount of gas vented, 1,200 Mcf per well from ERG’s report, was reduced by 100% to account for flaring. No emissions are included in this category.

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

[278] 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.

[279] 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.

[280] 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.

[281] 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.

Table 5-11: 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** | |

## 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[282] and the average heat content, 1,209 BTU/scf, from ENVIRON's CENRAP emission inventory[283] was used to calculate emissions (Table 5-12). Other studies that included flaring emissions from well completion are ENVIRON study in Southern Ute,[284] San Juan Public Lands Center in Colorado,[285] Tumble-weed II in Utah[286], and Buys & Associates in Utah[287]

[282] 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.

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

[284] 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.

[285] 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.

[286] 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:

Table 5-12: 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 were 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. [288] Since oil wells in the Eagle Ford vent casinghead natural gas, the same emission parameters were used for both natural gas and oil wells. As shown in Table 5-13, ENVIRON's CENRAP EI (Western Gulf Basin)[289], ENVIRON Southern Ute[290], and San Juan Public Lands Center in Colorado[291] used the same $NO_X$ and CO emission factors reported in AP42. Only All Consulting inventory in the Marcellus[292] used a different emission factor for $NO_X$. No VOC emissions were calculated for completion flaring in the Eagle Ford.

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.

[287] 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.

[288] 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.

[289] 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.

[290] 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.

[291] 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.

[292] 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 5-13: 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 |

Interviews with local companies operating in the Eagle Ford found that 100% of the completions are now flared. Industry representatives at the May 21st, 2012 meeting of the Eagle Ford Emissions Inventory Group Workshop confirm the all completion venting is now controlled by flares. Although it is preferable to have detailed data, but it is not available and the information provided by the industry is the best data available.

Equation 5-5, Ozone season day completion flares emissions

$E_{Comp.Vent.BC}$ = $NUM_{BC}$ x $V_{vented}$ x 1,000 scf/Mscf x HEAT /1,000,000 MMBtu/BTU x $FEF_{AP42}$ 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 type C wells (Gas or Oil)

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

$V_{vented}$ = Volume of vented gas per completion, 1,200 Mcf/event in Table 5-11 (from ENVIRON's CENRAP emission inventory for the Western Gulf Basin)

HEAT = Heat content of the gas, 1,209 BTU/scf in Table 5-12 (from ENVIRON's CENRAP emission inventory)

$FEF_{AP42}$ = Flare emission factor, 0.068 lbs of $NO_X$/MMBtu and 0.37 lbs of CO/MMBtu in Table 5-13 (from AP42)

PER = Percentage of wells controlled by flares, 1.00 (local industry data)

Sample Equation: $NO_X$ emissions from completion flares for oil wells in Karnes County in 2011

$E_{Comp.Vent.BC}$ = 47 x 1,200 Mcf/event x 1,000 scf/Mscf x 1,209 BTU/scf /1,000,000 MMBtu/BTU x 0.068 lbs of $NO_X$/MMBtu x 1.00 / 2,000 lbs/ton / 365 days/year

= 0.033 tons of $NO_X$ per day from completion flares for oil wells in Karnes County

Table 5-14: $NO_X$ Emissions from Completion Flares, 2011

| County | FIPS Code | Gas Wells 2310021600 VOC | Gas Wells 2310021600 $NO_X$ | Oil Wells 2310010700 VOC | Oil Wells 2310010700 $NO_X$ |
|---|---|---|---|---|---|
| Atascosa | 48013 | 0.000 | 0.003 | 0.000 | 0.006 |
| Bee | 48025 | 0.000 | 0.000 | 0.000 | 0.000 |
| Brazos | 48041 | 0.000 | 0.000 | 0.000 | 0.003 |
| Burleson | 48051 | 0.000 | 0.000 | 0.000 | 0.002 |
| DeWitt | 48123 | 0.000 | 0.021 | 0.000 | 0.007 |
| Dimmit | 48127 | 0.000 | 0.016 | 0.000 | 0.028 |
| Fayette | 48149 | 0.000 | 0.000 | 0.000 | 0.002 |
| Frio | 48163 | 0.000 | 0.001 | 0.000 | 0.007 |
| Gonzales | 48177 | 0.000 | 0.001 | 0.000 | 0.022 |
| Grimes | 48185 | 0.000 | 0.001 | 0.000 | 0.001 |
| Houston | 48225 | 0.000 | 0.000 | 0.000 | 0.000 |
| Karnes | 48255 | 0.000 | 0.009 | 0.000 | 0.033 |
| La Salle | 48283 | 0.000 | 0.020 | 0.000 | 0.021 |
| Lavaca | 48285 | 0.000 | 0.000 | 0.000 | 0.001 |
| Lee | 48287 | 0.000 | 0.000 | 0.000 | 0.001 |
| Leon | 48289 | 0.000 | 0.002 | 0.000 | 0.002 |
| Live Oak | 48297 | 0.000 | 0.011 | 0.000 | 0.002 |
| Madison | 48313 | 0.000 | 0.000 | 0.000 | 0.003 |
| McMullen | 48311 | 0.000 | 0.016 | 0.000 | 0.011 |
| Maverick | 48323 | 0.000 | 0.000 | 0.000 | 0.001 |
| Milam | 48331 | 0.000 | 0.000 | 0.000 | 0.000 |
| Washington | 48477 | 0.000 | 0.000 | 0.000 | 0.000 |
| Webb | 48479 | 0.000 | 0.042 | 0.000 | 0.008 |
| Wilson | 48493 | 0.000 | 0.000 | 0.000 | 0.005 |
| Zavala | 48507 | 0.000 | 0.002 | 0.000 | 0.004 |
| Total | | 0.000 | 0.146 | 0.000 | 0.170 |

# 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".[293] The methodology to calculate emissions from production was based on results from TCEQ's Barnett Shale special inventory. Other data sources include TexN Model, ERG's Fort Worth Natural Gas Study in the Barnett, and ENVIRON's CENRAP emission inventory. This section does not include emissions from equipment and fugitives at large central facilities including compressor stations and processing facilities.

Schlumberger Limited provided data on the number of production wells drilled in the Eagle Ford[294] by year and production in barrels of oil equivalent (BOE) is provided by the railroad commission[295] in Table 6-1 with a detailed breakdown in Appendix E. Production of natural gas, oil, or condensate in each county was calculated using Equation 6-1.

Table 6-1: Number of Wells Drilled and Production in the Eagle Ford, 2008-2012

| Year | Number of Wells Drilled | | Production | | | |
|---|---|---|---|---|---|---|
| | Liquid | Gas | Oil (MMbbl) | Condensate (MMbbl) | Gas (BCF) | BOE (MMbbl) |
| 2008 | 92 | 113 | 0.13 | 0.08 | 0.73 | 0 |
| 2009 | 63 | 150 | 0.31 | 0.84 | 18.98 | 4 |
| 2010 | 338 | 559 | 5.53 | 6.86 | 117.53 | 30 |
| 2011 | 1,259 | 1,081 | 47.18 | 29.17 | 448.59 | 138 |
| 2012 | 2,789 | 712 | 145.59 | 55.97 | 909.22 | 315 |

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, 449 BCF of Natural Gas, 47.18 MMbbl of Oil, or 29.17 MMbbl of condensate in 2011 (from Railroad Commission)
- $W_{County\cdot B}$ = Annual number natural gas or liquid wells drilled in County B from 2008 to 2011 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)

Sample Equation: Oil production for Atascosa County in 2011

$P_{BC}$ = 47.18 MMbbl of Oil x 51 oil wells drilled in Atascosa / 1,746 total number of oil wells drilled in the Eagle Ford

= 1.36 MMbbl of oil produced in Atascosa County, 2011

[293] 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.

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

[295] Railroad Commission of Texas, April 3, 2012. "Eagle Ford Information". Available online: http://www.rrc.state.tx.us/eagleford/index.php. Accessed: 10/01/2013.

## 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. "[296] This section describes emission calculations from wellhead compressors at the well pad and does not include compressor stations. Compressor station emissions are included in the midstream process described in the following chapter. Figure 6-1 shows a wellhead compressor, while Table 6-2 lists wellhead compressor parameters provided by previous studies. The Barnett Shale special inventory survey determined an average of 0.189 compressors per site with average horsepower of 159.

Figure 6-1: Photo of a Wellhead Compressor[297]


[296] 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.

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

Table 6-2: Wellhead Compressor Parameters from Previous Studies

| Compressor Parameters | Engine Type | 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 | All | | **0.189 per well** | 0.40 | 0.02 | 0.45 | 1 |
| Horsepower | Natural Gas, Lean - 2 Cycle | 269 | **229** | 264 | 242 | 207 | 50 |
| | Natural Gas, Lean - 4 Cycle | | **386** | | | | |
| | Natural Gas, Rich - 2 Cycle | | **124** | | | | |
| | Natural Gas, Rich - 4 Cycle | | **153** | | | | |
| | Diesel | | **143** | | | | |
| Gas Consumption Rate | All | | 233.2 MMscf/yr | | | | 10,000 Btu/hp-hr |
| Compressor Requirements | All | | | 3.21 hp-hr/Mscf | | | |
| Annual Hours | All | 6,000 | **7,684** | | 8,760 | 8,760 | 8,760 |
| Load Factor | All | 0.43 | | | 0.85 | 0.80 | |

The number of compressors per site in the Barnett Shale was lower than ERG's Fort Worth natural gas study result of 0.40 compressors per well site[298] and ENVIRON's CENWRAP result of 0.45 compressors per site in the Western Gulf Basin. [299] The Barnett Shale Special inventory found wellhead compressors ran for an average of 7,684 hours, while ENVIRON's Haynesville Shale[300] report and San Juan Public Lands Center's study in Colorado[301] used 8,760 hours.

The majority of the engines surveyed in the Barnett Special Inventory were 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.

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>0.7%</td><td rowspan="11">93.4%</td></tr>
<tr><td>NG, Lean - 2 Cycle w/ NSCR</td><td>0.3%</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>

298 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.

299 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.

300 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.

301 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.

The types of controls 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."[302]

$NO_X$ and VOC emission factors in Table 6-4 from attainment counties in the Barnett Shale special inventory, CO emission factors from ENVIRON's CENRAP emission inventory for the Western Gulf Basin,[303] and TexN model data were used to calculate emissions from wellhead compressors in the Eagle Ford Shale. The percentage of compressors by engine type was based on results from the Barnett Shale special inventory in attainment counties. Only half of the natural gas wells drilled in 2011 are predicted to be in production by the end of 2013. The following equations were used to calculate emissions from wellhead compressors.

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[302] 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.

[303] 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

<table>
<tr><th>Pollutant</th><th>Engine Type</th><th>Barnett Shale Special Inventory (Attainment Counties 2009)</th><th>TexN Model (Eagle Ford Counties)</th><th>ERG's Fort Worth Natural Gas Study</th><th>ENVIRON, Haynesville Shale[304]</th><th>ENVIRON's CENRAP EI (Western Gulf Basin)</th><th>ERG's Texas EI (attainment counties)[305]</th><th>AP-42[306] (uncontrolled, 90 - 105% Load)</th><th>San Juan Public Lands Center, Colorado[307]</th><th>EPA Region 8, Oil and Gas Production[308]</th></tr>
<tr><td rowspan="5">$NO_X$ EF</td><td>Natural Gas, Lean - 2 Cycle</td><td>7.059 tons/year</td><td rowspan="4"></td><td rowspan="5">0.55 g/hp-hr</td><td rowspan="5">2.00 g/hp-hr</td><td rowspan="2">3.10 g/hp-hr</td><td rowspan="5">7.57 g/hp-hr</td><td rowspan="2">4.08 lbs/MMBtu</td><td rowspan="5">2.21 lbs/MMBtu</td><td rowspan="2">4,162 lbs/MMscf</td></tr>
<tr><td>Natural Gas, Lean - 4 Cycle</td><td>9.360 tons/year</td></tr>
<tr><td>Natural Gas, Rich - 2 Cycle</td><td>2.247 tons/year</td><td rowspan="2">14.28 g/hp-hr</td><td rowspan="2">2.21 lbs/MMBtu</td><td rowspan="2">2,254 lbs/MMscf</td></tr>
<tr><td>Natural Gas, Rich - 4 Cycle</td><td>21.644 tons/year</td></tr>
<tr><td>Diesel</td><td>36.725 tons/year</td><td>2.14 g/hp-hr</td><td></td><td></td><td></td></tr>
<tr><td rowspan="5">VOC EF</td><td>Natural Gas, Lean - 2 Cycle</td><td>3.255 tons/year</td><td rowspan="4"></td><td rowspan="5">0.82 g/hp-hr</td><td rowspan="5">1.00 g/hp-hr</td><td rowspan="2">1.51 g/hp-hr</td><td rowspan="5">0.35 g/hp-hr</td><td rowspan="2">0.030 lbs/MMBtu</td><td rowspan="5">0.030 lbs/MMBtu</td><td rowspan="2">120.4 lbs/MMscf</td></tr>
<tr><td>Natural Gas, Lean - 4 Cycle</td><td>1.083 tons/year</td></tr>
<tr><td>Natural Gas, Rich - 2 Cycle</td><td>1.009 tons/year</td><td rowspan="2">0.84 g/hp-hr</td><td rowspan="2">0.118 lbs/MMBtu</td><td rowspan="2">30.2 lbs/MMscf</td></tr>
<tr><td>Natural Gas, Rich - 4 Cycle</td><td>0.387 tons/year</td></tr>
<tr><td>Diesel</td><td>0.255 tons/year</td><td>0.19 g/hp-hr</td><td></td><td></td><td></td></tr>
</table>

[304] 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.

[305] 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.

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

[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. Available online: http://ocs.fortlewis.edu/forestplan/DEIS/pdf/120507_TSD&App%20A.pdf. Accessed: 04/03/2012.

[308] 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.

| Pollutant | Engine Type | Barnett Shale Special Inventory (Attainment Counties 2009) | TexN Model (Eagle Ford Counties) | ERG's Fort Worth Natural Gas Study | ENVIRON, Haynesville Shale[309] | ENVIRON's CENRAP EI (Western Gulf Basin) | ERG's Texas EI (attainment counties)[310] | AP-42[311] (uncontrolled, 90 - 105% Load) | San Juan Public Lands Center, Colorado[312] | EPA Region 8, Oil and Gas Production[313] |
|---|---|---|---|---|---|---|---|---|---|---|
| CO EF | Natural Gas, Lean | | | 4.77 g/hp-hr | 4.00 g/hp-hr | **2.29 g/hp-hr** | 3.85 g/hp-hr | 3.720 lbs/MMBtu | 3.720 lbs/MMBtu | 3,794 lbs/MMscf |
| | Natural Gas, Rich | | | | | **4.63 g/hp-hr** | | 0.317 lbs/MMBtu | | 568 lbs/MMscf |
| | Diesel | | **1.70 g/hp-hr** | | | | | | | |

309 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.

310 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.

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

312 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.

313 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.

Table 6-5: Wellhead Compressor Emission Factors from the Barnett Special Shale Inventory

| Region | Engine Type | $NO_X$ | | | | VOC | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | n | Percentage | total tons per Year | Tons per engine/year | n | Percentage | total tons per Year | Tons per engine/year |
| All Counties | Diesel | 3 | 0.2% | 76.1 | 25.35 | 2 | 0.1% | 0.4 | 0.19 |
| | Natural Gas, Lean - 2 Cycle | 12 | 0.8% | 67.9 | 5.66 | 12 | 0.8% | 32.0 | 2.67 |
| | Natural Gas, Lean - 4 Cycle | 34 | 2.3% | 190.9 | 5.61 | 34 | 2.3% | 34.0 | 1.00 |
| | Natural Gas, Rich - 2 Cycle | 14 | 1.0% | 64.6 | 4.62 | 14 | 1.0% | 16.6 | 1.19 |
| | Natural Gas, Rich - 4 Cycle | 1,406 | 95.7% | 15,189.9 | 10.80 | 1,406 | 95.8% | 509.7 | 0.36 |
| Attainment | Diesel | 2 | 0.3% | 73.4 | 36.72 | 1 | 0.2% | 0.3 | 0.26 |
| | Natural Gas, Lean - 2 Cycle | 8 | 1.3% | 56.5 | 7.06 | 8 | 1.3% | 26.0 | 3.25 |
| | Natural Gas, Lean - 4 Cycle | 12 | 2.0% | 112.3 | 9.36 | 12 | 2.0% | 13.0 | 1.08 |
| | Natural Gas, Rich - 2 Cycle | 2 | 0.3% | 4.5 | 2.25 | 2 | 0.3% | 2.0 | 1.01 |
| | Natural Gas, Rich - 4 Cycle | 585 | 96.1% | 12,661.8 | 21.64 | 585 | 96.2% | 226.2 | 0.39 |
| Non-Attainment | Diesel | 1 | 0.1% | 2.6 | 2.62 | 1 | 0.1% | 0.1 | 0.12 |
| | Natural Gas, Lean - 2 Cycle | 4 | 0.5% | 11.5 | 2.87 | 4 | 0.5% | 6.0 | 1.50 |
| | Natural Gas, Lean - 4 Cycle | 22 | 2.6% | 78.5 | 3.57 | 22 | 2.6% | 21.0 | 0.95 |
| | Natural Gas, Rich - 2 Cycle | 12 | 1.4% | 60.1 | 5.01 | 12 | 1.4% | 14.6 | 1.22 |
| | Natural Gas, Rich - 4 Cycle | 821 | 95.5% | 2,528.1 | 3.08 | 821 | 95.5% | 283.5 | 0.35 |

Equation 6-2: Ozone season day wellhead compressors $NO_X$ and VOC emission factors

$EF_{Compresor.E}$ = $EM_{Barnett.E}$ / $NU_{Barnett.E}$

Where,

$EF_{Compresor.E}$ = $NO_X$ or VOC emission factor in attainment counties for compressor engine type E in Table 6-5 (from Barnett Shale Area Special Inventory)

$EM_{Barnett.E}$ = Total $NO_X$ or VOC emissions in attainment counties compressor engine type E in Table 6-5 (from the Barnett Shale Area Special Inventory)

$NU_{Barnett.E}$ = Total number of Compressors in attainment counties for compressor engine type E in Table 6-5 (from the Barnett Shale Area Special Inventory)

Sample Equation: $NO_X$ emissions factor in attainment counties for Natural Gas, Rich Burn - 4 Cycle Wellhead Compressors

$E_{Compresor.E}$ = 12,662 tons of $NO_X$ per year from Natural Gas, Rich Burn - 4 Cycle Wellhead Compressors / 585 Natural Gas, Rich Burn - 4 Cycle Wellhead Compressors

= 21.64 tons of $NO_X$ /year for Natural Gas, Rich Burn - 4 Cycle Wellhead Compressors in attainment counties

Equation 6-3, Ozone season day wellhead compressors $NO_X$ and VOC emissions

$E_{Compresor.BE}$ = [ ∑ ($NU_{.Previous.B}$) + $NU_{.Current.B}$ / 2 ] x $PER_{Serviced}$ x $PER_{Engine.E}$ x $EF_{Compresor.E}$ / 365 days/year

Where,

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

$NU_{.Previous.B}$ = Annual number of gas wells drilled in county B in previous years from Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)

$NU_{.Current.B}$ = Number of gas wells drilled in county B in current year from Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)

$PER_{Serviced}$ = Percentage of natural gas wells serviced by wellhead compressors, 0.189 in Table 6-2 (from Barnett Shale Area Special Inventory)

$PER_{Engine.E}$ = Percent of Engine type E, 1.3% for Natural Gas, Lean - 2 Cycle, 2.0% for Natural Gas, Lean - 4 Cycle, 0.3% for Natural Gas, Rich - 2 Cycle, 96.1% for Natural Gas, Rich - 4 Cycle, and 0.2% for Diesel in attainment counties in Table 6-5 (from Barnett Shale Area Special Inventory)

$EF_{Compresor.E}$ = $NO_X$ or VOC emission factor for compressors engine type E in attainment counties in Table 6-4 (from Barnett Shale Area Special Inventory)

Sample Equation: $NO_X$ emissions from Natural Gas, Rich Burn - 4 Cycle Wellhead Compressors in Karnes County in 2011

$E_{Compresor.BE}$ = [(10 gas wells drilled in 2008 + 15 gas wells drilled in 2009 + 51 gas wells drilled in 2010) + 64 gas wells drilled in 2011 / 2] x 0.189 compressors per well x 0.961 Natural Gas Compressors x 21.644 tons of $NO_X$ /year / 365 days/year

= 1.167 tons of $NO_X$ per day from Natural Gas, Rich Burn - 4 Cycle Wellhead Compressors in Karnes County, 2011

Equation 6-4, Ozone season day wellhead compressors CO emissions

$$E_{Compresor.BE} = [\sum(NU_{.Previous.B}) + NU_{.Current.B} / 2] \times PER_{Comp} \times HP_{Comp.E} \times HRS_{Comp} \times PER_{Engine.E} \times EF_{Compresor.E} / 907{,}184.74 \text{ grams per ton} / 365 \text{ days/year}$$

Where,

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

$NU_{.Previous.B}$ = Annual number of gas wells drilled in county B in previous years from Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)

$NU_{.Current.B}$ = Annual number of gas wells drilled in county B in current year from Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)

$PER_{Comp}$ = Percentage of natural gas wells serviced by wellhead compressors, 0.189 in Table 6-2 (from Barnett Shale Area Special Inventory)

$HP_{Comp.E}$ = Average horsepower of Engine type E from Table 6-2 (from Barnett Shale Area Special Inventory)

$HRS_{Comp}$ = Hours per year for compressors, 7,684 hours in Table 6-3 (from Barnett Shale Area Special Inventory)

$PER_{Engine.E}$ = Percent of Engine type E, 1.3% for Natural Gas, Lean - 2 Cycle, 2.0% for Natural Gas, Lean - 4 Cycle, 0.3% for Natural Gas, Rich - 2 Cycle, 96.1% for Natural Gas, Rich - 4 Cycle, and 0.2% for Diesel in attainment counties in Table 6-5 (from Barnett Shale Area Special Inventory)

$EF_{Compresor.E}$ = CO emission factor for compressors engine type E, 4.63 g/hp-hr for Rich-Burn, 2.29 g/hp-hr for Lean Burn, and 1.70 g/hp-hr for Diesel in Table 6-4 (from ENVIRON's CENRAP emission inventory in the Western Gulf Basin and TexN model)

Sample Equation: CO emissions from Rich Burn Natural Gas, Rich Burn - 4 Cycle Wellhead Compressors in Karnes County in 2011

$E_{Compresor.BE}$ = [(10 gas wells drilled in 2008 + 15 gas wells drilled in 2009 + 51 gas wells drilled in 2010) + 64 gas wells drilled in 2011 / 2] x 0.189 compressors per well x 153 hp x 7,684 hours x 0.961 Natural Gas, Rich Burn 4 Cycle Compressors x 4.63 g/hp-hr / 907,184.74 grams per ton / 365 days/year

= 0.322 tons of CO per day from Rich Burn Natural Gas, Rich Burn - 4 Cycle Wellhead Compressors in Karnes County, 2011

### 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."[314] 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 6-7) and each heater emits 0.142 tons/year of $NO_X$ and 0.008 tons/year of VOC annually (Table 6-8).

[314] 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: $NO_X$ and VOC Emissions from Wellhead Compressors, 2011

| County | FIPS Code | Natural Gas, Lean - 2 Cycle | | Natural Gas, Lean - 4 Cycle | | Natural Gas, Rich - 2 Cycle | | Natural Gas, Rich - 4 Cycle | | Diesel | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 20200252 | | 20200251 | | 20200251 | | 20200253 | | 2265006015 | |
| | | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ |
| Atascosa | 48013 | 0.000 | 0.001 | 0.000 | 0.002 | 0.000 | 0.000 | 0.004 | 0.243 | 0.000 | 0.001 |
| Bee | 48025 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.002 | 0.103 | 0.000 | 0.000 |
| Brazos | 48041 | 0.001 | 0.001 | 0.000 | 0.002 | 0.000 | 0.000 | 0.005 | 0.270 | 0.000 | 0.001 |
| Burleson | 48051 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.002 | 0.092 | 0.000 | 0.000 |
| DeWitt | 48123 | 0.003 | 0.007 | 0.002 | 0.014 | 0.000 | 0.001 | 0.028 | 1.577 | 0.000 | 0.005 |
| Dimmit | 48127 | 0.003 | 0.006 | 0.001 | 0.011 | 0.000 | 0.000 | 0.023 | 1.264 | 0.000 | 0.004 |
| Fayette | 48149 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.049 | 0.000 | 0.000 |
| Frio | 48163 | 0.000 | 0.001 | 0.000 | 0.002 | 0.000 | 0.000 | 0.004 | 0.221 | 0.000 | 0.001 |
| Gonzales | 48177 | 0.000 | 0.001 | 0.000 | 0.002 | 0.000 | 0.000 | 0.003 | 0.173 | 0.000 | 0.001 |
| Grimes | 48185 | 0.000 | 0.001 | 0.000 | 0.002 | 0.000 | 0.000 | 0.004 | 0.227 | 0.000 | 0.001 |
| Houston | 48225 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.022 | 0.000 | 0.000 |
| Karnes | 48255 | 0.002 | 0.005 | 0.001 | 0.010 | 0.000 | 0.000 | 0.021 | 1.167 | 0.000 | 0.003 |
| La Salle | 48283 | 0.004 | 0.008 | 0.002 | 0.016 | 0.000 | 0.001 | 0.033 | 1.820 | 0.000 | 0.005 |
| Lavaca | 48285 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.001 | 0.076 | 0.000 | 0.000 |
| Lee | 48287 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.002 | 0.103 | 0.000 | 0.000 |
| Leon | 48289 | 0.001 | 0.002 | 0.000 | 0.004 | 0.000 | 0.000 | 0.008 | 0.454 | 0.000 | 0.001 |
| Live Oak | 48297 | 0.002 | 0.004 | 0.001 | 0.007 | 0.000 | 0.000 | 0.015 | 0.843 | 0.000 | 0.002 |
| Madison | 48313 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.002 | 0.086 | 0.000 | 0.000 |
| McMullen | 48311 | 0.003 | 0.007 | 0.002 | 0.014 | 0.000 | 0.001 | 0.028 | 1.572 | 0.000 | 0.005 |
| Maverick | 48323 | 0.000 | 0.001 | 0.000 | 0.002 | 0.000 | 0.000 | 0.004 | 0.243 | 0.000 | 0.001 |
| Milam | 48331 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.011 | 0.000 | 0.000 |
| Washington | 48477 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.002 | 0.103 | 0.000 | 0.000 |
| Webb | 48479 | 0.008 | 0.017 | 0.004 | 0.033 | 0.001 | 0.001 | 0.067 | 3.765 | 0.000 | 0.011 |
| Wilson | 48493 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.022 | 0.000 | 0.000 |
| Zavala | 48507 | 0.000 | 0.001 | 0.000 | 0.001 | 0.000 | 0.000 | 0.003 | 0.162 | 0.000 | 0.000 |
| Total | | 0.030 | 0.065 | 0.015 | 0.130 | 0.002 | 0.005 | 0.262 | 14.665 | 0.000 | 0.043 |

Table 6-7: 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 |

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.[315] This data, combine with ENVIRON's CENRAP emission inventory methodology[316], was 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[317], EPA Region 8 study on Oil and Gas Production[318], and ENVIRON's Haynesville Shale emission inventory.[319]

[315] 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.

[316] 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.

[317] 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.

[318] 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.

[319] 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.

Table 6-8: 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[320] (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 |

[320] 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.

The following equations were 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 6-5, Ozone season day natural gas well heaters $NO_X$ and VOC emissions

$E_{Gas.Heaters.B}$ = [ ∑ ($NU_{.Previous.B}$) + $NU_{.Current.B}$ / 2 ] x $PER_{Heat.ERG}$ x $EF_{Gas.Heaters}$ / 365 days/year

Where,

- $E_{Gas.Heaters.B}$ = Ozone season day $NO_X$ or VOC emissions from natural gas wellhead heaters in county B
- $NU_{.Previous.B}$ = Annual number of gas wells drilled in county B in previous years from Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)
- $NU_{.Current.B}$ = Number of gas wells drilled in county B in current year from Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)
- $PER_{Heat.ERG}$ = Percentage of natural gas wells serviced by wellhead heaters, 0.05 in Table 6-7 (from Barnett Shale Area Special Inventory)
- $EF_{Gas.Heaters}$ = $NO_X$ or VOC emission factor for heaters, 0.142 tons/year for $NO_X$ or 0.008 tons/year for VOC in Table 6-8 (from Barnett Shale Area Special Inventory)

Sample Equation: $NO_X$ emissions from gas well heaters in Karnes County, 2011

$E_{Gas.Heaters.B}$ = [(10 natural gas wells drilled in 2008 + 15 natural gas wells drilled in 2009 + 51 natural gas wells drilled in 2010) + 64 natural gas wells drilled in 2011 / 2] x 0.05 heaters per natural gas well x 0.142 tons/year for $NO_X$ / 365 days/year

= 0.0021 tons of $NO_X$ per day from gas well heaters in Karnes County, 2011

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

$E_{Gas.Heaters.B}$ = [ ∑ ($NU_{Previous.B}$) + $NU_{.Current.B}$ / 2 ] x $PER_{Heatert.ERG}$ x ($Q_{Heater.ERG}$ x $HRS_{Gas.Heat}$ x $hc_{ENVIRON}$ x $EF_{Gas.Heaters}$) / $HV_{ENVIRON}$ / 2,000 lbs/ton / 365 days/year

Where,

- $E_{Gas.Heaters.B}$ = Ozone season day CO emissions from natural gas wellhead heaters in county B
- $NU_{Previous.B}$ = Annual number of natural gas wells drilled in county B in previous years from Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)
- $NU_{Current.B}$ = Annual number of natural gas wells drilled in county B in current year from Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)
- $PER_{Heater.ERG}$ = Percentage of natural gas wells serviced by wellhead heaters, 0.05 in Table 6-7 (from Barnett Shale Area Special Inventory)
- $Q_{Heater.ERG}$ = Heater rating, 0.64 MMBtu/hr in Table 6-7 (from ERG's Texas Emission inventory)
- $HRS_{Gas.Heat}$ = Annual hours of operation for natural gas well heaters, 5,346 in Table 6-7 (from Barnett Shale Area Special Inventory)
- $hc_{ENVIRON}$ = Heater cycle, 1 in Table 6-7 (from ENVIRON's CENRAP emission inventory in the Western Gulf Basin)
- $EF_{Gas.Heaters}$ = CO emission factor for compressors, 84 lbs/MMscf in Table 6-8 (from ENVIRON's CENRAP emission inventory in the Western Gulf Basin)

$HV_{ENVIRON}$ = Natural Gas heating Value, 1,209 MMBtu/MMscf in Table 6-7 (from ENVIRON's CENRAP emission inventory in the Western Gulf Basin)

Sample Equation: CO emissions from gas well heaters in Karnes County, 2011

$E_{Gas.Heaters.B}$ = [(10 natural gas wells drilled in 2008 + 15 natural gas wells drilled in 2009 + 51 natural gas wells drilled in 2010) + 64 natural gas wells drilled in 2011 / 2] x 0.05 heaters per natural gas well x (0.64 MMBtu/hr x 5,346 hours x 1 x 84 lbs/MMscf ) / 1,209 MMBtu/MMscf / 2,000 lbs/ton / 365 days/year

= 0.0018 tons of CO per day from gas well heaters in Karnes County, 2011

Equation 6-7, Ozone season day oil well heaters $NO_X$, VOC, and CO emissions

$E_{Oil.Heaters.B}$ = [ ∑ ($NU_{.Previous.B}$) + $NU_{.Current.B}$ / 2 ] x $PER_{Heat.ERG}$ x ($Q_{Heater.ERG}$ x $HRS_{Oil.Heat}$ x $hc_{ENVIRON}$ x $EF_{Oil.Heaters}$) / $HV_{ERG}$ / 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

$NU_{.Previous.B}$ = Annual number of oil wells drilled in county B in previous years from Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)

$NU_{.Current.B}$ = Annual number of oil wells drilled in county B in current year from Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)

$PER_{Heat.ERG}$ = Percentage of oil wells serviced by wellhead heaters, 0.91 in Table 6-7 (from ERG's Texas Emission inventory)

$Q_{Heater.ERG}$ = Heater rating, 0.64 MMBtu/hr in Table 6-7 (from ERG's Texas Emission inventory)

$HRS_{Oil.Heat}$ = Annual hours of operation oil wellhead heaters, 4,076 in Table 6-7 (from ERG's Texas Emission inventory)

$hc_{ENVIRON}$ = Heater cycle, 1 in Table 6-7 (from ENVIRON's CENRAP emission inventory in the Western Gulf Basin)

$EF_{Oil.Heaters}$ = $NO_X$, 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 6-8 (from ENVIRON's CENRAP emission inventory in the Western Gulf Basin)

$HV_{ERG}$ = Natural Gas heating Value, 1,655 MMBtu/MMscf in Table 6-7 (from ERG's Texas Emission inventory)

Sample Equation: $NO_X$ emissions from oil well heaters in Karnes County, 2011

$E_{Gas.Heaters.B}$ = [(0 oil wells drilled in 2008 + 1 oil well drilled in 2009 + 53 oil wells drilled in 2010) + 247 oil wells drilled in 2011 / 2] x 0.91 heaters per oil well x (0.64 MMBtu/hr x 4,076 hours x 1 x 100 lbs/MMscf ) / 1,655 MMBtu/MMscf / 2,000 lbs/ton / 365 days/year

= 0.0349 tons of $NO_X$ per day from oil well heaters in Karnes County, 2011

Table 6-9: $NO_X$ and VOC Emissions from Wellhead Heaters, 2011

| County | FIPS Code | 2310011100 | |
|---|---|---|---|
| | | VOC | $NO_X$ |
| Atascosa | 48013 | 0.000 | 0.006 |
| Bee | 48025 | 0.000 | 0.000 |
| Brazos | 48041 | 0.001 | 0.011 |
| Burleson | 48051 | 0.000 | 0.007 |
| DeWitt | 48123 | 0.001 | 0.010 |
| Dimmit | 48127 | 0.002 | 0.037 |
| Fayette | 48149 | 0.000 | 0.004 |
| Frio | 48163 | 0.001 | 0.010 |
| Gonzales | 48177 | 0.001 | 0.022 |
| Grimes | 48185 | 0.000 | 0.003 |
| Houston | 48225 | 0.000 | 0.002 |
| Karnes | 48255 | 0.002 | 0.037 |
| La Salle | 48283 | 0.001 | 0.026 |
| Lavaca | 48285 | 0.000 | 0.001 |
| Lee | 48287 | 0.000 | 0.004 |
| Leon | 48289 | 0.000 | 0.003 |
| Live Oak | 48297 | 0.000 | 0.006 |
| Madison | 48313 | 0.000 | 0.004 |
| McMullen | 48311 | 0.001 | 0.018 |
| Maverick | 48323 | 0.000 | 0.003 |
| Milam | 48331 | 0.000 | 0.000 |
| Washington | 48477 | 0.000 | 0.001 |
| Webb | 48479 | 0.001 | 0.022 |
| Wilson | 48493 | 0.000 | 0.004 |
| Zavala | 48507 | 0.000 | 0.006 |
| Total | | 0.014 | 0.246 |

### 6.3 Production 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 Eagle Ford 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, while Figure 6-3 has a satellite imagery of flaring in the Eagle Ford shale at night.

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 6-10.[321] Emission factors, 0.068 lbs of $NO_X$/MMBtu and 0.37 lbs of CO/MMBtu, from AP42 were used to calculate

[321] 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.

emissions from wellhead flares (Table 6-11).[322] These emission factors are used in most oil and gas production emission inventories including ERG's Texas emission inventory for attainment counties[323] and ENVIRON study in the Haynesville Shale[324].

Figure 6-2: Flares Near a Petroleum and Gas Storage Tanks in McMullen County, Texas[325]

[322] 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.

[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. 4-25. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820784003FY1026-20101124-ergi-oilGasEmissionsInventory.pdf. Accessed: 04/10/2012.

[324] 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.

[325] 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 6-10: Production Flares Parameters for Wells from Previous Studies

<table>
<tr><th rowspan="2">Parameters</th><th rowspan="2">Barnett Shale Special Inventory</th><th rowspan="2">ENVIRON, Haynesville Shale</th><th colspan="2">ENVIRON's CENRAP EI (Western Gulf Basin)</th><th rowspan="2">ERG's Texas EI (attainment counties)</th><th rowspan="2">Tumbleweed II, Utah</th></tr>
<tr><th>Gas</th><th>Oil and Condensate</th></tr>
<tr><td>Flow Rate (Stock Tank)</td><td rowspan="5">2.92 MMscf/yr</td><td rowspan="7">8.84 MCF Flared / BCF produced</td><td rowspan="7">8.84 MCF Flared / BCF produced</td><td rowspan="7">0.836 MCF Flared / 1,000 bbl</td><td rowspan="7">297.15 MCF Flared / BCF produced</td><td>60.9 scf/hr</td></tr>
<tr><td>Flow Rate (Pilot Light)</td><td>50 scf/hr</td></tr>
<tr><td>Fuel Rate (Stock Tank)</td><td>0.081 MMBtu/hr</td></tr>
<tr><td>Fuel Rate (Pilot Light)</td><td>0.051 MMBtu/hr</td></tr>
<tr><td>Total Volume of Gas Flared</td><td>2.5 MMscf</td></tr>
<tr><td>Count per Site</td><td>0.008</td><td>2</td></tr>
<tr><td>Flaring Duration</td><td>5,548</td><td>8,760</td></tr>
<tr><td>Heat Value (Stock Tank)</td><td></td><td rowspan="2">950 BTU/SCF</td><td rowspan="2">1,209 BTU/SCF</td><td rowspan="2">1,655 BTU/SCF</td><td rowspan="2">1,209 BTU/SCF</td><td>1,334 btu/scf</td></tr>
<tr><td>Heat Value (Pilot Light)</td><td></td><td>1,028 btu/scf</td></tr>
</table>

Figure 6-3: Eagle Ford Flares at Night from NASA's Suomi satellite[326]

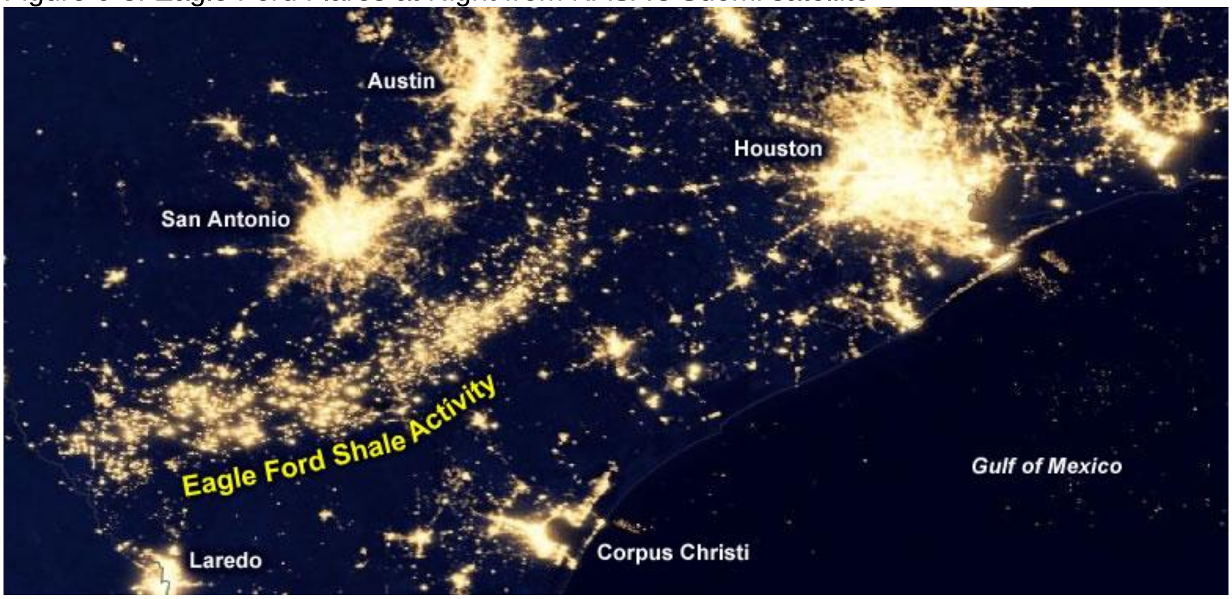


Table 6-11: Production Flares Emission Factors from Previous Studies

| 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 |

A random sample of wells across the Eagle Ford was selected to determine how much natural gas is flared at natural gas wells and oil wells. Since determining a suitable sample size is not always clear-cut, several major factors must be considered. Due to time and budget constraints, a 95% 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.[327]

Equation 6-8: Number of wells needed to estimate flare emissions

$$RN = [CLV^2 \times 0.25 \times POP] / [CLV^2 \times 0.25 + (POP - 1) CIN^2]$$

Where,

RN = Number of survey responses needed to accurately represent the population
CLV = 95% confidence level, 1.96
POP = Population size, 7,156 wells (from Railroad Commission of Texas)
CIN = ± 10% confidence interval, 0.1

[326] Geology.com., 2013. "Eagle Ford Shale". Available online: http://geology.com/articles/eagle-ford/. Accessed: 10/03/2013.
[327] Rea, L. M. and Parker, R. A., 1992. "Designing and Conducting Survey Research". Jossey-Bass Publishers: San Francisco.

Sample Equation: Number of wells needed for a 95% confidence level and 10% confidence interval:

$$RN = [(1.96)^2 \times (0.25) \times 7{,}156] / [(1.96)^2 \times (0.25) + (7{,}156 - 1) \times (0.1)^2]$$
$$= 94.8 \text{ wells}$$

Thus, data from 95 wells will be needed in order to meet the 95% level of confidence, and the ±10% confidence interval for equipment population. Since 110 wells were included in the initial analysis, the sampling meets the required sample size for a 95% confidence level with a ± 10% confidence interval. Wells with at least 1 years of production were selected from a random sampling across the basin and at least one well was selected from every county.[328] As shown in Table 6-12, the average amount of natural gas flared at gas wells was 2.68 MMCF flared/BCF of natural gas produced, while for liquid wells it was 0.14 MMCF flared/MMbbl of oil produced. Only 37 percent of the wells surveyed reported flaring of natural gas.

Table 6-12: Results from the Sample Survey in the Eagle Ford, 2008-2012

| | Natural Gas Wells | Oil Wells |
|---|---|---|
| Sample Size | 61 Wells | 59 Wells |
| Number of Wells Flared | 15 Wells | 26 Wells |
| Total Production | 67,834,344 scf | 6,388,110 bbl |
| Total Amount of Gas Flared | 181,830 scf | 918,010 scf |
| Average | 2.68 MMCF/BCF | 0.14 MMCF/MMbbl |
| Standard Deviation | 9.51 MMCF/BCF | 0.43 MMCF/MMbbl |
| Confidence Level | 2.39 MMCF/BCF | 0.11 MMCF/MMbbl |

The following formula, with data from the Railroad commissions, ENVIRON's CENRAP Emission Inventory, and EPA's AP42, was used to calculate flare $NO_X$ and CO emissions in the Eagle Ford. VOC emissions from flaring are based on the formula provided by TCEQ.[329]

Equation 6-9, Ozone season day wellhead flaring $NO_X$ and CO emissions

$$E_{Flare.BC} = Q_{Flare,C} / 1{,}000 \times HV_{C.ENVIRON} \times PROD_C \times (NU_{.Wells.BC} / NU_{.Wells.C}) \times EF_{Flares} / 365 \text{ days/year} / 2{,}000 \text{ lbs/ton}$$

Where,

- $E_{Flare.BC}$ = Ozone season day $NO_X$ or CO emissions from wellhead flaring in county B for substance C
- $Q_{Flare,C}$ = Volume of gas flared for substance C, 2.68 MMCF Flared/BCF produced or 0.14 MMCF Flared/MMbbl produced in Table 6-12 (from local data)
- $HV_{C.ENVIRON}$ = Heating value for substance C, 1,209 BTU/SCF for natural gas and 1,655 BTU/SCF for oil/condensate in Table 6-10 (from ENVIRON's CENRAP Emission Inventory for the Western Gulf Basin)
- $PROD_C$ = Eagle Ford production for substance C, 381.34 BCF or 47.18 MMbbl of Oil in 2011 (from Railroad Commission)
- $NU_{.Wells.BC}$ = Annual number of wells drilled in county B for substance C from Equation 6-1 (based on data from Schlumberger Limited)

[328] Railroad Commission of Texas. "Specific Lease Query". Austin, Texas. Available online: http://webapps.rrc.state.tx.us/PDQ/quickLeaseReportBuilderAction.do. Accessed 06/01/2012.
[329] Michael Ege, Emissions Assessment Section. TCEQ. E-mail sent May 03, 2013 2:47 PM. Austin, Texas.

$NU_{.Wells.C}$ = Total annual number of wells drilled in the Eagle Ford for Substance C in the Eagle Ford from Equation 6-1 (based on data from Schlumberger Limited)

$EF_{Flares}$ = $NO_X$ or CO flaring emission factors, 0.068 lbs of $NO_X$/MMBtu and 0.37 lbs of CO/MMBtu in Table 6-11 (from AP42)

Sample Equation: $NO_X$ emissions from flares at oil wells in Karnes County, 2011

$E_{Flare.BC}$ = 0.14 MMCF Flared/MMbbl / 1,000 x 1,655 BTU/SCF x 47.18 MMbbl of Oil x (301 oil wells drilled in Karnes County / 1,748 total number of oil wells drilled in the Eagle Ford) x 0.068 lbs of $NO_X$/MMBtu / 365 days/year / 2,000 lbs/ton

= 0.180 tons of $NO_X$ per day from flares at oil wells in Karnes County

## 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."[330] A photograph, Figure 6-4, from Energyindustryphotos.com shows an dehydrator and separator in Karnes County[331]

"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 Texas."[332] 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.

Methodology and emission factors from ENVIRON's CENRAP emission inventory for the Western Gulf Basin[333] were used to calculate VOC emissions from dehydrators flash

[330] 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.

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

[332] 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.

[333] 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.

vessels and regenerator vents in the Eagle Ford (Table 6-14). This methodology is similar to the one used in by ENVIRON in the Haynesville Shale.[334]

Table 6-13: $NO_X$ and VOC Emissions from Production Flares, 2011

| County | FIPS Code | Natural Gas Wells 31000204 | | Oil Wells 31000160 | |
|---|---|---|---|---|---|
| | | VOC | $NO_X$ | VOC | $NO_X$ |
| Atascosa | 48013 | 0.006 | 0.002 | 0.061 | 0.030 |
| Bee | 48025 | 0.002 | 0.001 | 0.001 | 0.001 |
| Brazos | 48041 | 0.004 | 0.002 | 0.075 | 0.037 |
| Burleson | 48051 | 0.002 | 0.001 | 0.052 | 0.026 |
| DeWitt | 48123 | 0.037 | 0.014 | 0.072 | 0.036 |
| Dimmit | 48127 | 0.029 | 0.011 | 0.339 | 0.169 |
| Fayette | 48149 | 0.001 | 0.000 | 0.030 | 0.015 |
| Frio | 48163 | 0.004 | 0.002 | 0.089 | 0.044 |
| Gonzales | 48177 | 0.003 | 0.001 | 0.227 | 0.113 |
| Grimes | 48185 | 0.004 | 0.001 | 0.018 | 0.009 |
| Houston | 48225 | 0.001 | 0.000 | 0.010 | 0.005 |
| Karnes | 48255 | 0.023 | 0.008 | 0.362 | 0.180 |
| La Salle | 48283 | 0.041 | 0.015 | 0.232 | 0.115 |
| Lavaca | 48285 | 0.001 | 0.000 | 0.013 | 0.007 |
| Lee | 48287 | 0.002 | 0.001 | 0.028 | 0.014 |
| Leon | 48289 | 0.009 | 0.003 | 0.020 | 0.010 |
| Live Oak | 48297 | 0.020 | 0.007 | 0.039 | 0.019 |
| Madison | 48313 | 0.002 | 0.001 | 0.039 | 0.019 |
| McMullen | 48311 | 0.034 | 0.012 | 0.140 | 0.069 |
| Maverick | 48323 | 0.004 | 0.001 | 0.023 | 0.011 |
| Milam | 48331 | 0.000 | 0.000 | 0.002 | 0.001 |
| Washington | 48477 | 0.002 | 0.001 | 0.005 | 0.002 |
| Webb | 48479 | 0.084 | 0.031 | 0.126 | 0.063 |
| Wilson | 48493 | 0.000 | 0.000 | 0.047 | 0.023 |
| Zavala | 48507 | 0.004 | 0.001 | 0.053 | 0.026 |
| Total | | 0.317 | 0.115 | 2.104 | 1.045 |

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

Figure 6-4: Dehydrator and Separator in Karnes County


Table 6-14: 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[335] |
|---|---|---|---|---|
| 14.17 lbs per year/well | 2.622 lbs/MMscf | 2.622 lbs/MMscf | **1.632 lbs/MMscf** | 8.0 lbs/MMscf |

Equation 6-10, Ozone season day wellhead dehydrators emissions

$$E_{Dehydrators.B} = PROD_{.C} \times (NU_{Wells.C.B} / NU_{Wells.C}) \times EF_{Dehydrators} / 365 \text{ days/year} / 2{,}000 \text{ lbs/ton}$$

Where,

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

$PROD_{.C}$ = Eagle Ford natural gas production from well type C, 381,337 MMscf from natural gas wells or 67,248 MMscf from oil wells (from Railroad Commission)

[335] 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.

$NU_{Wells.C.B}$ = Number of well type C drilled in county B from Equation 6-1 (based on data from Schlumberger Limited)

$NU_{Wells.C}$ = Total number of well type C drilled in the Eagle Ford from Equation 6-1 (based on data from Schlumberger Limited)

$EF_{Dehydrators}$ = $NO_X$, VOC, or CO dehydrator emission factors, 1.632 lbs of VOC/MMscf in Table 6-14 (from ERG's Texas Emission Inventory)

Sample Equation: VOC emissions from wellhead dehydrators at natural gas wells in Karnes County, 2011

$E_{Dehydrators.B}$ = 381,337 MMscf of natural gas x (140 natural gas wells drilled in Karnes County / 1,898 natural gas wells drilled in the Eagle Ford) x 1.632 lbs of VOC/MMscf / 365 days/year / 2,000 lbs/ton

= 0.063 tons of VOC per day from wellhead dehydrators at natural gas wells in Karnes County, 2011

Table 6-15: VOC Emissions from Wellhead Dehydrators, 2011

| County | FIPS Code | Natural Gas Wells | | Oil Wells (Casinghead) | |
|---|---|---|---|---|---|
| | | 2310021400 | | 2310021400 | |
| | | VOC | $NO_X$ | VOC | $NO_X$ |
| Atascosa | 48013 | 0.015 | 0.000 | 0.004 | 0.000 |
| Bee | 48025 | 0.005 | 0.000 | 0.000 | 0.000 |
| Brazos | 48041 | 0.012 | 0.000 | 0.005 | 0.000 |
| Burleson | 48051 | 0.004 | 0.000 | 0.004 | 0.000 |
| DeWitt | 48123 | 0.101 | 0.000 | 0.005 | 0.000 |
| Dimmit | 48127 | 0.079 | 0.000 | 0.024 | 0.000 |
| Fayette | 48149 | 0.002 | 0.000 | 0.002 | 0.000 |
| Frio | 48163 | 0.012 | 0.000 | 0.006 | 0.000 |
| Gonzales | 48177 | 0.009 | 0.000 | 0.016 | 0.000 |
| Grimes | 48185 | 0.010 | 0.000 | 0.001 | 0.000 |
| Houston | 48225 | 0.001 | 0.000 | 0.001 | 0.000 |
| Karnes | 48255 | 0.063 | 0.000 | 0.026 | 0.000 |
| La Salle | 48283 | 0.109 | 0.000 | 0.017 | 0.000 |
| Lavaca | 48285 | 0.003 | 0.000 | 0.001 | 0.000 |
| Lee | 48287 | 0.004 | 0.000 | 0.002 | 0.000 |
| Leon | 48289 | 0.023 | 0.000 | 0.001 | 0.000 |
| Live Oak | 48297 | 0.053 | 0.000 | 0.003 | 0.000 |
| Madison | 48313 | 0.004 | 0.000 | 0.003 | 0.000 |
| McMullen | 48311 | 0.091 | 0.000 | 0.010 | 0.000 |
| Maverick | 48323 | 0.010 | 0.000 | 0.002 | 0.000 |
| Milam | 48331 | 0.000 | 0.000 | 0.000 | 0.000 |
| Washington | 48477 | 0.005 | 0.000 | 0.000 | 0.000 |
| Webb | 48479 | 0.227 | 0.000 | 0.009 | 0.000 |
| Wilson | 48493 | 0.001 | 0.000 | 0.003 | 0.000 |
| Zavala | 48507 | 0.009 | 0.000 | 0.004 | 0.000 |
| Total | | 0.853 | 0.000 | 0.150 | 0.000 |

### 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."[336] The picture provided in Figure 6-5 shows a separator and storage tanks at a site near Kennedy in the Eagle Ford[337]

Figure 6-5: 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.[338] The Barnett Shale special Inventory had a total of 20,663 storage tanks[339] from over 4,933 survey locations or 4.19 tanks per site.

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336 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.

337 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.

338 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.

339 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

Emission factors from the Barnett Shale Special Inventory for oil and condensate tanks were 183 g/hr/oil tank and 429 g/hr/condensate tank in Table 6-16. ENVIRON's Upstream Oil and Gas Tank survey in Texas[340] 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.[341] 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 Colorado[342], ENVIRON's CENRAP emission inventory[343], and EPA Region 8 data on oil and gas production[344]. The following formula, with data from the Barnett Shale special inventory and ERG's Fort Worth natural gas study, was used to calculate emissions for oil and condensate storage tanks in the Eagle Ford.

ERG's condensate tank survey found that the Production-Weighted Emission Factor was 10.5 lb/bbl in the Eagle Ford.[345] The emission factor for the condensate tanks are "before the effects of any controls were calculated".[346] The study found that 92.2 percent of the condensate tanks surveyed had production controls and the control efficiency was 98.5 percent in the Eagle Ford.[347] ERG recommended either using 11.8 percent or 0% controls on the tanks not surveyed, however that would results in an unrealistic high emission rate from condensate tanks. ERG survey results on condensate tanks were used for all condensate production in the Eagle Ford. The same percentage control and control efficiency was used for oil storage tanks because better data is not available. Interviews with local companies operating in the Eagle Ford found that all

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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.

340 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.

341 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.

342 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.

343 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.

344 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.

345 Eastern Research Group, Inc. Oct. 10, 2012. "Condensate Tank Oil and Gas Activities". Morrisville, NC. prepared for Texas Commission on Environmental Quality. p. 2-25. Available online: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5821199776FY1211-20121031-ergi-condensate_tank.pdf. Accessed 03/12/2013.

346 *Ibid*. p. 2-19.

347 *Ibid*. p. 2-41.

tanks have controls on them and every company has a leak prevention program. Industry representatives at the May 21st, 2012 meeting of the Eagle Ford Emissions Inventory Group Workshop confirmed that the storage tanks have controls. The oil tanks emission rate of 1.60 lbs/bbl from ERG's Texas Oil and Gas Production emissions was used in this emission inventory.[348]

Equation 6-11, Ozone season day emissions from condensate storage tanks

$E_{Tanks.Con.B}$ = $PROD_{.Gas}$ x ($NU_{Wells.B}$ / $NU_{Wells}$) x [1- (PerCont x ContEff)] x $EF_{Tank.Con}$ / 365 days/year / 2,000 lbs/ton

Where,

$E_{Tanks.Con.B}$ = Ozone season day VOC emissions from condensate storage tanks in county B

$PROD_{.Con}$ = Eagle Ford condensate production, 29,169,705 bbl of condensate (from Railroad Commission)

$NU_{Wells.B}$ = Number of gas wells drilled in county B from Equation 6-1 (based on data from Schlumberger Limited)

$NU_{Wells}$ = Total number of gas wells in the Eagle Ford drilled from Equation 6-1 (based on data from Schlumberger Limited)

PerCont = Percent of Tanks Controlled, 92.2% (from ERG's condensate tank Study)

ContEff = Control Efficiency, 98.5% (from ERG's condensate tank Study)

$EF_{Tank.Con}$ = VOC emission factor for condensate, 10.5 lbs/bbl in Table 6-11 (from ERG's condensate tank Study)

Sample Equation: VOC emissions from wellhead condensate storage tanks in Karnes County, 2011

$E_{Tanks.Con.B}$ = 29,169,705 bbl of condensate x (140 natural gas wells in Karnes County / 1,898 natural gas wells in the Eagle Ford) x [1- (0.922 x 0.985)] x 10.5 lbs/bbl / 365 days/year / 2,000 lbs/ton

= 2.842 tons of VOC from wellhead condensate storage tanks in Karnes County, 2011

[348] 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.

Table 6-16: Storage Tanks VOC Emission Factors from Previous Studies

<table>
<tr><th rowspan="2">Substance</th><th rowspan="2">ERG's condensate tank Study (Eagle Ford)</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></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>10.5 lbs/bbl</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></td></tr>
<tr><td>Production Water Tank</td><td></td><td>30 g/hr/tank</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Table 6-17: VOC Emissions from Wellhead Condensate and Oil Storage Tanks, 2011

| County | FIPS Code | Condensate Tanks 2310011010 | | Oil Tanks 2310011020 | |
|---|---|---|---|---|---|
| | | VOC | $NO_X$ | VOC | $NO_X$ |
| Atascosa | 48013 | 0.670 | 0.000 | 0.277 | 0.000 |
| Bee | 48025 | 0.223 | 0.000 | 0.005 | 0.000 |
| Brazos | 48041 | 0.528 | 0.000 | 0.337 | 0.000 |
| Burleson | 48051 | 0.183 | 0.000 | 0.234 | 0.000 |
| DeWitt | 48123 | 4.547 | 0.000 | 0.326 | 0.000 |
| Dimmit | 48127 | 3.573 | 0.000 | 1.532 | 0.000 |
| Fayette | 48149 | 0.101 | 0.000 | 0.136 | 0.000 |
| Frio | 48163 | 0.528 | 0.000 | 0.402 | 0.000 |
| Gonzales | 48177 | 0.386 | 0.000 | 1.027 | 0.000 |
| Grimes | 48185 | 0.467 | 0.000 | 0.081 | 0.000 |
| Houston | 48225 | 0.061 | 0.000 | 0.043 | 0.000 |
| Karnes | 48255 | 2.842 | 0.000 | 1.635 | 0.000 |
| La Salle | 48283 | 4.933 | 0.000 | 1.048 | 0.000 |
| Lavaca | 48285 | 0.142 | 0.000 | 0.060 | 0.000 |
| Lee | 48287 | 0.203 | 0.000 | 0.125 | 0.000 |
| Leon | 48289 | 1.035 | 0.000 | 0.092 | 0.000 |
| Live Oak | 48297 | 2.375 | 0.000 | 0.174 | 0.000 |
| Madison | 48313 | 0.183 | 0.000 | 0.174 | 0.000 |
| McMullen | 48311 | 4.121 | 0.000 | 0.630 | 0.000 |
| Maverick | 48323 | 0.467 | 0.000 | 0.103 | 0.000 |
| Milam | 48331 | 0.020 | 0.000 | 0.011 | 0.000 |
| Washington | 48477 | 0.223 | 0.000 | 0.022 | 0.000 |
| Webb | 48479 | 10.251 | 0.000 | 0.570 | 0.000 |
| Wilson | 48493 | 0.041 | 0.000 | 0.212 | 0.000 |
| Zavala | 48507 | 0.426 | 0.000 | 0.239 | 0.000 |
| Total | | 38.529 | 0.000 | 9.495 | 0.000 |

Equation 6-12, Ozone season day emissions from oil storage tanks

$E_{Tanks.Oil.B}$ = $PROD_{.Oil}$ x ($NU_{Wells.Oil.B}$ / $N_{Wells.Oil}$) x [1- (PerCont x ContEff)] x $EF_{Tank.Oil}$ / 365 days/year / 2,000 lbs/ton

Where,

$E_{Tanks.Oil \cdot B}$ = Ozone season day VOC emissions from oil storage tanks in county B
$PROD_{.Oil}$ = Eagle Ford natural Oil production, 47,177,345 bbl (from Railroad Commission)
$NU_{Wells.Oil.B}$ = Number of oil wells drilled in county B from Equation 6-1 (based on data from Schlumberger Limited)
$NU_{Wells.Oil}$ = Total number of oil wells drilled in the Eagle Ford from Equation 6-1 (based on data from Schlumberger Limited)
PerCont = Percent of Tanks Controlled, 92.2% (from ERG's condensate tank Study)
ContEff = Control Efficiency, 98.5% (from ERG's condensate tank Study)
$EF_{Tank.Oil}$ = VOC emission factor for substance C, 1.60 lbs/bbl in Table 6-11 (from ERG's Texas EI)

Sample Equation: VOC emissions from wellhead oil storage tanks in Karnes County, 2011

$E_{Tanks.Oil\ B}$ = 47,177,345 bbl of oil x (301 oil wells drilled in Karnes County / 1,748 oil wells drilled in the Eagle Ford) x [1- (0.922 x 0.985)] x 1.60 lbs/bbl / 365 days/year / 2,000 lbs/ton

= 1.635 tons of VOC from wellhead oil storage tanks in Karnes County, 2011

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."[349]

## 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 Eagle Ford emission inventory. 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[350], Armendariz study on the Barnett[351], and ERG's Fort Worth Natural Gas Study [352], calculated fugitive emissions from wells in Texas.

Fugitive VOC emissions for oil wells are based on ERG methodology for Texas[353] and EPA protocol for equipment leaks.[354] 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.[355] The Barnett shale special inventory, 781

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

[350] 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.

[351] 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.

[352] 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.

[353] 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.

[354] 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.

[355] 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.

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 6-18. The formula listed below was used to calculate fugitive emissions from natural gas wells, while Equation 6-14 was used to calculate fugitive emissions from oil wells.

Equation 6-13, Ozone season day VOC fugitive emissions from natural gas wells

$E_{Gas.Fugitive.B} = [\sum (NU_{.Previous.B}) + NU_{.Current.B} / 2] \times EF_{Gas.Fugitive} \times 24 \text{ hours/day} / 907{,}184.74 \text{ grams/ton}$

Where,

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

$NU_{.Previous.B}$ = Annual number of natural gas wells drilled in county B in previous years from Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)

$NU_{.Current.B}$ = Annual number of natural gas wells drilled in county B in current year from Table 6-1 and Equation 6-1 (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 6-18 (from Barnett Shale Special Inventory)

Sample Equation: VOC fugitive emissions from natural gas wells in Karnes County, 2011

$E_{Gas.Fugitive.B}$ = [(10 gas wells drilled in 2008 + 15 gas wells drilled in 2009 + 51 gas wells drilled in 2010) + 64 gas wells drilled in 2011 / 2] x 104.89 grams/hour/well x 24 hours/day / 907,184.74 grams/ton

= 0.300 tons of VOCs from fugitives at natural gas wells in Karnes County

Equation 6-14, Ozone season day VOC fugitive emissions from oil wells

$E_{Oil.Fugitive.B} = [\sum (NU_{.Previous.B}) + NU_{.Current.B} / 2] \times EF_{Oil.Fugitive} / 2{,}000 \text{ lbs/ton} / 365 \text{ days/year}$

Where,

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

$NU_{.Previous.B}$ = Annual number of oil wells drilled in county B in previous years from Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)

$NU_{.Current.B}$ = Annual number of oil wells drilled in county B in current year from Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)

$EF_{Oil.Fugitive}$ = VOC emission factor for fugitives from oil wells, 368.27 lbs/year/well in Table 6-18 (from ERG's Texas emission inventory)

Sample Equation: VOC fugitive emissions from oil wells in Karnes County, 2011

$E_{Oil.Fugitive.B}$ = [(0 oil wells drilled in 2008 + 1 oil wells drilled in 2009 + 53 oil wells drilled in 2010) + 247 oil wells drilled in 2011 / 2] x 368.27 lbs/year/well / 2,000 lbs/ton / 365 days/year

=0.090 tons of VOCs from fugitives at oil wells in Karnes County

Table 6-18: 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

Table 6-19: VOC Fugitive Emissions from Production, 2011

| County | FIPS Code | Natural Gas Wells 2310021501 | | Oil Wells 2310011501 | |
|---|---|---|---|---|---|
| | | VOC | $NO_X$ | VOC | $NO_X$ |
| Atascosa | 48013 | 0.062 | 0.000 | 0.014 | 0.000 |
| Bee | 48025 | 0.026 | 0.000 | 0.001 | 0.000 |
| Brazos | 48041 | 0.069 | 0.000 | 0.026 | 0.000 |
| Burleson | 48051 | 0.024 | 0.000 | 0.019 | 0.000 |
| DeWitt | 48123 | 0.405 | 0.000 | 0.018 | 0.000 |
| Dimmit | 48127 | 0.325 | 0.000 | 0.090 | 0.000 |
| Fayette | 48149 | 0.012 | 0.000 | 0.009 | 0.000 |
| Frio | 48163 | 0.057 | 0.000 | 0.023 | 0.000 |
| Gonzales | 48177 | 0.044 | 0.000 | 0.055 | 0.000 |
| Grimes | 48185 | 0.058 | 0.000 | 0.006 | 0.000 |
| Houston | 48225 | 0.006 | 0.000 | 0.004 | 0.000 |
| Karnes | 48255 | 0.300 | 0.000 | 0.090 | 0.000 |
| La Salle | 48283 | 0.468 | 0.000 | 0.058 | 0.000 |
| Lavaca | 48285 | 0.019 | 0.000 | 0.003 | 0.000 |
| Lee | 48287 | 0.026 | 0.000 | 0.009 | 0.000 |
| Leon | 48289 | 0.117 | 0.000 | 0.005 | 0.000 |
| Live Oak | 48297 | 0.216 | 0.000 | 0.013 | 0.000 |
| Madison | 48313 | 0.022 | 0.000 | 0.011 | 0.000 |
| McMullen | 48311 | 0.404 | 0.000 | 0.038 | 0.000 |
| Maverick | 48323 | 0.062 | 0.000 | 0.007 | 0.000 |
| Milam | 48331 | 0.003 | 0.000 | 0.001 | 0.000 |
| Washington | 48477 | 0.026 | 0.000 | 0.002 | 0.000 |
| Webb | 48479 | 0.967 | 0.000 | 0.039 | 0.000 |
| Wilson | 48493 | 0.006 | 0.000 | 0.011 | 0.000 |
| Zavala | 48507 | 0.042 | 0.000 | 0.015 | 0.000 |
| Total | | 3.767 | 0.000 | 0.564 | 0.000 |

## 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".[356] 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.[357] To calculate loading emission factors for each specific county,

[356] 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.

[357] 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.

average temperature data from 1980 to 2010 was calculated using ArcGIS software[358] and data from NOAA[359] 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[360] 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 were 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 6-20 and Table 6-21.

To calculate emission factors for loading loss for each county, true vapor pressure is required. Equation 6-15 and Equation 6-16, from ERG's Texas emission inventory, was used to calculate the true vapor pressure for crude oil and condensate in each county.

Equation 6-15, 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 6-20 (based on data from NOAA)

Sample Equation: Ozone Season day true vapor pressure for crude oil in Karnes County

$$P_{Crude.oil} = (0.057 \times 77.0 \text{ degrees Fahrenheit}) - 0.58$$

= 3.81 psi for crude oil in Karnes County, ozone season day

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

[359] 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.

[360] 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 6-20: 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 |

Table 6-21: 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 6-16, True vapor pressure for condensate

$P_{Condensate}$ = (0.077 x $T_B$) – 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 6-20 (based on data from NOAA)

Sample Equation: Ozone Season day true vapor pressure for condensate in Karnes County

$P_{Condensate}$ = (0.077 x 77.0 degrees Fahrenheit) – 1.03
= 4.90 psi for condensate in Karnes County, ozone season day

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 6-17, VOC emission factor for loading loss

$EF_{Loading.BC}$ =12.46 x [S x $P_{BC}$ x $M_C$ / ($T_B$ + 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 6-20 (from EPA's AP42)

$P_{BC}$ = True vapor pressure for County B for substance C in Table 6-20 and Table 6-21 (from Equation 6-15 and Equation 6-16)

$M_C$ = Molecular weight of tank vapors for substance C, 50 lb/lb-mole for oil and 68 lb/lb-mole for condensate in Table 6-20 (from EPA's AP42)

$T_B$ = Atmospheric temperature in degrees Fahrenheit for County B in Table 6-20 and Table 6-21 (based on data from NOAA)

Sample Equation: Ozone Season day emission factor for condensate in Karnes County

$EF_{Loading.BC}$ =12.46 x [1.00 x 4.90 psi x 68 lb/lb-mole / (77.0 degrees Fahrenheit + 459.67)]
= 7.73 lbs of VOC / 1,000 gallons for condensate in Karnes County, ozone season day

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

Equation 6-18, Ozone season day VOC emissions from loading loss

$E_{Loading.BC}$ = ($NU_{Wells.BC}$ / $NU_{.Wells.C}$) x $PROD_C$ x $EF_{Loading.BC}$ x 42 gallons per barrel / 365 days/year / 2,000 lbs/ton

Where,

$E_{Loading.BC}$ = Ozone season day VOC emissions from loading loss in county B for substance C

$NU_{.Wells.BC}$ = Annual number of wells drilled in county B for substance C from Equation 6-1 (based on data from Schlumberger Limited)

$NU_{.Wells.C}$ = Total number of wells drilled in the Eagle Ford for substance C from Equation 6-1 (based on data from Schlumberger Limited)

$PROD_C$ = Eagle Ford production for substance C, 47,177,345 bbl of Oil or 29,169,705 bbl of condensate in 2011 (from Railroad Commission)

$EF_{Loading.BC}$ = VOC emission factor for loading loss for County B and Substance C in Table 6-20 and Table 6-21 (from Equation 6-17)

Sample Equation: Ozone season day VOC loading loss emissions from oil in Karnes County, 2011

$E_{Loading.BC}$ = 301 oil wells in Karnes County / 1,748 total oil wells x 47,177.345 Mbbl of oil per year x 42 gallons per barrel x 4.421 lbs of VOC/1000 gallons of oil in Karnes County / 365 days/year / 2,000 lbs/ton

= 2.066 tons of VOC per ozone season day from oil loading loss in Karnes County

Table 6-22: VOC Emissions from Production Loading Loss, 2011

| County | FIPS Code | Condensate 2310011201 | | Oil 2310011202 | |
|---|---|---|---|---|---|
| | | VOC | $NO_X$ | VOC | $NO_X$ |
| Atascosa | 48013 | 0.347 | 0.000 | 0.223 | 0.000 |
| Bee | 48025 | 0.007 | 0.000 | 0.076 | 0.000 |
| Brazos | 48041 | 0.426 | 0.000 | 0.178 | 0.000 |
| Burleson | 48051 | 0.295 | 0.000 | 0.062 | 0.000 |
| DeWitt | 48123 | 0.414 | 0.000 | 1.540 | 0.000 |
| Dimmit | 48127 | 1.925 | 0.000 | 1.197 | 0.000 |
| Fayette | 48149 | 0.172 | 0.000 | 0.034 | 0.000 |
| Frio | 48163 | 0.504 | 0.000 | 0.176 | 0.000 |
| Gonzales | 48177 | 1.297 | 0.000 | 0.130 | 0.000 |
| Grimes | 48185 | 0.103 | 0.000 | 0.157 | 0.000 |
| Houston | 48225 | 0.055 | 0.000 | 0.021 | 0.000 |
| Karnes | 48255 | 2.066 | 0.000 | 0.957 | 0.000 |
| La Salle | 48283 | 1.322 | 0.000 | 1.658 | 0.000 |
| Lavaca | 48285 | 0.076 | 0.000 | 0.048 | 0.000 |
| Lee | 48287 | 0.158 | 0.000 | 0.068 | 0.000 |
| Leon | 48289 | 0.117 | 0.000 | 0.348 | 0.000 |
| Live Oak | 48297 | 0.221 | 0.000 | 0.806 | 0.000 |
| Madison | 48313 | 0.220 | 0.000 | 0.062 | 0.000 |
| McMullen | 48311 | 0.797 | 0.000 | 1.390 | 0.000 |
| Maverick | 48323 | 0.129 | 0.000 | 0.156 | 0.000 |
| Milam | 48331 | 0.014 | 0.000 | 0.007 | 0.000 |
| Washington | 48477 | 0.027 | 0.000 | 0.075 | 0.000 |
| Webb | 48479 | 0.723 | 0.000 | 3.462 | 0.000 |
| Wilson | 48493 | 0.265 | 0.000 | 0.014 | 0.000 |
| Zavala | 48507 | 0.300 | 0.000 | 0.142 | 0.000 |
| Total | | 11.974 | 0.000 | 12.972 | 0.000 |

## 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."[361]

To calculate natural gas wells 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 6-23).[362] 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 6-23: 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 6-24, from ERG's Texas emission inventory, were used to calculate emissions from natural gas wells blowdowns. "Flaring and/or green practices may be used to control emissions from the blowdown process."[363] Although emission

[361] 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.

[362] 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: 01/24/2013.

[363] 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:

reductions due to flaring and green completions are not calculated for 2011, flaring has a control efficiency of 98 percent and green completion has a control efficiency of 100%.[364] Emissions were not calculated for oil wells because industry representatives noted that oil well workovers or maintenance can occur, but not blowdowns in the Eagle Ford.

Table 6-24: 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)[365] | |
|---|---|---|---|
| | | Gas | Oil |
| 0.026 tons/ year/well | 0.099 tons/year/well | **0.160 tons/blowdown** | 0.846 tons/blowdown |

The following equation from ERG was used to calculate VOC emissions from blowdowns at each well in the Eagle Ford.

Equation 6-19, Blowdowns VOC emissions from each well

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

Where,

$EF_{Blowdown}$ = Blowdowns VOC emission factor for natural gas wells
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
$MW_{gas}$ = Molecular weight of the gas, 20 g/mol (from ERG's Texas emission inventory)
T = Atmospheric temperature, 298 K
$F_{VOC}$ = Mass fraction of VOC in the vented gas, 0.036 (from ERG's Texas emission inventory)

Sample Equation: VOC emissions from blowdowns at natural gas wells

$EF_{Blowdown}$ = (1 x 173.9 MCF/event) / [(0.082 L-atm/mol-K / 20 g/mo) x 298 K x 0.00003531 Mscf/liter)] x (0.036 / 907,184.74 grams/ton)
= 0.160 tons/blowdown for natural gas wells

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

Equation 6-20, Ozone season day VOC emissions from blowdowns at natural gas wells

$E_{Blowdowns.B}$ = [ ∑ ($NU_{.Pre.B}$) + $NU_{.Current.B}$ / 2 ] x $N_{Blowdown}$ x [1 - ($C_{flare}$ x $CE_{flare}$) - $C_{green}$] x $EF_{Blowdown}$ / 365 days/year

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

[364] *Ibid*.

[365] 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.

Where,

$E_{Blowdowns.B}$ = Ozone season day VOC emissions from blowdowns in county B for natural gas wells

$NU_{.Pre.BC}$ = Annual number of natural gas wells drilled in county B in previous years for substance C from Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)

$NU_{.Current.BC}$ = Annual number of natural gas wells drilled in county B in current year for substance C from 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)

$EF_{Blowdown}$ = VOC emission factor for blowdowns 0.160 tons/blowdown (from Equation 6-19 and ERG's Texas Emission Inventory)

Sample Equation: Ozone season day blowdown VOC emissions from natural gas wells in Karnes County, 2011

$E_{Blowdowns.B}$ = [(10 natural gas wells drilled in 2008 + 15 natural gas wells drilled in 2009 + 51 natural gas wells drilled in 2010) + 64 natural gas wells drilled in 2011 / 2] x 0.71 blowdowns/year x [1 - (0% x 98%) – 0%] x 0.160 tons/blowdown / 365 days/year

= 0.034 tons of VOC per ozone season day from natural gas well blowdowns in Karnes County, 2011

Table 6-25: VOC Emissions from Blowdowns, 2011

| County | FIPS Code | Gas Wells | | Oil Wells | |
|---|---|---|---|---|---|
| | | 2310021600 | | 2310010700 | |
| | | VOC | $NO_X$ | VOC | $NO_X$ |
| Atascosa | 48013 | 0.007 | 0.000 | 0.000 | 0.000 |
| Bee | 48025 | 0.003 | 0.000 | 0.000 | 0.000 |
| Brazos | 48041 | 0.008 | 0.000 | 0.000 | 0.000 |
| Burleson | 48051 | 0.003 | 0.000 | 0.000 | 0.000 |
| DeWitt | 48123 | 0.045 | 0.000 | 0.000 | 0.000 |
| Dimmit | 48127 | 0.036 | 0.000 | 0.000 | 0.000 |
| Fayette | 48149 | 0.001 | 0.000 | 0.000 | 0.000 |
| Frio | 48163 | 0.006 | 0.000 | 0.000 | 0.000 |
| Gonzales | 48177 | 0.005 | 0.000 | 0.000 | 0.000 |
| Grimes | 48185 | 0.007 | 0.000 | 0.000 | 0.000 |
| Houston | 48225 | 0.001 | 0.000 | 0.000 | 0.000 |
| Karnes | 48255 | 0.034 | 0.000 | 0.000 | 0.000 |
| La Salle | 48283 | 0.052 | 0.000 | 0.000 | 0.000 |
| Lavaca | 48285 | 0.002 | 0.000 | 0.000 | 0.000 |
| Lee | 48287 | 0.003 | 0.000 | 0.000 | 0.000 |
| Leon | 48289 | 0.013 | 0.000 | 0.000 | 0.000 |
| Live Oak | 48297 | 0.024 | 0.000 | 0.000 | 0.000 |
| Madison | 48313 | 0.002 | 0.000 | 0.000 | 0.000 |
| McMullen | 48311 | 0.045 | 0.000 | 0.000 | 0.000 |
| Maverick | 48323 | 0.007 | 0.000 | 0.000 | 0.000 |
| Milam | 48331 | 0.000 | 0.000 | 0.000 | 0.000 |
| Washington | 48477 | 0.003 | 0.000 | 0.000 | 0.000 |
| Webb | 48479 | 0.108 | 0.000 | 0.000 | 0.000 |
| Wilson | 48493 | 0.001 | 0.000 | 0.000 | 0.000 |
| Zavala | 48507 | 0.005 | 0.000 | 0.000 | 0.000 |
| Total | | 0.422 | 0.000 | 0.000 | 0.000 |

## 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."[366]

Pneumatic devices emission factors from ENVIRON's CENRAP emission inventory and ERG's Texas emission inventory[367] are based on EPA's natural gas star program[368] (Table

[366] 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.
[367] 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:

6-26). 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.

Table 6-26: 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.

Equation 6-21, VOC emissions from pneumatic devices at each well

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

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, 0.031 Mcf/hr/device for liquid level controller and 0.0168 Mcf/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

Sample Equation: VOC emissions from pneumatic devices at each well

$$EF_{Pneumatic} = [(0.1054 / 907{,}184.74 \text{ grams/ton}) \times (0.031 \text{ Mcf/hr/device} \times 2 \times 8760 \text{ hours/year} + 0.0168 \text{ Mcf/hr/device} \times 1 \times 8760 \text{ hours/year})] \times [1 \text{ atm} / (0.082 \text{ L-atm/mol-K} / 19.68 \text{ g/mol} \times 298 \times 0.00003531 \text{ Mscf/liter})]$$

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http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820784003FY1026-20101124-ergi-oilGasEmissionsInventory.pdf. Accessed: 04/10/2012.

[368] 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.

= 1.83 tons/year/well from pneumatic devices at each well

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

Equation 6-22, Ozone season day VOC emissions from pneumatic devices

$E_{Pneumatic.B}$ = [ ∑ ($NU_{.Pre.B}$) + $NU_{.Current.B}$ / 2 ] x $EF_{Pneumatic}$ / 365 days/year

Where,

$E_{Pneumatic.B}$ = Ozone season day VOC emissions from pneumatic devices in county B

$NU_{.Pre.BC}$ = Annual number of natural gas wells drilled in county B in previous years for substance C from Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)

$NU_{.Current.BC}$ = Annual number of natural gas wells drilled in county B in current year for substance C from Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)

$EF_{Pneumatic}$ = VOC emission factor for pneumatic devices, 1.83 tons/year/well (from Equation 6-21)

Sample Equation: Ozone season day pneumatic devices VOC emissions from natural gas wells in Karnes County, 2011

$E_{Pneumatic.B}$ = [(10 natural gas wells drilled in 2008 + 15 natural gas wells drilled in 2009 + 51 natural gas wells drilled in 2010) + 64 natural gas wells drilled in 2011 / 2] x 1.83 tons/year/well / 365 days/year

= 0.54 tons of VOC per day from natural gas well pneumatic devices in Karnes County, 2011

As part of TCEQ's ongoing efforts to improve the area source oil and gas emissions inventory, the TCEQ requested "data associated with pneumatic devices operating at active gas well sites outside of the 23-county Barnett Shale area for calendar year 2011".[369] The results of TCEQ's Pneumatic Survey were not available in time for the Eagle Ford emission inventory and are not included.

[369] TCEQ. "Area Source Emissions: Statewide Pneumatic Devices Survey". Austin, Texas. Available online: http://www.tceq.texas.gov/airquality/areasource/ASEI.html. Accessed 10/22/2013.

Table 6-27: VOC Emissions from Pneumatic Devices, 2011

| County | FIPS Code | Gas Wells | |
|---|---|---|---|
| | | 2310020700 | |
| | | VOC | $NO_X$ |
| Atascosa | 48013 | 0.113 | 0.000 |
| Bee | 48025 | 0.048 | 0.000 |
| Brazos | 48041 | 0.125 | 0.000 |
| Burleson | 48051 | 0.043 | 0.000 |
| DeWitt | 48123 | 0.731 | 0.000 |
| Dimmit | 48127 | 0.586 | 0.000 |
| Fayette | 48149 | 0.023 | 0.000 |
| Frio | 48163 | 0.103 | 0.000 |
| Gonzales | 48177 | 0.080 | 0.000 |
| Grimes | 48185 | 0.105 | 0.000 |
| Houston | 48225 | 0.010 | 0.000 |
| Karnes | 48255 | 0.541 | 0.000 |
| La Salle | 48283 | 0.844 | 0.000 |
| Lavaca | 48285 | 0.035 | 0.000 |
| Lee | 48287 | 0.048 | 0.000 |
| Leon | 48289 | 0.210 | 0.000 |
| Live Oak | 48297 | 0.391 | 0.000 |
| Madison | 48313 | 0.040 | 0.000 |
| McMullen | 48311 | 0.729 | 0.000 |
| Maverick | 48323 | 0.113 | 0.000 |
| Milam | 48331 | 0.005 | 0.000 |
| Washington | 48477 | 0.048 | 0.000 |
| Webb | 48479 | 1.746 | 0.000 |
| Wilson | 48493 | 0.010 | 0.000 |
| Zavala | 48507 | 0.075 | 0.000 |
| Total | | 6.799 | 0.000 |

## 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[370] to 365 trucks in Pinedale Anticline Project, Wyoming survey.[371] Cornell University only estimated 15 trucks per well pad in the Marcellus,[372] while San Juan Public Lands Center had a higher

[370] 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.

[371] 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.

[372] 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.[373] TxDOT estimated that 353 trucks per year visit each well site.[374] 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.[375] NCTCOG ultimately assumed an average trip rate of one truck every three days or 0.33 truck trips per day per gas well. This estimate is per wellbore; a well site with multiple wellbores would generate this rate of trips for each wellbore.[376]

For light duty vehicles, Tumble-weed II study in Utah report 365 vehicles annually[377], while Jonah Infill in Wyoming stated that there was 122 light duty vehicles during production[378] Data from ENVIRON report in Colorado, 73.2 light duty vehicles, was used to estimate emissions. Data on idling rates from the ENVIRON report was also 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.[379] 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.[380]

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

[373] 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.

[374] Richard Schiller, P.E. Fort, Worth District. Aug. 5, 2010. “Barnett Shale Gas Exploration Impact on TxDOT Roadways”. TxDOT, Forth Worth. Slide 18.

[375] 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.

[376] North Central Texas Council of Governments. Aug. 2012. “Development of Oil and Gas Mobile Source Inventory in the Barnett Shale in the 12-County Dallas-Fort Worth Area”. Texas Commission on Environmental Quality Grant Number: 582-11-13174. Arlington, Texas. p.16.

[377] 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.

[378] 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.

[379] 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.

[380] Railroad Commission of Texas. “Specific Lease Query”. Austin, Texas. Available online: http://webapps.rrc.state.tx.us/PDQ/quickLeaseReportBuilderAction.do. Accessed 06/01/2012.

Table 6-28: 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)[381] | TxDOT, Barnett | NCTCOG, Barnett |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HDDV | Annual Number/Well | Water Truck | 15 | 158 | 1 | 3.3 | 35 | 5 - 13.3 | 2-3 | 365 | < 1 trip per day | 353 | **0.33 trips/day per well** |
| | | Product Truck | | | 80 | | | | | | | | |
| | | Maintenance | | | - | 0.9 | | | | | | | |
| | Distance (miles) | Water Truck | 62.5 | 12.5 | 80 | 37.8 | 9.5 | - | - | 10 | - | - | **22 (2012 and 2018)** |
| | | 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** | - | - | - | - | - | - | 6 hours /day per truck |
| | | 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** | | | | | | | |

[381] 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.

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 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.

On-road VOC, $NO_X$, and CO emissions during production for heavy duty trucks and light duty trucks was calculated in Equation 6-23 and Equation 6-24. The inputs into the formula were based on local data, MOVES output emission factors, TxDOT, and data from ENVIRON's survey in Colorado. $NO_X$ emission reductions of 0.057 from the use of TxLED in affect counties were included in the calculations of on-road emissions

Equation 6-23, Ozone season day on-road emissions during production

$$E_{Onroad.ABC} = [\sum (NU_{.Pre.B}) + NU_{.Current.B} / 2] \times TRIPS_A \times (DIST_{B.RCC} \times 2) \times (1 - TxLED_{TCEQ}) \times OEF_{A.MOVES} / WPAD_{B.RCC} / 907{,}184.74 \text{ grams per ton} / 365 \text{ days/year}$$

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)
- $NU_{.Pre.BC}$ = Annual number of natural gas wells drilled in county B in previous years for substance C from Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)
- $NU_{.Current.BC}$ = Annual number of natural gas wells drilled in county B in current year for substance C from Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)
- $TRIPS_A$ = Number of trips for vehicle type A, 120.45 for heavy duty trucks (from NCTCOG in the Barnett), 68.5 for light duty trucks for production, and 4.7 light duty trucks for maintenance in Table 6-28 (from ENVIRON's Colorado report)
- $DIST_{B.RCC}$ = 11 miles each way for Heavy duty vehicles (from NCTCOG in the Barnett) and distance to the nearest town for light duty vehicles in county B, Table 3-5 (from Railroad Commission of Texas)
- $TxLED_{TCEQ}$ = On-road emission reductions from TxLED, 0.057 for $NO_X$ from Heavy Duty Diesel Trucks, 0.0 for VOC, 0.0 for CO, and 0.0 for Gasoline Light Duty Vehicles (from TCEQ)
- $OEF_{A.MOVES}$ = $NO_X$, VOC, or CO on-road emission factor for vehicle type A in Table 3-10 (from MOVES Model)
- $WPAD_{B.RCC}$ = Number of Wells per Pad for county B for light duty vehicles (calculated from data provided by the Railroad Commission of Texas)

Sample Equation: Ozone season day heavy duty truck exhaust $NO_X$ emissions during production from oil gas wells in Karnes County, 2011

$E_{Onroad.ABC}$ = [(0 oil wells drilled in 2008 + 1 oil wells drilled in 2009 + 53 oil wells drilled in 2010) + 247 oil wells drilled in 2011 / 2] x 120.45 trips x (11 miles x 2) x (1 – 0.057) x 9.55 grams/mile / 1 / 907,184.74 grams per ton / 365 days/year
= 0.013 tons of $NO_X$ per ozone season day from Heavy duty truck exhaust at oil wells in Karnes County, 2011

Equation 6-24, Ozone season day idling emissions during production

$$E_{Idling.ABC} = [\sum (NU_{.Pre.B}) + NU_{.Current.B} / 2] \times TRIPS_A \times IDLE_A \times (1 - TxLED_{TCEQ}) \times IEF_{A.EPA} / WPAD_{B.RCC} / 907{,}184.74 \text{ grams per ton} / 365 \text{ days/year}$$

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)

$NU_{.Pre.BC}$ = Annual number of natural gas wells drilled in county B in previous years for substance C from Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)

$NU_{.Current.BC}$ = Annual number of natural gas wells drilled in county B in current year for substance C from Table 6-1 and Equation 6-1 (based on data from Schlumberger Limited)

$TRIPS_A$ = Annual number of trips for vehicle type A, 120.45 for heavy duty trucks (from NCTCOG in the Barnett), 68.5 for light duty trucks for production, and 4.7 light duty trucks for maintenance in Table 6-28 (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 6-28 (from ENVIRON's Colorado report)

$IEF_{A.EPA}$ = $NO_X$, VOC, or CO idling emission factor for vehicle type A in Table 3-10 (from EPA based on the MOVES model)

$TxLED_{TCEQ}$ = On-road emission reductions from TxLED, 0.057 for $NO_X$ from Heavy Duty Diesel Trucks, 0.0 for VOC, 0.0 for CO, and 0.0 for Gasoline Light Duty Vehicles (from TCEQ)

$WPAD_{B.RCC}$ = Number of Wells per Pad for county B (calculated from data provided by the Railroad Commission of Texas)

Sample Equation: Ozone season day heavy duty truck idling $NO_X$ emissions during production from oil gas wells in Karnes County, 2011

$E_{Onroad.ABC}$ = [(0 oil wells drilled in 2008 + 1 oil wells drilled in 2009 + 53 oil wells drilled in 2010) + 247 oil wells drilled in 2011 / 2] x 120.45 trips x 0.9 hours x (1 – 0.057) x 178.42 grams/hour / 1.25 / 907,184.74 grams per ton / 365 days/year

= 0.008 tons of $NO_X$ per ozone season day from Heavy duty truck idling at oil wells in Karnes County, 2011

Table 6-29: $NO_X$ and VOC Emissions from On-Road Vehicles used during Production in the Eagle Ford, 2011

| County | FIPS Code | Heavy Duty Trucks Exhaust | | Heavy Duty Trucks Idling | | Light Duty Trucks Exhaust (Maintenance) | | Light Duty Trucks Idling (Maintenance) | | Light Duty Trucks Exhaust (Production) | | Light Duty Trucks Idling (Production) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MVDSCS21RX | | MVDSCLOFIX | | MVDSLC21RX | | MVDSLC21RX | | MVDSLC21RX | | MVDSLC21RX | |
| | | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ |
| Atascosa | 48013 | 0.000 | 0.003 | 0.001 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Bee | 48025 | 0.000 | 0.001 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Brazos | 48041 | 0.000 | 0.005 | 0.001 | 0.004 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Burleson | 48051 | 0.000 | 0.003 | 0.001 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| DeWitt | 48123 | 0.001 | 0.010 | 0.002 | 0.007 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.001 |
| Dimmit | 48127 | 0.001 | 0.018 | 0.003 | 0.012 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.001 |
| Fayette | 48149 | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Frio | 48163 | 0.000 | 0.005 | 0.001 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 |
| Gonzales | 48177 | 0.001 | 0.009 | 0.002 | 0.006 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.001 |
| Grimes | 48185 | 0.000 | 0.002 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Houston | 48225 | 0.000 | 0.001 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Karnes | 48255 | 0.001 | 0.019 | 0.004 | 0.013 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.001 |
| La Salle | 48283 | 0.001 | 0.018 | 0.003 | 0.012 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.002 | 0.000 | 0.001 |
| Lavaca | 48285 | 0.000 | 0.001 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Lee | 48287 | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Leon | 48289 | 0.000 | 0.003 | 0.001 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Live Oak | 48297 | 0.000 | 0.007 | 0.001 | 0.005 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.001 |
| Madison | 48313 | 0.000 | 0.002 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| McMullen | 48311 | 0.001 | 0.014 | 0.003 | 0.010 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.001 |
| Maverick | 48323 | 0.000 | 0.003 | 0.001 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Milam | 48331 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Washington | 48477 | 0.000 | 0.001 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Webb | 48479 | 0.001 | 0.025 | 0.005 | 0.018 | 0.000 | 0.000 | 0.000 | 0.000 | 0.004 | 0.007 | 0.001 | 0.002 |
| Wilson | 48493 | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Zavala | 48507 | 0.000 | 0.003 | 0.001 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Total | | 0.010 | 0.159 | 0.030 | 0.110 | 0.001 | 0.001 | 0.000 | 0.001 | 0.011 | 0.017 | 0.004 | 0.011 |

# 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.[382]

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."[383] 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.[384]

"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

[382] TCEQ. "TCEQ Document Search". Available online: https://webmail.tceq.state.tx.us/gw/webpub. Accessed 06/08/2012.
[383] 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.
[384] 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.

sources may include equipment leaks, storage tanks, glycol dehydrators, flares, and condensate and/or wastewater loading."[385]

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.[386]

"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."[387] Water can "cause corrosion when combined with carbon dioxide (CO2) or hydrogen sulfide (H2S) 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."[388]

"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 (CH4), but most gas also contains varying degrees of liquids including ethane (C2H6), propane (C3H8), normal butane (C4H10),

[385] 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.
[386] 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.
[387] 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.
[388] *Ibid*.

isobutane (C4H10), 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."[389]

"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."[390]

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.[391]  Figure 7-2 shows a facility for processing gas liquid under construction in the Eagle Ford Shale.[392]  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

[389] *Ibid*.
[390] *Ibid*.
[391] 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.
[392] 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.

### 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 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."[393]

Cryogenic plants are being built in the Eagle Ford by oil and gas companies, including 11 built by Thomas Russell Co.[394], 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."[395]

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."[396]

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393 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.

394 Thomas Russell Co. "Project Experience". Available online: http://www.thomasrussellco.com/projects.html. Accessed 06/08/2012.

395 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.

396 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[397]


"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."[398] 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.

[397] Energyindustryphotos.com. "Eagle Ford Shale Play Photos". Available online: http://eaglefordshaleblog.com/2012/04/09/eagle-ford-shale-play-photos/. Accessed: 06/08/2012.

[398] 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[399]


## 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.[400] 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 be included in TCEQ's point source database as midstream facilities are built and start production.

[399] Energyindustryphotos.com. "Eagle Ford Shale Play Photos". Available online: http://eaglefordshaleblog.com/2012/04/09/eagle-ford-shale-play-photos/. Accessed: 05/01/2012.
[400] 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 equipment manufacture, oil and gas producer, and permit 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)[401], 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.[402] 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. A detailed breakdown of permitted mid-stream sources in the AACOG region is provided in Appendix D.

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 actual 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.

[401] 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.

[402] 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 |

| 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).[403] 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 were 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, store, and transport. When equipment types are similar, data from the Barnett Shale special inventory was 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.[404] 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."[405] 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.[406] 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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403 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.

404 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.

405 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.

406 *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."[407] Under the point source testing program, field personnel determined the amount of air pollution released at compressor stations and other midstream facilities.[408] The sites visited included 8 compressor stations, 1 processing facility, and 1 saltwater treatment facility.[409]

"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."[410] 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.

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[407] 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.
[408] *Ibid*.
[409] *Ibid*., pp. 3-3 – 3-4.
[410] *Ibid*., p. 3-23.

## 7.3 Emission from Mid-stream Sources

Ozone precursor emissions from midstream sources were 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. 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 (TCEQ Permit Database) | | 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 | 44 | 4.40 |
| Produced Water Storage Tanks | 204 | 0.62 | 799 | 1.24 | | |
| 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 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 were 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 were 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 were 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 were used instead of the Barnett Shale special inventory because there is not enough data for condensate and crude oil loading from the Barnett survey.

Using ERG Fort Worth Gas Study methodology, emissions from the Eagle Ford was calculated to be 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 were not used to calculate emissions.

A list of which proposed emission factors that was 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 was calculated. CO emissions were 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.

Table 7-6: Comparison between Eagle Ford Mid-Stream Emissions using TCEQ Permit Database, Barnett Special Inventory, and ERG's Survey Methodologies, 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 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 equipment at midstream facilities

$$E_{Midstream.AB} = NUM_{AB.TCEQ} \times MSFEF_A \,/\, 365 \text{ days/year}$$

Where,

$E_{Midstream.AB}$ = Ozone season day $NO_X$ or VOC emissions from midstream facilities for Equipment type A in county B

$NUM_{AB.TCEQ}$ = Number of Equipment type A in county B from midstream sources in Table 7-2 (from TCEQ permit database)

$MSFEF_A$ = $NO_X$ or VOC emission factor for equipment type A at midstream facilities in Table 7-6 (from Barnett Shale special inventory and TCEQ permit database)

Sample Equation: Heater/Boilers $NO_X$ emissions from Mid Stream Sources in Karnes County, 2011

$E_{Midstream.AB}$ = 5 Heater/Boiler x 0.37 Tons of $NO_X$/Unit/Year / 365 days/year
= 0.005 Tons of $NO_X$ from Heater/Boilers at Mid Stream Sources in Karnes County, 2011

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 mid-stream emission factors from the TCEQ's 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.

Emissions from Eagle Ford mid-stream sources were 12.4 tons of VOC and 8.8 tons of $NO_X$ in 2011. For 2012, emissions from Mid-Stream sources were 39.3 tons of VOC and 21.o tons of $NO_X$ per day. There are a large number of crude storage tanks, produced water storage tanks, and condensate tanks at mid-stream sources 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, Barnett Special Inventory, and ERG's Survey for Mid-Stream Sources Methodologies to Calculate Emissions from Eagle Ford Mid-stream sources (tons/day)

| Year | Number of Mid-Stream Facilities | 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

### 7.3.1 Stack Parameters

Stack parameters used in the June 2006 photochemical modeling episode for mid-stream sources were based on similar facility in TCEQ point source emission inventory.[411] Eagle Ford mid-stream sources were split into crude petroleum & natural gas, natural gas liquids, natural gas transmission, and petroleum bulk stations & terminals. For each type, average stack height, stack diameter, temperature, and velocity were calculated from similar size facilities in TCEQ point source database (Table 7-8)

Table 7-8: Stack Parameters and temperature by SIC Code from TCEQ June 2006 Point Source Database

| Type | SIC Code | Stack height (m) | Stack diameter (m) | Temperature (K) | Velocity (m/s) |
|---|---|---|---|---|---|
| Crude Petroleum & Natural Gas | 1311 | 8 | 0.3 | 679 | 21 |
| Natural Gas Liquids | 1321 | 10 | 0.6 | 645 | 20 |
| Natural Gas Transmission | 4922 | 9 | 0.7 | 650 | 19 |
| Petroleum Bulk Stations & Terminals | 5171 | 12 | 0.7 | 602 | 7 |
| Weighted Average | | 9 | 0.5 | 657 | 20 |

[411] TCEQ, Nov. 28, 2012. "afs.osd_2006_STARS_extract_for_CB06_cat_so2_lcpRPO.v2.gz". Available online: ftp://amdaftp.tceq.texas.gov/pub/Rider8/ei/basecase/point/AFS/. Accessed 03/08/2013.

## 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."[412]

"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."[413] "Eagle Ford is considered one of world's largest oil- and gas-investments in terms of costs. During 2013 it is estimated that the volume of investment will be on the order of $30 billion. They calculate that all the investments in EFS have in 2012 generated over 116,000 jobs just in the provinces covering EFS geographically and many more jobs in peripheral areas. In purely economic terms the investments have meant twice as much for the region."[414]

VOC, $NO_X$ and CO emissions were 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 did not project emissions past this year. Projections of activity in the Eagle Ford used a methodology similar to ENVIRON's Haynesville Shale emission inventory which was based on three scenarios: low development, medium development, and aggressive development.[415] 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

[412] Bentek Energy LLC, April 18, 2011. "Eagle Ford Shale – Deep in the Heart of Texas". p. 24. Evergreen, CO.
[413] 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.
[414] PeakOil.com, August 21, 2013. "Eagle Ford Shale – a snapshot of today's activity". Available online: http://peakoil.com/production/eagle-ford-shale-a-snapshot-of-todays-activity. Accessed 10/30/2013.
[415] 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.[416] "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."[417] 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."[418] In addition, the "Eagle Ford shale in the dry gas portion of the play has more technically recoverable resources than the Barnett shale."[419]

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.[420] Price for Eagle Ford crude oil and condensate has increase dramatically from 47 dollars per barrel to over 102 dollars per barrel from 2009 to September 2013[421] (Figure 8-1), while U.S. wellhead price for natural gas was $3.3 per Mscf in December 2012[422].

"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."[423] "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."[424]

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[416] 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.

[417] 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.

[418] 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.

[419] 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

[420] Texas Alliance of Energy Producers, September, 2013. "Market Information: Oil & Natural Gas". Available online: http://www.texasalliance.org/marketinformation.php. Accessed 04/30/2012.

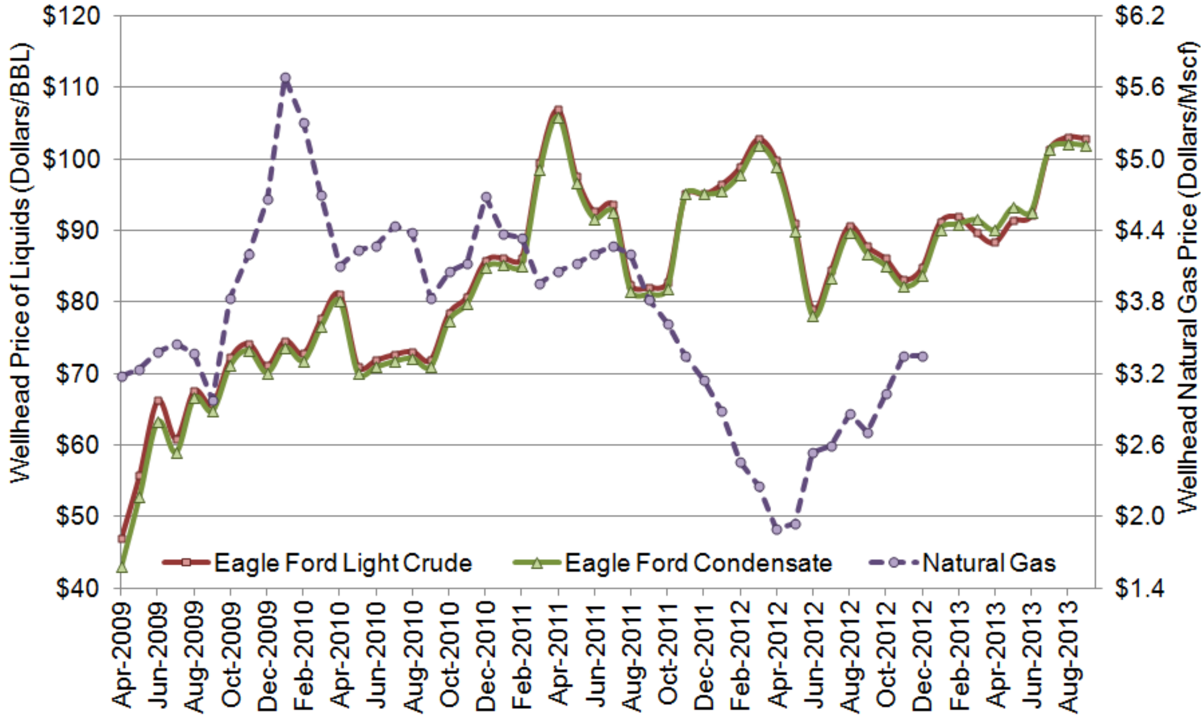
[421] Plains Marketing, L.P. "Crude Oil Price Bulletin - Recap". Houston, Texas. Available online: http://www.paalp.com/_filelib/FileCabinet/Crude%20Oil%20Price%20Bulletins/Monthly/2013/september_Recap.pdf. Accessed: 10/14/2013.

[422] U.S. Energy Information Administration, September 30, 2013. "U.S. Natural Gas Wellhead Price". Available online: http://www.eia.gov/dnav/ng/hist/n9190us3m.htm. Accessed 10/14/2013.

[423] 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.

[424] 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 8-1: Monthly Price for Eagle Ford Crude Oil and Condensate from Plains Marketing and Natural Gas from EIA, 2009-2013




*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 after February 2013

## 8.1 Historical Production

Number of wells drilled and production has increase dramatically in the last 5 years from almost nothing in 2008 to significant production 2012. As shown in Table 8-1, the number of oil wells drilled had grown from 89 in 2008 to 2,789 in 2012, while the number of gas wells drilled has increased from 109 in 2008 to 712 in 2012.[425] Production has increased from only 0.1 MMbbl of oil produced in 2008 to 145.59 MMbbl of oil produced in 2012. There was also a significant increase in natural gas and condensate production: 1 BCF in 2008 to 909 BCF in 2012 and 0.1 MMbbl to 55.97 MMbbl.[426]

Table 8-1: Number of Wells Drilled and Production in the Eagle Ford, 2008-2012

| Year | Number of Wells Drilled | | Production | | | |
|---|---|---|---|---|---|---|
| | Liquid | Gas | Oil (MMbbl) | Condensate (MMbbl) | Gas (BCF) | BOE (MMbbl) |
| 2008 | 92 | 113 | 0.13 | 0.08 | 0.73 | 0 |
| 2009 | 63 | 150 | 0.31 | 0.84 | 18.98 | 4 |
| 2010 | 338 | 559 | 5.53 | 6.86 | 117.53 | 30 |
| 2011 | 1,259 | 1,081 | 47.18 | 29.17 | 448.59 | 138 |
| 2012 | 2,789 | 712 | 145.59 | 55.97 | 909.22 | 315 |

[425] Schlumberger Limited. “STATS Rig Count History”. Available online: http://stats.smith.com/new/history/statshistory.htm. Accessed: 04/21/2012.
[426] 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.

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 for each month, is the Commission's estimate of the expected, final statewide production for a given month."[427] "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."[428] The Railroad Commission of Texas September 2013 adjustment factors of 1.2271 for oil wells and 1.2457 for gas well applies only to preliminary statewide totals for that month and is not used to adjust production totals in the Eagle Ford.[429]

There was an increase in the number of drill rigs operating in Texas's Western Gulf Basin since early 2010.[430] The number of drill rigs operating in the Eagle Ford, provided in Figure 8-2, increased from 56 in January 2010 to 197 rigs in September 2013. From January 2011 to September 2013, annual increase in the number of rigs was 80 percent. The growth of drill rigs averaged 0.94 rigs weekly, but there was a slight decline in the number of rigs in the last 15 months. Fewer rigs are needed in the Eagle Ford because drill rigs are becoming more powerful and drilling times per well are decreasing

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 8-3). Since October 2011, the number of land drill rigs has leveled off at just fewer than 1,800 rigs.[431]

Drill rigs operations are focusing on the Eagle Ford because it is "rated as the lowest cost play among North American shale plays in the liquids rich regions". [432] 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 8-4 shows that Eagle Ford had the

[427] The Railroad Commission of Texas Sept 18, 2013. "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 10/15/2013.
[428] *Ibid*.
[429] *Ibid*.
[430] Baker Hughes Investor Relations. "Interactive Rig Counts". Available online: http://gis.bakerhughesdirect.com/Reports/RigCountsReport.aspx. Accessed: 10/14/2013.
[431] Baker Hughes Investor Relations. "Interactive Rig Counts". Available online: http://gis.bakerhughesdirect.com/Reports/RigCountsReport.aspx. Accessed: 10/14/2013.
[432] 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.

second highest well return rate of the major unconventional shale plays at 46 percent.[433] 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.

Figure 8-2: Horizontal Trajectory Rig Counts by Week in the Eagle Ford, 2010-2012

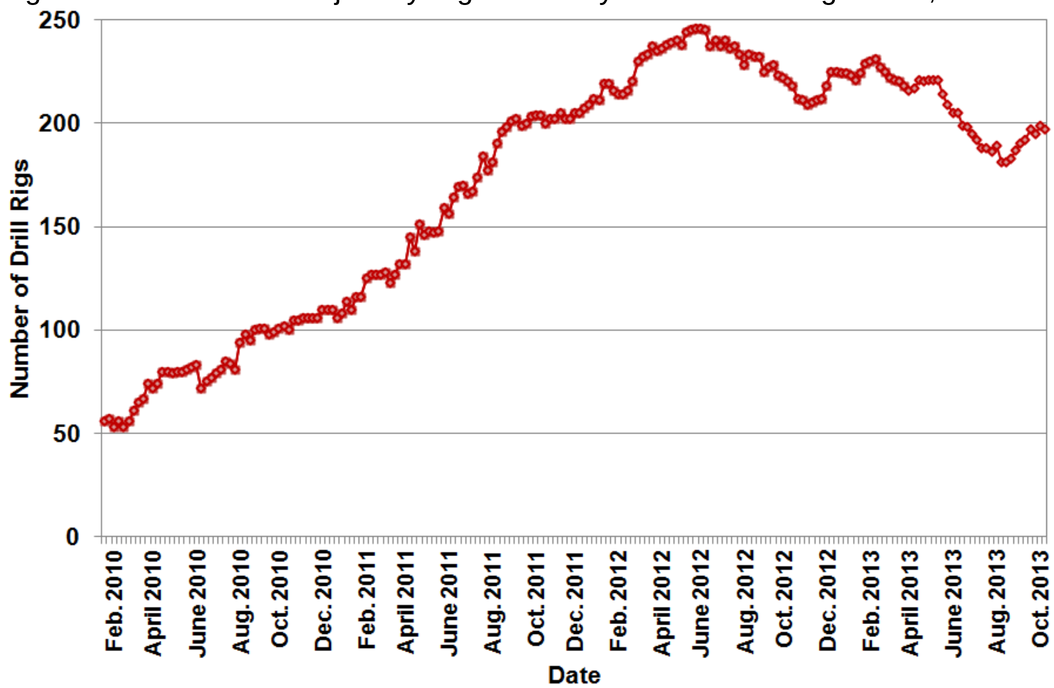
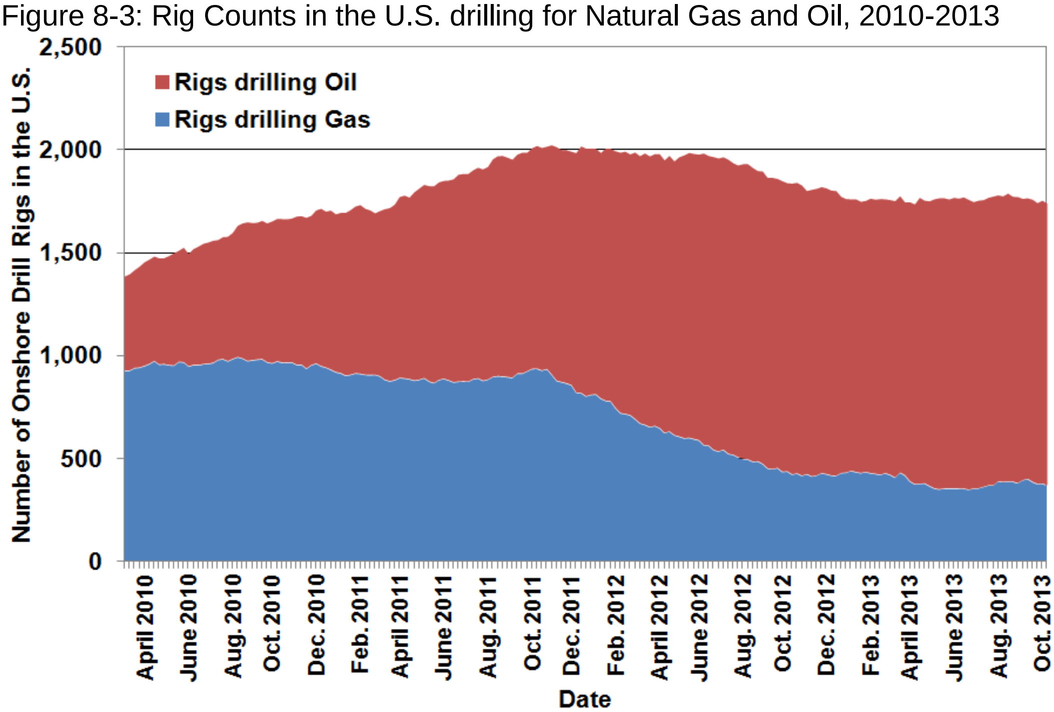
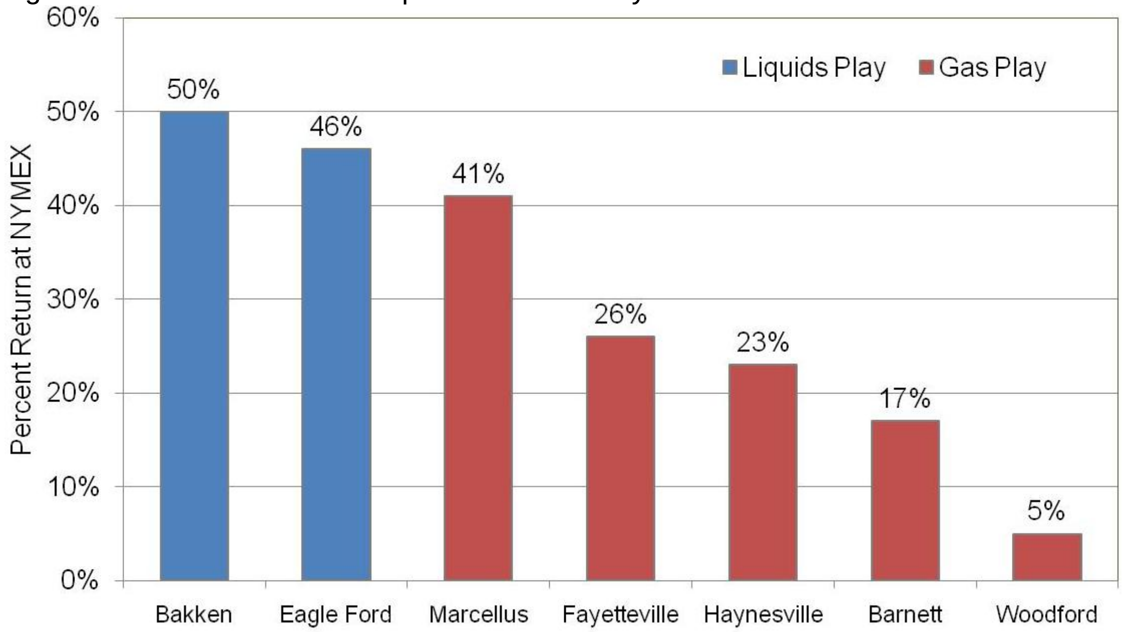



Figure 8-3: Rig Counts in the U.S. drilling for Natural Gas and Oil, 2010-2013




433 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 8-4: 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".[434] "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."[435]

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"[436] ERG projected that $NO_X$ emissions will decrease from 55,238 tons/year in 2008 to 31,282 tons/year in 2018.

[434] 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.

[435] *Ibid*.

[436] *Ibid*. p. 6-6.

### 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[437]

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."[438]

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."[439] 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."[440] 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.[441]

### 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."[442] As shown in the graph below (Figure 8-5), UTSA forecasts liquid production in the Eagle Ford will peak around 485 MMbbl in 2020 and then decline.[443]

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[437] 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.

[438] 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.

[439] *Ibid*. p. 19.

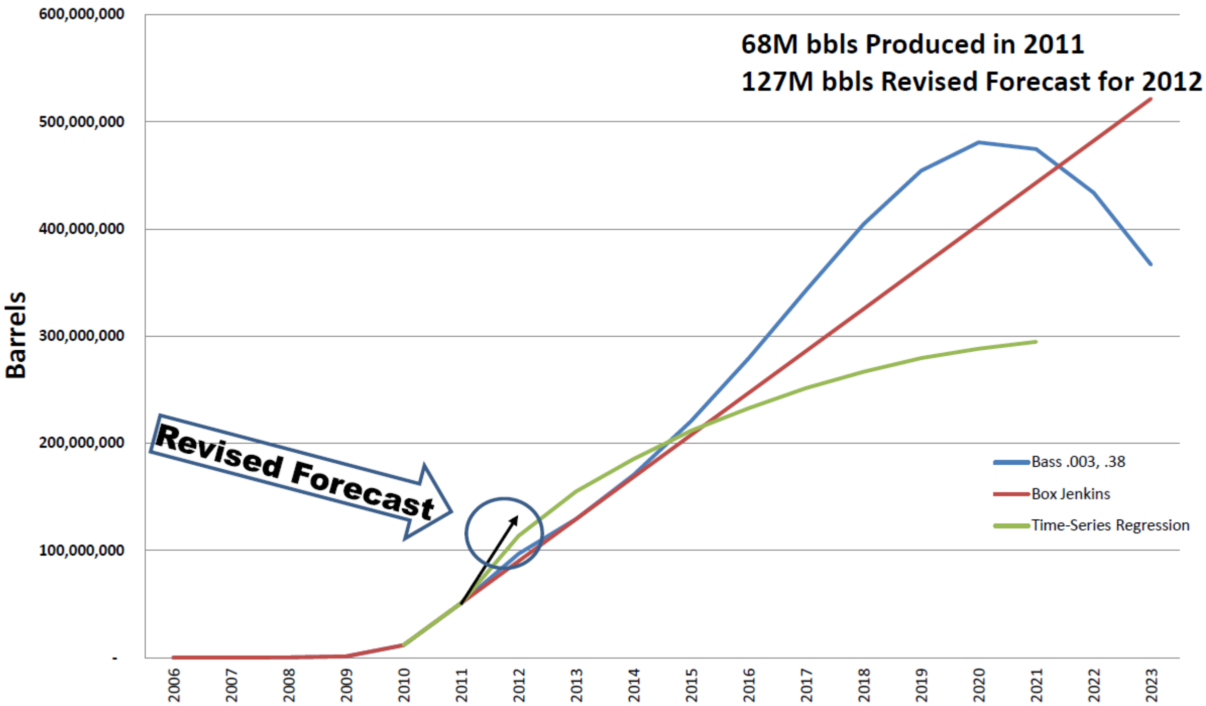
[440] *Ibid*.

[441] *Ibid*. p. 60.

[442] 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.

[443] Thomas Tunstall, Ph.D., Director, Center for Community and Business Research, January 14th , 2013. "Ongoing Impact of the Eagle Ford Shale on South Texas." UTSA. San Antonio, Texas. Slide 60.

Figure 8-5: UTSA's Eagle Ford Shale Oil/Condensate Annual Production Forecast (bbl) Scenarios




### 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."[444] David Porter, Texas Railroad Commissioner, estimates that nearly three decades are needed just to "fully develop" the Eagle Ford.[445]

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.[446] 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.[447] 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

[444] 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.
[445] 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.
[446] 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.
[447] 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.

company estimates “that there will be over 25 years of rig time on the Gates Ranch alone”.[448]

## 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 197 rigs in October 2013.[449] While the number of new drill rigs has increased an average of 49 rigs a year since January 2010, the drill rig count reached a peak in June 2012 that has yet to be matched. Three different scenarios were used to estimate future rig counts:

- Low Development: Decrease of 12 rigs per year
- Moderate Development: No new rigs per year
- Aggressive Development: Increase of 24 rigs per year (one half of the annual increase)

The following equation was 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

$$RPROJ_B = (RCUR_A) + [RNEW \times (YEAR_B - YEAR_A)]$$

Where,

$RPROJ_B$ = Number of drill rigs for Year B

$RCUR_A$ = Number of current drill rigs in Year A, 197 for September 2013 (from Schlumberger Limited)

RNEW = Increase in the number of drill rigs each year under each scenario (-12 rigs for Low, 0 rigs for Moderate, 24 rigs for Aggressive Development with a cap of 250 rigs total)

$YEAR_B$ = Projection year B, June 2015 or June 2018.

$YEAR_A$ = Base year A, June 8, 2012

Sample Equation: Number of drill rigs operating in the Eagle Ford under the low scenario for 2015

$RPROJ_B$ = (197 drill rigs operating in Sept 2012) + [-12 annual reduction under the low scenario x (July 2015 – Sept 2012)]

= 164 drill rigs operating in the Eagle Ford under the low scenario in 2015

The aggressive projection scenario is capped at 250 rigs to prevent the use of unrealistically high numbers of drill rigs in the calculations for the Eagle Ford. The maximum of 250 rigs operating in the Eagle Ford represents 14 percent of the 1,736 on-shore drill rigs operating in the United States in 2011. Under the aggressive growth scenario, the maximum number of rigs reaches 250 before 2016 (Figure 8-6). Table 8-2 lists the predicted number of drill rigs in the Eagle Ford 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 2018.

[448] Available online: http://eaglefordshaleblog.com/2011/08/25/future-of-eagle-ford-shale-well-spacing/. Accessed 06/13/2012.
[449] Baker Hughes. “Interactive US Rig Counts”. Available online: http://gis.bakerhughesdirect.com/RigCounts/default2.aspx. Accessed 10/14/2013.

Figure 8-6: Projected Horizontal Trajectory Rig Counts in the Eagle Ford, 2010-2018

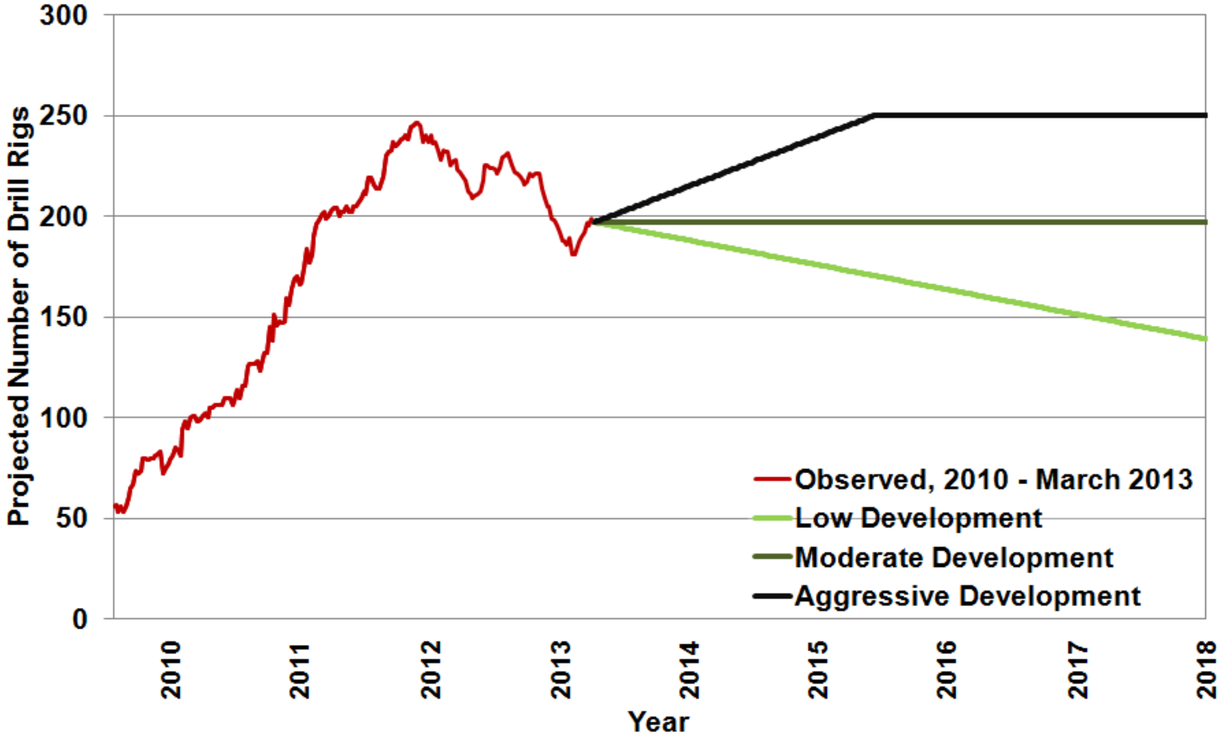



Table 8-2: Projected Horizontal Trajectory Rig Counts in the Eagle Ford, 2010-2018

| Year | Low Development | Moderate Development | Aggressive Development |
|---|---|---|---|
| 2010 | 86 | 86 | 86 |
| 2011 | 168 | 168 | 168 |
| 2012 | 228 | 228 | 228 |
| 2013 | 192 | 192 | 192 |
| 2014 | 188 | 197 | 215 |
| 2015 | 176 | 197 | 239 |
| 2016 | 164 | 197 | 250 |
| 2017 | 151 | 197 | 250 |
| 2018 | 139 | 197 | 250 |

Projected equipment types and emission factors for Eagle Ford operations were 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.”[450] The future trend for shale wells “is towards the use of electrical rigs, and the average age of the engines used on the electrical rigs for these well types are only two years.”[451]

[450] 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: http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820783985FY0901-20090715-ergi-Drilling_Rig_EI.pdf. Accessed: 04/09/2012.

[451] 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:

Future projections of emission factors for drill rig engines were based on the Tier emission factors provided in Table 8-3 for large diesel generators. Emission factors for Tier 2 generators were based on emission factors for engines ≥ 750 from TCEQ's Texas Emissions Reduction Plan (TERP).[452] $NO_X$ emission factors for Tier 4 Interim and Tier 4 engines >900 bkW were based on EPA's emission limit requirements,[453] while VOC and CO emission factors for these engines were based on certified engine data from Caterpillar.[454] For large generators, Tier 4 Interim engines and Tier 4 engines 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 were used for Eagle Ford emission inventory calculations because EPA's stationary diesel generators emission limits and timing for Tier 3 engines do not apply to generators >560 bkW.[455] Almost all generators used on drill rigs are >560 bkW and new generators are increasing in power output. All engines in use in 2011 were estimated to be Tier 2 because the rapid construction of 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 10 percent turnover rate for generators per year and all mechanical drill rigs will be removed from service by 2015. To calculate emissions from generators, the factor used to convert from kw-hr to hp-hr is 1.34.[456]

Mechanical drill rigs only made 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. The emission factors for mechanical drill rigs are from ERG's drill rig emission inventory for Texas.[457] $NO_X$ emission reductions of 0.062 from ERG's report for TxLED were used in the calculations of drill rig emissions. The projections do not include any re-fracturing of existing

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http://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820783985FY0901-20090715-ergi-Drilling_Rig_EI.pdf. Accessed: 04/09/2012.

[452] 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.

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

[454] Caterpillar, 2011. "TIER 4 Interim EPA Emissions Requirements for Diesel Generator Sets".

[455] Caterpillar, 2011. "Tier 4 Interim EPA Emission Requirements for Diesel Generator Sets".

[456] Diesel Service & Supply, 2011. "Electrical Power Calculators". Available online: http://www.dieselserviceandsupply.com/power_calculator.aspx. Accessed: 05/04/2012.

[457] Eastern Research Group, Inc. August 15, 2011. "Development of Texas Statewide Drilling Rigs Emission Inventories for the Years 1990, 1993, 1996, and 1999 through 2040". TCEQ Contract No. 582-11-99776. 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 10/15/13.

wells. There is plenty of undeveloped acreage in the Eagle Ford that oil companies can develop before using existing horizontal wells.

Table 8-4: Drill Rigs Emission Parameters, 2011, 2012, 2015, and 2018.

| Parameter | | 2011 | 2012 | 2015 | 2018 |
|---|---|---|---|---|---|
| Percent of Electric Drill Rigs | | 86.3% | 86.3% | 100% | 100% |
| Percent of Mechanical Drill Rigs | | 13.7% | 13.7% | - | - |
| Percent of Engines Tier 2 | | 100% | 100% | 70% | 40% |
| Percent of Engines Tier 4 Interim | | 0% | 0% | 30% | 30% |
| Percent of Engines Tier 4 | | - | - | - | 30% |
| EF for Generators | $NO_X$ EF (g/kw-hr) | 4.56 | 4.56 | 3.39 | 2.23 |
| | VOC EF (g/kw-hr) | 0.24 | 0.24 | 0.22 | 0.20 |
| | CO EF (g/kw-hr) | 2.67 | 2.67 | 2.02 | 1.37 |
| EF for Mechanical Rigs | $NO_X$ EF (tons/ 1,000 ft.) | 0.362 | 0.454 | - | - |
| | VOC EF (tons/ 1,000 ft.) | 0.016 | 0.022 | - | - |
| | CO EF (tons/ 1,000 ft.) | 0.067 | 0.064 | - | - |

### 8.3.2 Pump Engines

Since well hydraulic pump engines used for fracturing are becoming more efficient and total horsepower is increasing, well production has increased. Projections by Raymond James & Associates show that the average days of 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.[458]

The same emission factors used for generators operating on electric drill rigs were 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.[459] Total pump engine horsepower, 13,500 hp, and activity rate, 54 hours, remained the same as the 2011 base case emission inventory. Projection estimates of pump engine activity only takes into account hydraulic fracturing on new wells and does not include re-fracturing existing horizontal wells.

Table 8-5: Pump Engines Emission Parameters, 2011, 2012, 2015, and 2018.

| Parameter | 2011 | 2012 | 2015 | 2018 |
|---|---|---|---|---|
| Percent of Engines Tier 2 | 100% | 100% | 40% | 0% |
| Percent of Engines Tier 4 Interim | 0% | 0% | 60% | 40% |
| Percent of Engines Tier 4 | 0% | 0% | 0% | 60% |
| $NO_X$ EF (g/kw-hr) | 4.56 | 4.56 | 2.23 | 0.67 |
| VOC EF (g/kw-hr) | 0.24 | 0.24 | 0.20 | 0.17 |
| CO EF (g/kw-hr) | 2.67 | 2.67 | 1.37 | 0.50 |

[458] 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.

[459] 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.

### 8.3.3 Non-Road Equipment

The estimated activity rates, horsepower, load factors, and equipment populations of other non-road equipment used for pad construction, drilling, and hydraulic fracturing were kept the same for each projection year. Emission factors for other non-road equipment were projected using the TexN model. VOC, $NO_X$ and CO emission factors are projected to decrease from 2011 to 2018 (Table 8-6). All control strategies in the TexN model for the Eagle Ford region, including TxLED, were included in the model runs.

Table 8-6: TexN Model Emission Factors for Non-Road Equipment, 2011, 2015, and 2018.

| Phase | Equipment Type | SCC | Pollutant | 2011 | 2012 | 2015 | 2018 |
|---|---|---|---|---|---|---|---|
| Exploration | Diesel Off-highway trucks | 2270002051 | VOC | 0.18 | 0.18 | 0.16 | 0.14 |
| | | | $NO_X$ | 2.51 | 2.23 | 1.39 | 0.73 |
| | | | CO | 1.29 | 1.12 | 0.66 | 0.29 |
| Pad Construction | Diesel Rollers | 2270002015 | VOC | 0.44 | 0.40 | 0.33 | 0.28 |
| | | | $NO_X$ | 4.12 | 3.83 | 2.99 | 2.27 |
| | | | CO | 2.49 | 2.25 | 1.67 | 1.26 |
| | Diesel Scrapers | 2270002018 | VOC | 0.20 | 0.19 | 0.17 | 0.16 |
| | | | $NO_X$ | 3.16 | 2.90 | 2.06 | 1.36 |
| | | | CO | 2.11 | 1.93 | 1.43 | 1.00 |
| | Diesel Excavators | 2270002036 | VOC | 0.29 | 0.28 | 0.23 | 0.20 |
| | | | $NO_X$ | 3.82 | 3.49 | 2.44 | 1.70 |
| | | | CO | 1.58 | 1.45 | 1.02 | 0.63 |
| | Diesel Graders | 2270002048 | VOC | 0.40 | 0.37 | 0.30 | 0.25 |
| | | | $NO_X$ | 3.90 | 3.64 | 2.85 | 2.17 |
| | | | CO | 1.77 | 1.59 | 1.15 | 0.89 |
| | Diesel Loaders | 2270002060 | VOC | 0.27 | 0.24 | 0.20 | 0.18 |
| | | | $NO_X$ | 3.13 | 2.77 | 1.65 | 0.86 |
| | | | CO | 1.49 | 1.26 | 0.67 | 0.36 |
| | Diesel Tractors/Loaders/ Backhoes | 2270002066 | VOC | 1.25 | 1.15 | 0.87 | 0.66 |
| | | | $NO_X$ | 5.02 | 4.82 | 4.11 | 3.57 |
| | | | CO | 6.13 | 5.79 | 4.57 | 3.60 |
| | Diesel Crawler Tractor/Dozers | 2270002069 | VOC | 0.20 | 0.18 | 0.15 | 0.14 |
| | | | $NO_X$ | 2.08 | 1.81 | 0.85 | 0.31 |
| | | | CO | 1.02 | 0.79 | 0.22 | 0.12 |
| Drilling | Diesel Cranes | 2270002045 | VOC | 0.28 | 0.26 | 0.17 | 0.18 |
| | | | $NO_X$ | 3.66 | 3.34 | 1.96 | 1.61 |
| | | | CO | 1.07 | 0.96 | 0.57 | 0.49 |
| | Diesel Pumps | 2270006010 | VOC | 0.41 | 0.38 | 0.32 | 0.26 |
| | | | $NO_X$ | 4.41 | 4.19 | 3.48 | 2.80 |
| | | | CO | 1.80 | 1.65 | 1.30 | 1.01 |
| | Diesel Excavators | 2270002036 | VOC | 0.29 | 0.28 | 0.23 | 0.20 |
| | | | $NO_X$ | 3.82 | 3.49 | 2.44 | 1.70 |
| | | | CO | 1.58 | 1.45 | 1.02 | 0.63 |

| Phase | Equipment Type | SCC | Pollutant | 2011 | 2012 | 2015 | 2018 |
|---|---|---|---|---|---|---|---|
| Hydraulic Fracturing | Diesel Cranes | 2270002045 | VOC | 0.27 | 0.24 | 0.21 | 0.18 |
| | | | $NO_X$ | 3.78 | 3.49 | 2.66 | 1.91 |
| | | | CO | 1.23 | 1.10 | 0.82 | 0.60 |
| | Diesel Cranes | 2270002045 | VOC | 0.28 | 0.26 | 0.17 | 0.18 |
| | | | $NO_X$ | 3.66 | 3.34 | 1.96 | 1.61 |
| | | | CO | 1.07 | 0.96 | 0.57 | 0.49 |
| | Diesel Tractors/Loaders/ Backhoes | 2270002066 | VOC | 1.53 | 1.44 | 1.18 | 0.96 |
| | | | $NO_X$ | 5.41 | 5.13 | 4.32 | 3.56 |
| | | | CO | 7.22 | 6.85 | 5.81 | 4.86 |
| | Diesel Crawler Tractor/Dozers | 2270002069 | VOC | 0.27 | 0.22 | 0.16 | 0.14 |
| | | | $NO_X$ | 2.95 | 2.50 | 1.17 | 0.35 |
| | | | CO | 3.94 | 3.23 | 1.21 | 0.45 |
| | Diesel Forklift | 2270003020 | VOC | 0.23 | 0.21 | 0.16 | 0.14 |
| | | | $NO_X$ | 2.39 | 2.08 | 1.06 | 0.37 |
| | | | CO | 1.45 | 1.20 | 0.50 | 0.18 |
| | Diesel Generator Sets (87 hp) | 2270006005 | VOC | 0.68 | 0.64 | 0.54 | 0.44 |
| | | | $NO_X$ | 4.65 | 4.44 | 3.76 | 3.10 |
| | | | CO | 3.14 | 2.95 | 2.47 | 2.05 |
| | Diesel Generator Sets (50 hp) | 2270006005 | VOC | 1.04 | 0.98 | 0.80 | 0.64 |
| | | | $NO_X$ | 4.78 | 4.72 | 4.32 | 3.96 |
| | | | CO | 3.32 | 3.20 | 2.62 | 2.10 |
| | Water Pumps | 2270006010 | VOC | 0.41 | 0.38 | 0.32 | 0.26 |
| | | | $NO_X$ | 4.41 | 4.19 | 3.48 | 2.80 |
| | | | CO | 1.80 | 1.65 | 1.30 | 1.01 |
| | Blender Truck | 2270010010 | VOC | 0.22 | 0.21 | 0.18 | 0.16 |
| | | | $NO_X$ | 3.52 | 3.25 | 2.36 | 1.61 |
| | | | CO | 1.47 | 1.35 | 1.03 | 0.75 |
| | Sand Kings | 2270010010 | VOC | 0.38 | 0.34 | 0.24 | 0.18 |
| | | | $NO_X$ | 3.63 | 3.29 | 2.19 | 1.25 |
| | | | CO | 2.56 | 2.32 | 1.63 | 0.98 |
| | Blow Out Control Systems | 2270010010 | VOC | 0.53 | 0.52 | 0.51 | 0.51 |
| | | | $NO_X$ | 3.73 | 3.71 | 3.69 | 3.69 |
| | | | CO | 3.13 | 3.15 | 3.15 | 3.15 |
| | High Pressure Water Cannon | 2270010010 | VOC | 0.38 | 0.34 | 0.24 | 0.18 |
| | | | $NO_X$ | 3.63 | 3.29 | 2.19 | 1.25 |
| | | | CO | 2.56 | 2.32 | 1.63 | 0.98 |

### 8.3.4 Completion Venting and Flares

According to EPA's 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."[460] 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.

### 8.3.5 On-Road Emissions

To calculate on-road emissions, many parameters, such as number of on-road trips, vehicle speeds, vehicle types, distances travelled, and idling hours per trip during pad construction, and drilling, and hydraulic fracturing, were kept the same for each projection year. The number of vehicles, however, was determined by multiplying future projections of wells drilled and emission factors were 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.

## 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 were 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. In 2010, 895 wells were drilled by an average of 86 drill rigs which is equal to 35.0 days from spud to spud. Drilling time decreased by 2012, with 3,501 wells drilled by 228 drill rigs for an average of 23.8 days from spud to spud (Table 8-7).

As drill rigs become faster and more efficient, the number of wells the rig can drill each year will increase. For the high development scenario, calculations were based on one half the decrease in drilling time between 2011 and 2012 (4.7% per year), while calculations for the moderate scenario used a one-quarter decrease in drilling time (2.4%). The low development calculations do not account for any increase in drilling efficiencies (Table 8-8). Equation 8-2 was used to forecast the number of production wells for each year.

[460] 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 8-7: Average number of Drill Rigs and Spud to Spud times in the Eagle Ford, 2010-2012.

| Year | Average Number of Drill Rigs[461] | Number of Wells Drilled[462] | Number of days Spud to Spud |
|---|---|---|---|
| 2010 | 86 | 895 | 35.0 |
| 2011 | 168 | 2,340 | 26.2 |
| 2012 | 228 | 3,501 | 23.8 |

Table 8-8: Percent Increase in Drill Rig Efficiencies under each Projection Scenario, 2013-2018.

| Year | Low Development | Moderate Development | Aggressive Development |
|---|---|---|---|
| 2013 | 0.0% | 2.4% | 4.7% |
| 2014 | 0.0% | 4.7% | 9.5% |
| 2015 | 0.0% | 7.1% | 14.2% |
| 2016 | 0.0% | 9.5% | 18.9% |
| 2017 | 0.0% | 11.8% | 23.7% |
| 2018 | 0.0% | 14.2% | 28.4% |

Equation 8-2, Projection of production wells per year

$WPROJ_{BC} = RPROJ_{BC} \times [(WELL_{2012} / RIGS_{2012}) \times (1 + INCREASE_{C})]$

Where,

$WPROJ_{B}$ = Projected number of Wells in Year B for projection scenario C (Low, Moderate, or Aggressive)

$RPROJ_{BC}$ = Number of Drill Rigs in Year B for projection scenario C (from Equation 8-1)

$WELL_{2012}$ = Average Number of Wells Drilled in 2012, 3,501 Wells (from Baker Hughes)

$RIGS_{2012}$ = Average Number of Drill rigs in 2012, 228 Drill Rigs (from Schlumberger Limited)

$ICREASE_{C}$= Percent increase in drill rig efficiency under projection scenario C (from **Error! Reference source not found.**)

Sample Equation: Number of wells drilled in 2018 under the high projection scenario

$WPROJ_{BC}$ = 250 x [(3,501 / 228) x (1 + 0.28382)]

= 4,934 wells drilled in 2018 under the high projection scenario

Based on this formula, the cumulative number of production wells drilled in the Eagle Ford increases rapidly between 2012 and 2018 (Figure 8-7). The number of drill rigs has decreased rapidly in natural gas shale formations. For example, Barnett has experienced a 66% reduction, Haynesville an 80% reduction, and Fayetteville an 84% reduction from their peak numbers of drill rigs compared to October 2013 figures. Natural gas wellhead prices decreased from $5.69/Mscf in January 2010 to $3.35/Mscf in December 2012.[463] However, the number of natural gas wells drilled in the Eagle Ford should not decrease as

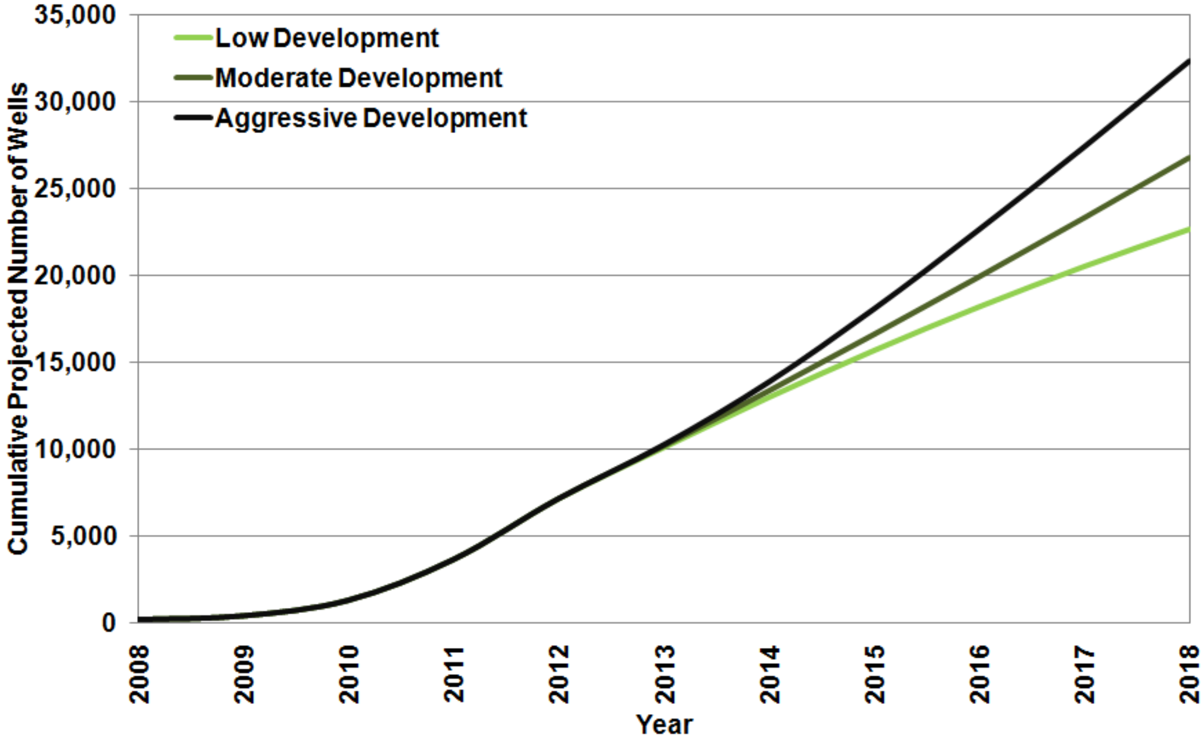
[461] Baker Hughes Investor Relations. "Interactive Rig Counts". Available online: http://gis.bakerhughesdirect.com/Reports/RigCountsReport.aspx. Accessed: 10/14/2013.

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

[463] 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.

rapidly as other shale plays because natural gas wells in the Eagle Ford can produce significant amounts of valuable condensate and the cost of development is lower in the Eagle Ford. To provide a breakdown between natural gas and liquid wells, the number of natural gas wells drilled under the low scenario was decreased by 10 percent per year and under the high scenario, the number of natural gas wells was increased by 10 percent per year.

Figure 8-7: 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 8-9, while the cumulative number of production wells drilled is listed in Table 8-10. The number of new production wells drilled per year is projected to be 2,138 under the low scenario, 3,458 under the moderate scenario, and 4,934 under the aggressive scenario in 2018. It is expected that only 378 new natural gas wells will be drilled under the low scenario, while there will be 712 and 1,261 new natural gas wells under the moderate and aggressive scenarios, respectively. The cumulative growth of wells in the Eagle ford is projected to be between 22,675 and 32,310 wells drilled by 2018.

"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."[464]

[464] 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 8-9: 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 | 2,789 | 712 | 2,789 | 712 | 2,789 | 712 |
| 2013 | 2,311 | 641 | 2,310 | 712 | 2,308 | 783 |
| 2014 | 2,315 | 577 | 2,460 | 712 | 2,753 | 862 |
| 2015 | 2,185 | 519 | 2,531 | 712 | 3,252 | 948 |
| 2016 | 2,050 | 467 | 2,603 | 712 | 3,528 | 1,042 |
| 2017 | 1,905 | 420 | 2,675 | 712 | 3,606 | 1,147 |
| 2018 | 1,760 | 378 | 2,746 | 712 | 3,673 | 1,261 |

Table 8-10: 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 | 4,537 | 2,610 | 4,537 | 2,610 | 4,537 | 2,610 |
| 2013 | 6,848 | 3,251 | 6,847 | 3,322 | 6,845 | 3,393 |
| 2014 | 9,163 | 3,828 | 9,306 | 4,034 | 9,599 | 4,255 |
| 2015 | 11,348 | 4,347 | 11,838 | 4,746 | 12,850 | 5,202 |
| 2016 | 13,397 | 4,814 | 14,441 | 5,458 | 16,378 | 6,245 |
| 2017 | 15,303 | 5,234 | 17,116 | 6,170 | 19,984 | 7,392 |
| 2018 | 17,062 | 5,613 | 19,862 | 6,882 | 23,657 | 8,653 |

#### 8.4.2 Estimated Ultimate Recovery

Estimated ultimate recovery (EUR) is the estimated amount of product recovered over the lifetime of a producing well. According to the EIA, Eagle Ford's 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.[465] Texas Oil & Gas Association estimates that the eastern oil zone has an EUR of 750,000 BOE, the western oil zone has an EUR of 250,000 BOE, and the wet gas zone has an EUR of 5-6,000,000 MCFe.[466] Oil and Gas analyst Michael Filloon determined that in the central part of the Eagle Ford, EURs are 965 Mboe and 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

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[465] 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.

[466] "Drill Baby Drill!: Eagle Ford Shale Update". presented at Texas Oil & Gas Association's, 2011 Annual Property Tax Conference, Feb. 22$^{nd}$ – 23$^{rd}$, 2011. Slide 8 of 33. Available online: http://www.property-tax.com/articles/TXOGADrillBabyDrill.pdf. Accessed: 04/13/2012.

645 Mboe. The black oil window has well costs of $7.9 million and EURs of 445 Mboe are expected in the most western part of the Eagle Ford shale play.[467]

From reviewing current production data from the Railroad Commission of Texas, industry sources may be over-estimating the EUR for each well drilled. The railroad commission reported 2,148 producing gas wells and 4,440 oil wells on schedule in the Eagle Ford between January 2004 and July 2013. During that time span, the wells produced 324,413,538 bbl of oil, 490,935,401 MCF of casing head natural gas, 1,593,484,778 MCF of natural gas, and 126,728,752 bbl of condensate.[468] Using this data, there was an average of 73,066 bbl of oil produced per oil well, 228,555 MCF of casing head natural gas produced per oil well on schedule, 741,846 MCF of natural gas produced per natural gas well, and 58,998 bbl of condensate produced per natural gas well on schedule.

To calculate estimated EUR per well, a conservative approach was used. While oil well production was broken down into 160,000 bbl for oil and 225,000 MCF for casinghead gas, natural gas well production was broken down into an average of 100,000 bbl of condensate and 1,250,000 MCF of natural gas per well. This breakdown between natural gas and condensate is similar to data provided by the Railroad Commission of Texas. Eagle Ford natural gas wells produced 265,580,796 BOE (69%) of Natural gas and 119,125,027BOE (31%) of condensate from January 2008 to July 2013.[469] 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, increases in hp used for hydraulic fracturing, reduced time needed to move rigs and equipment, and increased 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 increased the estimated 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 working experience increases 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 (Table 8-11). The EUR under the low development scenario remained the same.

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[467] 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.

[468] 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 10/15/2013.

[469] 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 10/15/2013.

Table 8-11: Increase in Estimated Ultimate Recovery (EUR) per Year per Well drilled, Moderate and Aggressive Development Scenario, 2008-2018

| Scenario | Year | Percent increase in EUR per year (from 2012) | 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) |
| Moderate Development Scenario | 2008 | 0% | 160,000 | 225,000 | 197,500 | 100,000 | 1,250,000 | 302,333 |
| | 2009 | 0% | 160,000 | 225,000 | 197,500 | 100,000 | 1,250,000 | 302,333 |
| | 2010 | 0% | 160,000 | 225,000 | 197,500 | 100,000 | 1,250,000 | 302,333 |
| | 2011 | 0% | 160,000 | 225,000 | 197,500 | 100,000 | 1,250,000 | 302,333 |
| | 2012 | 5% | 168,000 | 236,250 | 207,375 | 105,000 | 1,312,500 | 317,450 |
| | 2013 | 10% | 176,000 | 247,500 | 217,250 | 110,000 | 1,375,000 | 332,567 |
| | 2014 | 15% | 184,000 | 258,750 | 227,125 | 115,000 | 1,437,500 | 347,683 |
| | 2015 | 20% | 192,000 | 270,000 | 237,000 | 120,000 | 1,500,000 | 362,800 |
| | 2016 | 25% | 200,000 | 281,250 | 246,875 | 125,000 | 1,562,500 | 377,917 |
| | 2017 | 30% | 208,000 | 292,500 | 256,750 | 130,000 | 1,625,000 | 393,033 |
| | 2018 | 35% | 216,000 | 303,750 | 266,625 | 135,000 | 1,687,500 | 408,150 |
| Aggressive Development Scenario | 2008 | 0% | 160,000 | 225,000 | 197,500 | 100,000 | 1,250,000 | 302,333 |
| | 2009 | 0% | 160,000 | 225,000 | 197,500 | 100,000 | 1,250,000 | 302,333 |
| | 2010 | 0% | 160,000 | 225,000 | 197,500 | 100,000 | 1,250,000 | 302,333 |
| | 2011 | 0% | 160,000 | 225,000 | 197,500 | 100,000 | 1,250,000 | 302,333 |
| | 2012 | 10% | 176,000 | 247,500 | 217,250 | 110,000 | 1,375,000 | 332,567 |
| | 2013 | 20% | 192,000 | 270,000 | 237,000 | 120,000 | 1,500,000 | 362,800 |
| | 2014 | 30% | 208,000 | 292,500 | 256,750 | 130,000 | 1,625,000 | 393,033 |
| | 2015 | 40% | 224,000 | 315,000 | 276,500 | 140,000 | 1,750,000 | 423,267 |
| | 2016 | 50% | 240,000 | 337,500 | 296,250 | 150,000 | 1,875,000 | 453,500 |
| | 2017 | 60% | 256,000 | 360,000 | 316,000 | 160,000 | 2,000,000 | 483,733 |
| | 2018 | 70% | 272,000 | 382,500 | 335,750 | 170,000 | 2,125,000 | 513,967 |

### 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."[470] The U.S. Energy Information Administration computed a typical decline curve for Eagle Ford with 30 percent of production occurring within the first year (Figure 8-8). The curve was developed by Petrohawk based on data for condensate in the Hawkville Field.[471]

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."[472] To develop an Eagle Ford decline curve, shown in comparison to other shale basins in Figure 8-9, Schlumberger used data from 59 wells.[473] Harvard University predicted that Eagle Ford wells will decline 55 percent after the first year and another 40 percent after the second year.[474]

Decline curves calculated from other studies varied from a 56 percent decline in the Barnett[475] to an 82 percent decline in the Bakken[476] during the first year. Schlumberger found a 76 percent decline in the Eagle Ford during the first year[477] while Goodrich Petroleum reported an 81 percent decline in the Haynesville.[478] All decline curves from previous studies show a similar pattern: from high initial output followed by a rapid decline in

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470 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.

471 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.

472 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.

473 *Ibid*.

474 Leonardo Maugeri June 2013. "The Shale Oil Boom: A U.S. Phenomenon". Discussion Paper 2013-05, Belfer Center for Science and International Affairs, Harvard Kennedy School. Cambridge, MA. p. 4. Available online: http://belfercenter.ksg.harvard.edu/files/draft-2.pdf. Accessed 10/31/2013.

475 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.

476 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.

477 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.

478 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.

production as the well matures (Table 8-12). When the well is 10 years old, production from the well will be minimal because of the rapid decline.

Figure 8-8: Typical Decline curve for the Eagle Ford

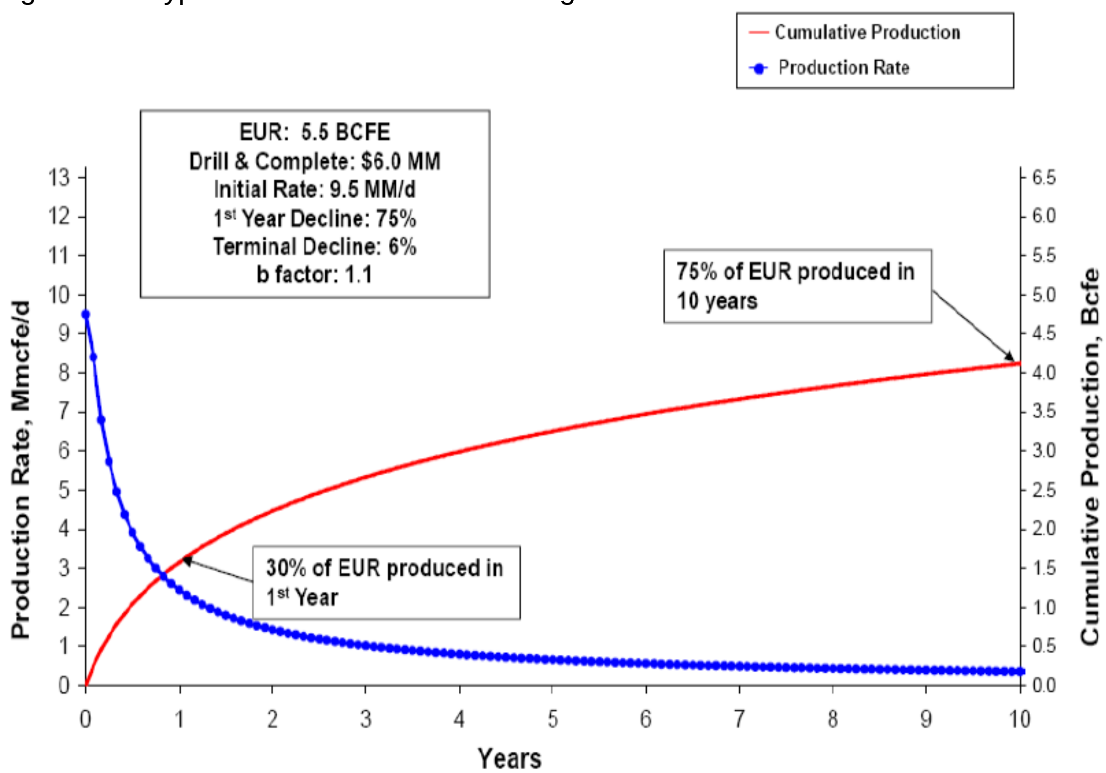


Figure 8-9: Decline Curves for Horizontal Sandstone and Shale Plays

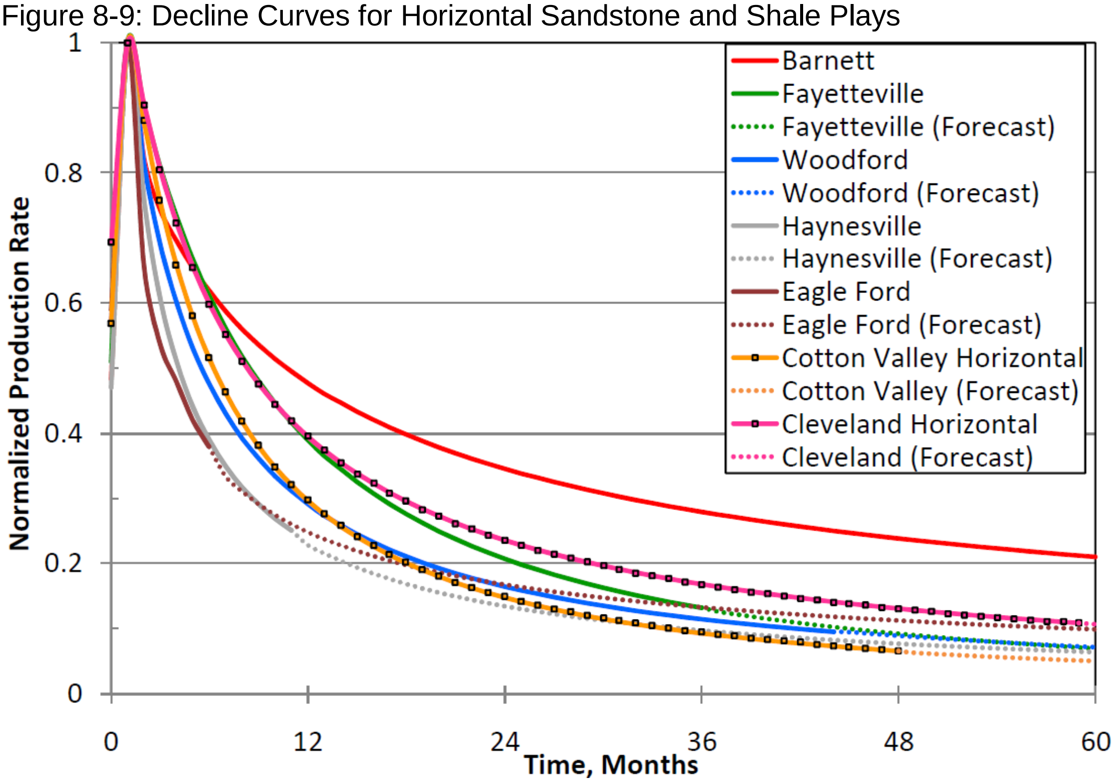

Table 8-12: Examples of Decline Curves from Previous Studies

| Production Month | Pickering Energy Partners, Barnet | Midland Basin, Wolfcamp [479] | Goodrich Petroleum, Haynesville | C. K. Cooper & Company. Eagle Ford[480] | Schlumberger Eagle Ford | HPDI, Barnett [481] | ENVIRON Haynesville [482] | MHA Petroleum Consultants | | | Harvard University Eagle Ford | **Eagle Ford based on RRC Data** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Haynesville Industry | Marcellus | Bakken | | |
| 12 months | 56% | 62% | 81% | 62% | 76% | 60% | 71% | 70% | 68% | 82% | 55% | 59% |
| 24 months | 27% | 31% | 34% | 20% | 29% | 35% | 32% | 42% | 24% | 34% | 40% | 60% |
| 36 months | 18% | 21% | 22% | 18% | 24% | 20% | 22% | 30% | 12% | 20% | 30% | 46% |
| 48 months | 12% | 16% | 17% | 16% | 15% | 8% | 16% | 25% | 11% | 14% | 20% | 16% |
| 60 months | 8% | 13% | 13% | | 9% | 0% | 13% | 19% | 10% | 12% | 20% | 70% |
| 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% | | ***11%**** |

*Based on projected EUR using local data to calculate exponential equation $y = e^{-0.06492}$

[479] 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.
[480] C. K. Cooper & Company. “Lucas Energy, Inc.” Ivrine, California. p. 11. Available online: http://www.billchippasshow.com/files/46180526.pdf. Accessed: 04/15/2012.
[481] 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.
[482] 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 forecast 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 95% 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.[483]

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 = 95% confidence level, 1.96
POP = Population size, 7,156 wells (from Railroad Commission of Texas)
CIN = ± 10% confidence interval, 0.1

Sample Equation: Number of wells needed for a 95% confidence level and 10% confidence interval:

$$RN = [(1.96)^2 \times (0.25) \times 7{,}156] / [(1.96)^2 \times (0.25) + (7{,}156 - 1) \times (0.1)^2]$$
$$= 94.8 \text{ wells}$$

Thus, data from 95 wells will be needed in order to meet the 95% level of confidence, and the ±10% confidence interval to develop a decline curve. Since 99 wells were included in the initial analysis, the sampling meets the required sample size for a 95% confidence level with a ± 10% confidence interval. Wells with at least 18 months of production were selected from across the basin and at least one well was selected from every county.[484] 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 February 2012.

There is a large amount of variability in production data and decline curves in the Eagle Ford. Efforts were made to get accurate and complete data from representative wells in the Eagle Ford. Following the methodology used by Schlumberger, any well with abrupt changes in monthly production rates was removed from the DCA calculations.[485] Some wells have tighter chokes to flatten 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 analysis of the decline curve are listed below.

- Traylor North, Lease 15229
- Moglia, Lease 254895, Well 5h
- Kallina, Lease 247729, Well 2h
- Baumann Gas Unit, Lease 250086, Well 2h
- La Bandera Ranch, Lease 254472, Well 1h
- Tovar West-Lloyd 77 Unit, Lease 15307

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[483] Rea, L. M. and Parker, R. A., 1992. “Designing and Conducting Survey Research”. Jossey-Bass Publishers: San Francisco.
[484] Railroad Commission of Texas. “Specific Lease Query”. Austin, Texas. Available online: http://webapps.rrc.state.tx.us/PDQ/quickLeaseReportBuilderAction.do. Accessed 06/01/2012.
[485] 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.

- Eskew North Unit, Lease 256977, Well 1
- Billings "B", Lease 256253, Well 12h
- Lowe, Lease 257679, Well 3h
- Gus Tips Gas 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
- Winton Unit, Lease 15049
- Lastly Unit, Lease 25168
- Miss Ellie, Lease 25197
- Hullabaloo, Lease 25251
- Mansker Ranch Gas Unit, Lease 253314, Well 4
- Vaquillas Borrego, Lease 238068, Well 28h
- Staggs, Lease 245000, Well 12h
- Kleinschmidt, Lease 25253
- Galloping Ghost Unit, Lease 25214
- Allee-Bowman Unit, Lease 14974
- Nathalie, Lease 25243
- Fun, Lease 25269
- Tlapek, Lease 14956
- Benge Unit, Lease 25266
- Fred Buchel Gas No 1, Lease 239214, Well 2
- La Rosita, Lease 14994
- Rally, Lease 15051
- Ondrasek Unit, Lease No: 25728
- Dulaney-Bruni, Lease 251652, Well 1
- Chaparrosa "A", Lease 15228
- Woolum, Lease 25377
- Chhorn Gas Unit, Lease 250898, Well 1h
- Evangeline Gas 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
- Zingara, Lease 256453, Well No
- Caroline Pielop, Lease 254447, Well 4h
- Varibus, Lease 255962, Well 7h
- Eskew West Unit, Lease 254315, Well 1
- Whitehurst, Lease 260166, Well 1h
- Lightsey-Lightsey, Lease 25698
- Afflerbach 01, Lease 263733, Well 01h
- Reynolds Gas Unit, Lease 261735, Well 1h
- Crabtree Unit A, Lease 09691
- Rangel Unit A Zav, Lease 15570
- Rangel Unit A Zav, Lease 15570
- Frisbie Unit, Lease 15649
- H.F.S., Lease 15293
- Hamilton Gas Unit No 1, Lease 264151, Well 1
- T Bird, Lease 260636, Well 1h
- Cenizo Ranch, Lease 15636
- B&B Unit, Lease 15464
- Fox Creek, Lease 15332
- Metting Neutzler 01, Lease 259779, Well 01h
- Halepeska Gas Unit 1, Lease 260868, Well 1
- Uvalle State, Lease 260904, Well 1h
- Lord A Unit, Lease No: 15886
- Fox Creek Ranch "A", Lease 15413
- Mecom-Wood Unit, Lease 25699
- Braune Unit, Lease 09575
- Jog Unit, Lease 09476
- Kothmann-Ranch, Lease 15735
- Briscoe Friday Ranch, Lease 262325, Well 7h
- Muir E, Lease 10118
- Bruns 01, Lease 260240, Well 01h
- Burns Ranch Iii, Lease 15592
- Watts, Lease 15271
- Three Sisters 01, Lease 259504, Well 01h
- Wheeler "5", Lease 40669
- Galvan Ranch, Lease 263660, Well A444h
- Worthey Ranch, Lease 263436, Well 7h

Average decline curves by product are provided in Figure 8-10, while decline curves by DOFP are shown in Figure 8-11. Condensate and casinghead gas have very similar decline curves for the first 18 months of production. Oil and natural gas have a slightly steeper decline curve in the first 8 months of production, but the decline curve is similar overall. When comparing wells with different DOFP, wells that started production in 2010 and 2011 had a more gradual decline curve compared to 2008 and 2009. “Most companies now “choke down” a well, reducing the initial flow rate. It may help improve ultimate recovery from the well, and also makes it easier for companies to deal with transportation issues such as pipelines that aren't yet connected.”[486]

Figure 8-10: Normalized Eagle Ford Decline Curves by Product

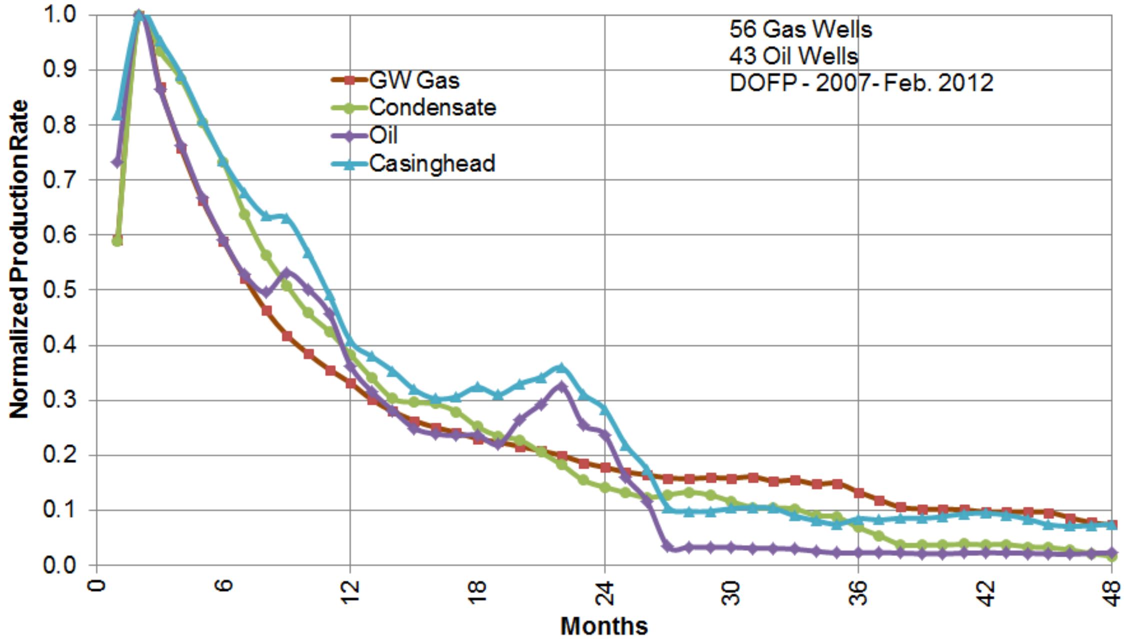
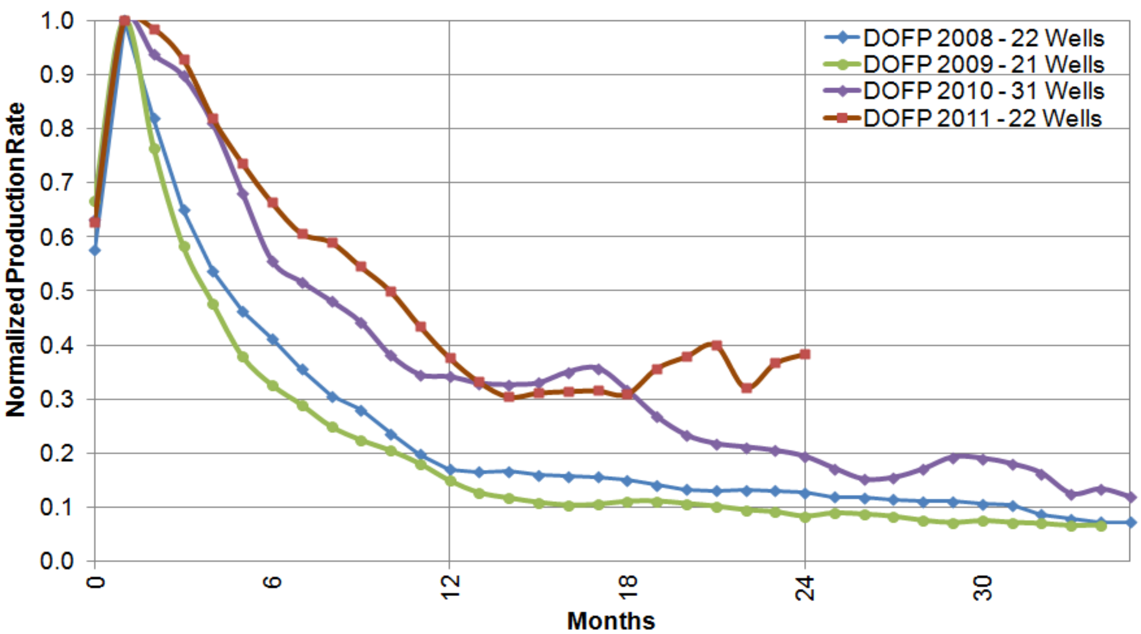



Figure 8-11: Normalized Eagle Ford Decline Curves by DOFP

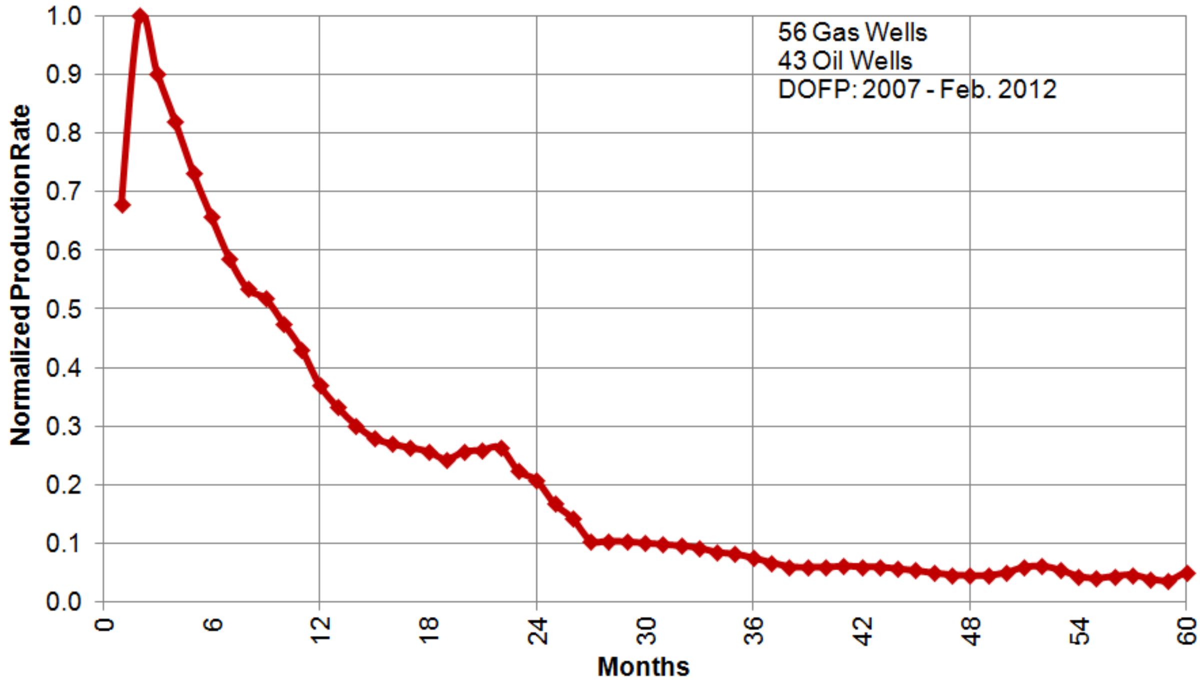



486 Fred Wang, research scientist with the Bureau of Economic Geology at the University of Texas at Austin, from Jennifer Hiller, Express-News. October 27, 2013 “Big output vs. well longevity” San Antonio Express-News. San Antonio, Texas. Available online: http://www.expressnews.com/business/eagle-ford-energy/article/Big-output-vs-well-longevity-4927065.php. Accessed 10/28/2013.

When the decline curves for all wells are averaged, as shown in Figure 8-12, the results indicate a significant reduction in production as the wells age. Since Eagle Ford is still a developing basin, long term production rates are unknown. The decline curve is projected beyond 60 months using an exponential equation of $y = e^{-0.06492x}$ based on \ production data from the surveyed wells.

The calculated normalized decline curve for Eagle Ford wells in the first year of production is not as steep as other studies: a 59% decline curve was calculated for Eagle Ford wells compared to a 69% average from other studies. However, the Eagle Ford curve declines more steeply in the following years compared to other basins. For example the Eagle Ford decline curve is 60% in year 2 and 46% in year 3, while other studies had an average of only 32% and 22%. Once a 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.

Figure 8-12: Average Normalized Eagle Ford Decline Curve




### 8.4.4 Production Projections

There can be a significant time delay between when a well is drilled and when the well starts to produce. “In fact, Eagle Ford drilling is moving faster than completion services (pressure pumping, etc.) can keep up.” The number of non-completed wells may have exceeded 1,600 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.”[487]

[487] 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.[488] To account for the delay between spud and production, only 33 percent of the wells start production in the first year while 33% was allocated to each year afterwards.

As mentioned, the U.S. Energy Information Administration estimates 30 percent of production occurs within the first year.[489] However, in the analysis of the 99 wells that were used to develop the average decline curve in the Eagle Ford, 51.3 percent of estimated total production occurred in the first year (Table 8-13). Using production data from 99 sample wells and the decline curve analysis, the EURs for the sample wells are 157,106 bbl for oil, 287,240 MCF for casinghead, 72,652 bbl for condensate, and 1,297,954 MCF for natural gas. This data from the surveyed wells are very similar to the estimated EURs used in the projection scenarios: 160,000 bbl for oil, 225,000 MCF for casinghead gas, 100,000 bbl for condensate, and 1,250,000 MCF for natural gas per wells.

Producers in the Eagle Ford are expected to concentrate efforts on the liquid portion of the play including increased drilling for oil and condensate instead of natural gas. Under the low development scenario, there is a 10 percent decrease in the number of natural gas wells, while the high scenario has an increase of 10 percent in natural gas wells.

Table 8-13: Inputs for the Three Projection Scenarios

| Factor | Low Development | Moderate Development | Aggressive Development |
|---|---|---|---|
| Number of New drill rigs per year | -12 | 0 | 24 |
| Maximum number of Drill Rigs | 197 | 197 | 250 |
| Percent of wells drilled that go into production per year | 33% | 33% | 33% |
| Oil EUR per well (bbl) | 160,000 | 160,000 | 160,000 |
| Casinghead Gas EUR per well (MCF) | 225,000 | 225,000 | 225,000 |
| Condensate EUR per well (bbl) | 100,000 | 100,000 | 100,000 |
| Natural Gas EUR per well (MCF) | 1,250,000 | 1,250,000 | 1,250,000 |
| Amount of EUR produced in the first year | 51.3% | 51.3% | 51.3% |
| Annual Growth in EUR per Well | 0% | 5% | 10% |
| Annual Change in Natural Gas Wells | -10% | 0% | 10% |
| Annual increase in Condensate Production per Well | 5% | 5% | 5% |

Estimated 2012-2018 production of oil, casinghead, condensate, and natural gas in the Eagle Ford was 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

$PWELL_{AC}$ = Annual number of Eagle Ford development type C wells in Year A (from Table 8-9)

[488] 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.

[489] 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.

$EUR_{Total}$ = Total EUR for Eagle Ford development well type C, 160,000 bbl per oil well, 225,000 MCF for casinghead gas, 100,000 bbl for condensate for gas wells, or 1,250,000 MCF for gas wells in 2011, Table 8-11

$GROW_A$ = 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, 51.3% (from Eagle Ford production data)

$DECLINE_A$ = Percentage of decline from decline curve in year A of production, Table 8-12 (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, 2013 oil production from Eagle Ford oil wells in the second year of production under moderate development scenario

$PPROJ_{ABC}$ = 2,310 wells x [160,000 bbl EUR x (1 + 0.10)] x 0.5130 x (1 - 0.5904) x (1 + 0.00)

= 85,413,819 bbl of oil from 2013 oil wells in the second year of production under moderate development scenario

Sample Equation, 2013 casinghead gas production from Eagle Ford oil wells in the second year of production under moderate development scenario

$PPROJ_{ABC}$ = 2,310 wells x [225,000 MCF EUR x (1 + 0.10)] x 0.5130 x (1 - 0.5904) x (1 + 0.00)

= 120,113,183 MCF of casinghead from 2013 oil wells in the second year of production under moderate development scenario

Sample Equation, 2013 condensate production from Eagle Ford natural gas wells in the second year of production under moderate development scenario

$PPROJ_{ABC}$ = 712 wells x [100,000 bbl EUR x (1 + 0.10)] x 0.5130 x (1 - 0.5904) x (1 + 0.10)

= 18,103,311 bbl of condensate from 2013 oil wells in the second year of production under moderate development scenario

Sample Equation, 2013 natural gas production from Eagle Ford natural gas wells in the second year of production under moderate development scenario

$PPROJ_{ABC}$ = 712 wells x [1,250,000 MCF EUR x (1 + 0.10)] x 0.5130 x (1 - 0.5904) x (1 + -0.10)

= 185,147,500 MCF of natural gas from 2013 oil wells in the second year of production under moderate development scenario

A detailed production projection table by well year and production year is provided in Appendix F. Production projections for each product by year were 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

$PPROJ_{ABC}$ = (639,450 bbl x 0.33) + (539,739 bbl x 0.33) + (160,883 bbl x 0.33) + (837,411 bbl x 0.33) + (452,645 bbl x 0.33) + (382,063 bbl x 0.33) + (11,330,329 bbl x 0.33) + (4,479,484 bbl x 0.33) + (2,421,290 bbl x 0.33) + (103,341,554 bbl x 0.33) + (42,329,035 bbl x 0.33) + (16,734,926 bbl x 0.33) + (240,676,769 bbl x 0.33) + (98,457,872 bbl x 0.33) + (0 bbl x 0.33) + (208,528,186 bbl x 0.33) + (0 bbl x 0.33) + (0 bbl x 0.33) +
= 243,669,545 bbl of oil produced in the Eagle Ford, 2013

Under the low development scenario, 412 MMbbl BOE is projected to be produced by Eagle Ford wells in 2018 (Table 8-14). It is projected that 705 MMbbl BOE will be produced under the moderate development scenario and 1,168 MMbbl BOE under the aggressive development scenario. Natural gas production is projected to be between 823 BCF under the low scenario to 2,437 BCF under the high scenario in 2018 (Figure 8-13). Similar to natural gas, it is projected that condensate will be between 54 MMbbl and 191 MMbbl (Figure 8-14). Oil production in the Eagle Ford is projected to increase rapidly to 480 MMbbl under the moderate development scenario and 761 MMbbl under the aggressive development scenario (Figure 8-15). Production is expected to increase under the low scenario until at least 2014 even though the projected number of drill rigs operating in the shale is decreasing in this projection scenario. This is similar to observations in the Barnett Shale where the number of drill rigs decreased, but production of natural gas increased as existing wells were brought into production and the remaining rigs were drilling new wells.

Projected total oil production is between 1,954 MMbbl in 2008 to 3,254 MMbbl in 2018, while natural gas production is projected to be 7,521 BCF in 2008 and 12,284 BCF in 2018. EIA's new Drilling Productivity Report estimated that the Eagle Ford has already reach 1.093 million barrels of oil per day.[490] Under the moderate scenario, production is not estimate to reach this level until 2015 and under the high scenario production will not be at this level until 2014. EIA estimated natural gas production is 4,532 MMcf/day[491], which is higher than the results from all scenarios.

[490] EIA, October, 2013. Drilling Productivity Report". Available online: http://www.eia.gov/petroleum/drilling/pdf/dpr-full.pdf. Accessed 10/30/2013.
[491] *Ibid*.

Table 8-14: 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 | 0 | 1 | 19 | 4 | 0 | 0 | 1 | 19 | 4 | 0 | 0 | 1 | 19 | 4 |
| 2010 | 6 | 2 | 7 | 106 | 30 | 6 | 2 | 7 | 106 | 30 | 6 | 2 | 7 | 106 | 30 |
| 2011 | 47 | 67 | 29 | 381 | 138 | 47 | 67 | 29 | 381 | 138 | 47 | 67 | 29 | 381 | 138 |
| 2012 | 146 | 208 | 56 | 702 | 315 | 146 | 208 | 56 | 702 | 315 | 146 | 208 | 56 | 702 | 315 |
| 2013 | 232 | 326 | 67 | 783 | 425 | 244 | 343 | 70 | 821 | 446 | 255 | 359 | 74 | 861 | 468 |
| 2014 | 299 | 420 | 64 | 705 | 477 | 328 | 461 | 74 | 799 | 530 | 363 | 510 | 85 | 908 | 594 |
| 2015 | 312 | 439 | 62 | 627 | 475 | 367 | 517 | 80 | 794 | 575 | 450 | 633 | 103 | 1,004 | 715 |
| 2016 | 314 | 441 | 60 | 552 | 462 | 407 | 573 | 88 | 790 | 621 | 559 | 786 | 127 | 1,120 | 865 |
| 2017 | 306 | 430 | 57 | 479 | 439 | 444 | 625 | 96 | 780 | 664 | 667 | 938 | 156 | 1,242 | 1,021 |
| 2018 | 293 | 411 | 54 | 412 | 412 | 480 | 675 | 104 | 764 | 705 | 761 | 1,070 | 191 | 1,367 | 1,168 |
| Total | 1,954 | 2,751 | 456 | 4,770 | 3,177 | 2,468 | 3,469 | 605 | 5,957 | 4,030 | 3,254 | 4,573 | 830 | 7,711 | 5,319 |

Figure 8-13: Annual Projected Gas Production in the Eagle Ford for the Three Scenarios

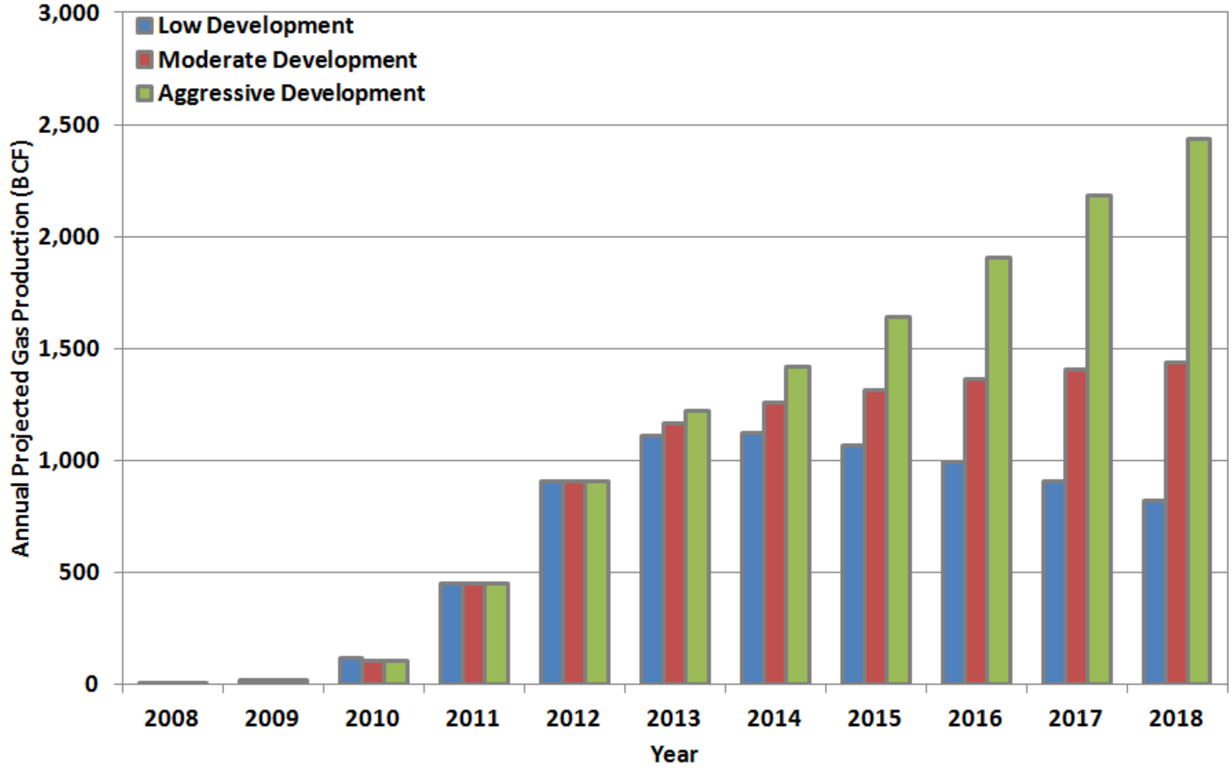



Figure 8-14: Annual Projected Condensate Production in the Eagle Ford for the Three Scenarios

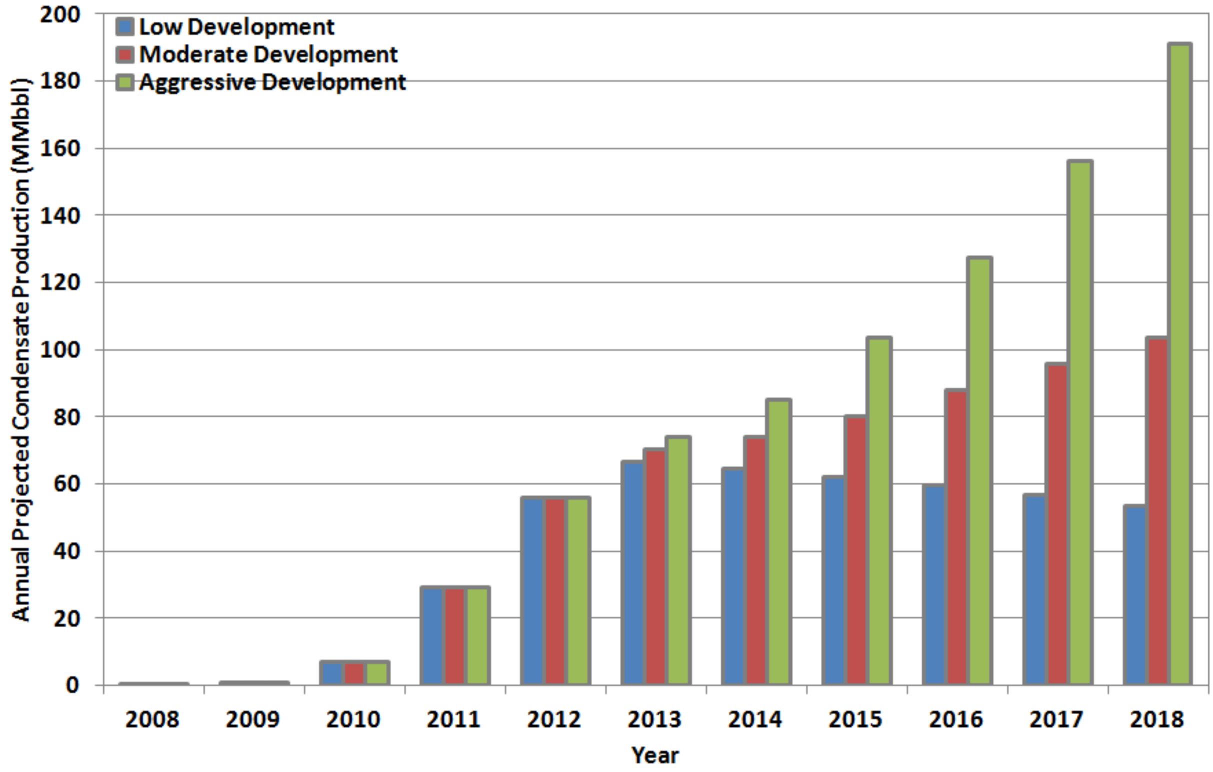
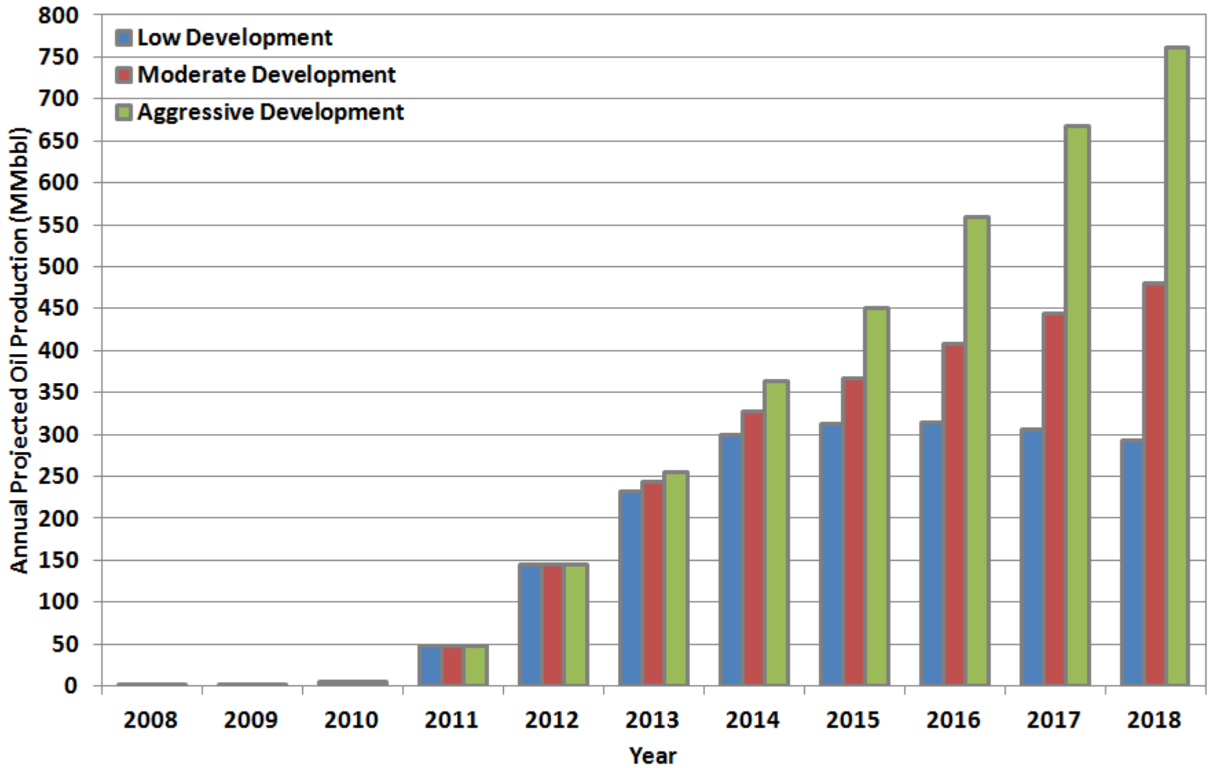


Figure 8-15: Annual Projected Oil Production in the Eagle Ford for the Three Scenarios




According to Bentek, Eagle Ford oil and natural gas production in 2016 could be as high as 1.6 million BOE per day.[492] These results are similar to the aggressive development scenario. Tony Scott, manager of oil and gas analysis for Bentek Energy, said "oil companies working in the Eagle Ford will boost production there to more than 1 million barrels per day by the end of 2013 and to more than 1.5 million barrels per day in 2018."[493] Phani Gadde, an analyst with Wood Mackenzie, said that the firm expects the Eagle Ford to reach the 1.6 million barrel mark by 2020. Drillinginfo said in September 2013 that it expects Eagle Ford oil production to peak in 2022 at about 1.8 million barrels of oil per day.[494] Pioneer Natural Resources estimate that Eagle Ford production will be approximately 1,250 MMBOE in 2020.[495] Although AACOG's calculated projections do not extend to 2020, the estimations from Pioneer are similar to AACOG's results for aggressive development.

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[492] Robert Baillieul, October 17th, 2013. "5 Mind Blowing Facts About the Eagle Ford". USAWEEK. Available online: http://www.usaweek.org/index.php/news/80-5-mind-blowing-facts-about-the-eagle-ford. Accessed 10/30/2013.

[493] Zain Shauk, Houston Chronicle, October 9, 2013. "Analyst offers bullish forecast on N. American oil output". Houston, Texas. Available online: http://www.mysanantonio.com/business/eagle-ford-energy/article/Analyst-offers-bullish-forecast-on-N-American-4882606.php. Accessed 10/30/2013.

[494] Jennifer Hiller, San Antonio Express News, October 24, 2013. "Has the Eagle Ford Shale crossed the 1 million barrel mark?". San Antonio, Texas, Available online: http://blog.mysanantonio.com/eagle-ford-fix/2013/10/has-the-eagle-ford-shale-crossed-the-1-million-barrel-mark/. Accessed 10/29/2013

[495] 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.

### 8.4.5 Production Emissions

Emissions from production were estimated based on the number of total wells drilled (Table 8-10) and annual production totals (Table 8-14) under each scenario. Future emissions for each source were calculated using the methodologies provided in chapter 6. All state or federal mandated controls were included in each projection scenario.

Future projections take into account EPA's amendments to air regulations for the oil and natural gas industry. "On April 17, 2012, the U.S. Environmental Protection Agency (EPA) issued cost-effective regulations to reduce harmful air pollution from the oil and natural gas industry while allowing continued, responsible growth in U.S. oil and natural gas production. The final rules include the first federal air standards for natural gas wells that are hydraulically fractured, along with requirements for several other sources of pollution in the oil and gas industry that currently are not regulated at the federal level."[496] Most emission factors in the Eagle Ford emission inventory are below the requirements of this rule; however emissions from condensate tanks at mid-stream sources were reduced because of this rule.

### 8.4.6 On-Road Emissions

To calculate emissions from the on-road vehicles operated during well production, parameters such as vehicle speed, vehicle type, distance travelled, and idling hours per trip, were kept consistent for each projection year. However, the number of vehicles used in the calculations varied to account for future projections of wells drilled and emission factors were 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 federally mandated controls, including TxLED and rules incorporated in the MOVES model, were 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."[497] Figure 8-16 shows that there were 617 midstream oil and gas facilities permitted by TCEQ between 2008 and March 2012 in Eagle Ford counties.

From 2008 to 2012, allowable VOC emissions from permitted facilities increased to 31.0 tons/day (Figure 8-17) and allowable $NO_X$ emissions increased to 33.8 tons/day (Figure 8-18). 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.

[496] EPA, April 17th, 2012. "Overview of Final Amendments to Air Regulations for the Oil and Natural Gas Industry". Available online: http://www.epa.gov/airquality/oilandgas/pdfs/20120417fs.pdf. Accessed 10/21/2013.
[497] 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.

Figure 8-16: Mid Stream Sources by Date of Review

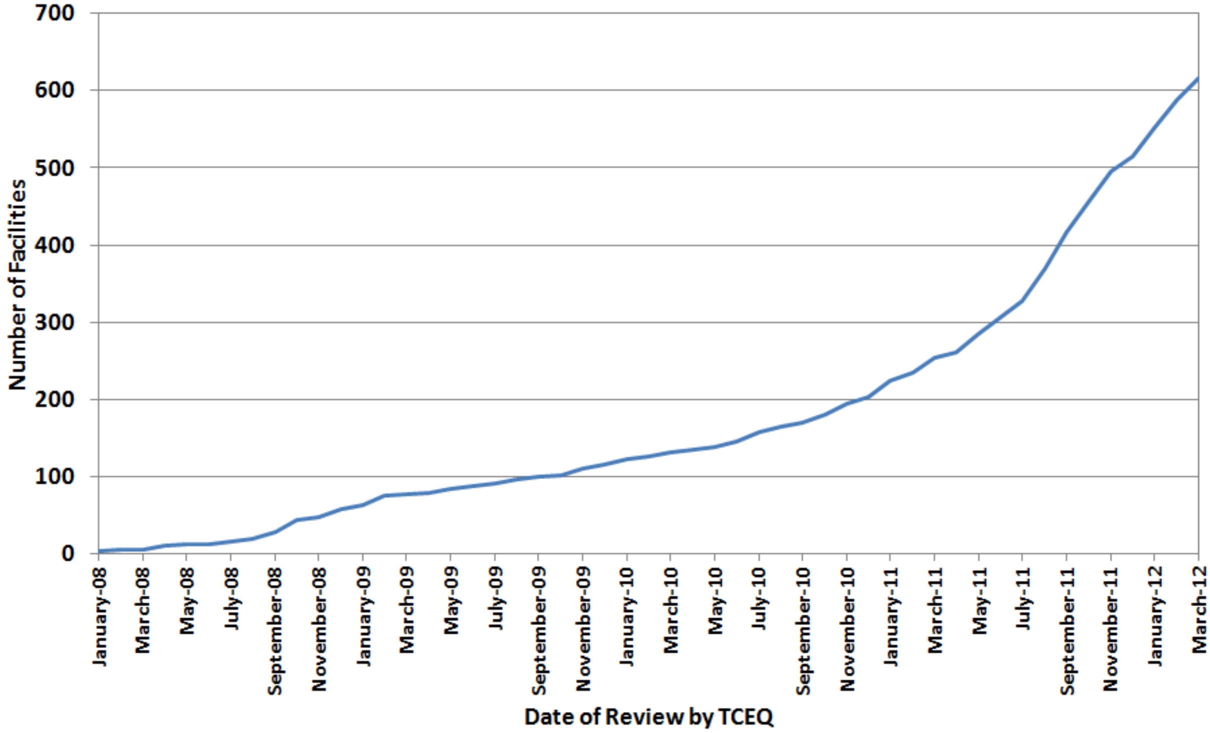



Figure 8-17: Mid Stream Sources $NO_X$ Emissions by County and Date of Review by TCEQ

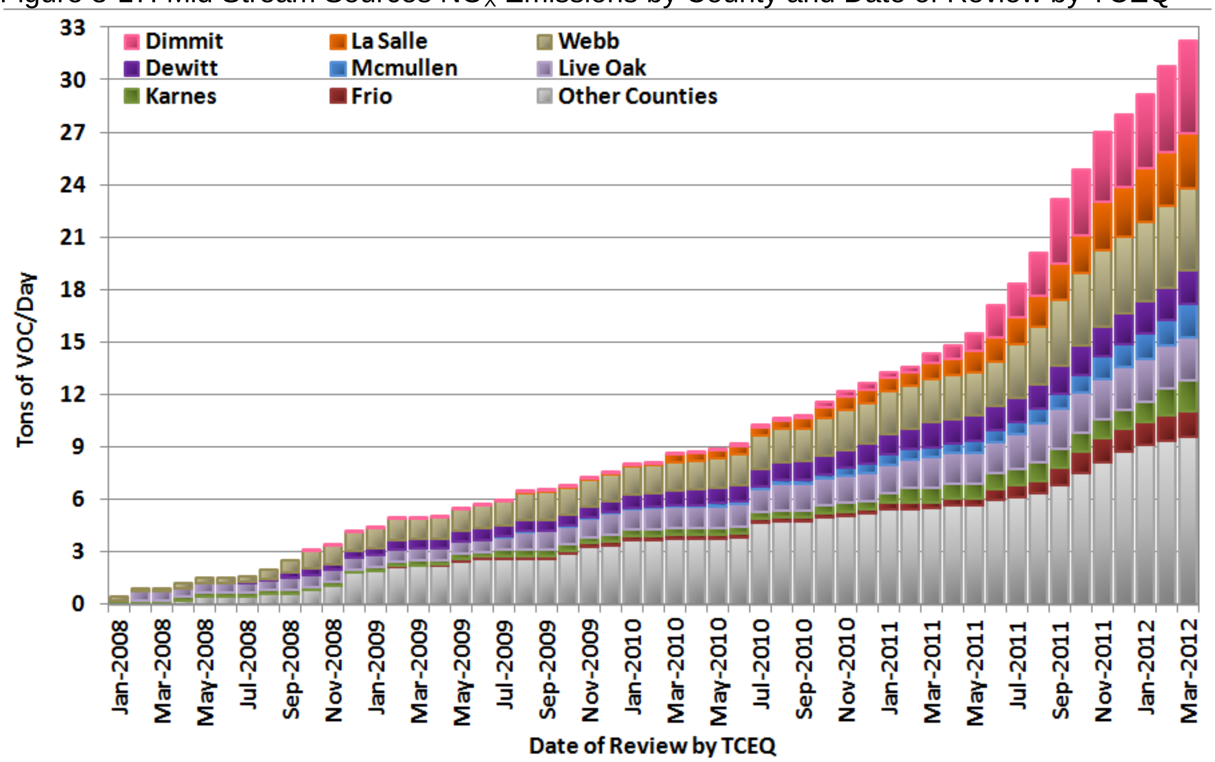
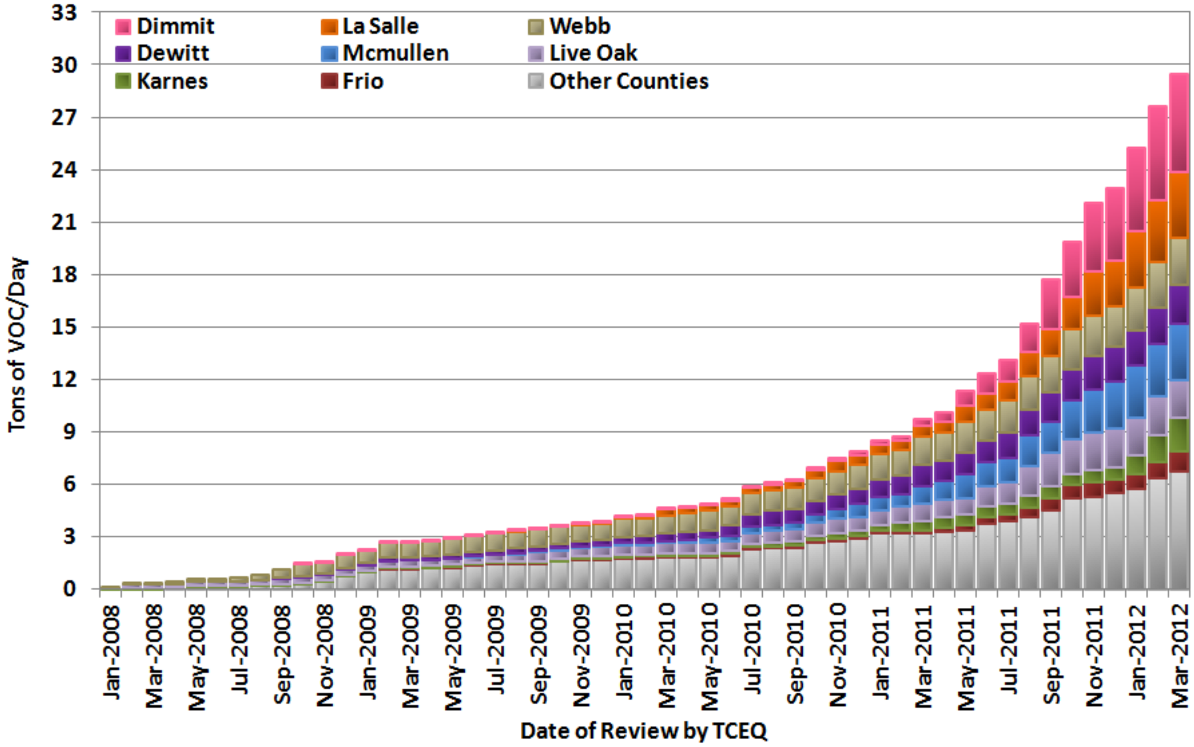


Figure 8-18: Mid Stream Sources VOC Emissions by County and Date of Review by TCEQ




Future projection of midstream sources was based on the emission calculation methodology provided in Chapter 7. Midstream source $NO_X$ and VOC emission factors are based on the Barnett Shale special inventory and TCEQ's 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 were 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 8-15, and shown in Figure 8-19 and Figure 8-20. Under the low development scenario, emissions from midstream sources increase to 40 tons/day of VOC and 27 tons/day of $NO_X$ by 2018. For the high development scenario, total emissions are projected to be 49 tons of VOC and 64 tons of $NO_X$ by 2018.

State and federal mandated controls were included in the projection scenarios including EPA's "Proposed Amendments to Air Regulations for the Oil and Natural Gas Industry." "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." [498]

[498] 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.

Table 8-15: Ozone Season Daily 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 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 |
| 2009 | 3 | 5 | 5 | 3 | 5 | 5 | 3 | 5 | 5 |
| 2010 | 5 | 5 | 9 | 5 | 5 | 9 | 5 | 5 | 9 |
| 2011 | 10 | 7 | 14 | 10 | 7 | 14 | 10 | 7 | 14 |
| 2012 | 29 | 18 | 30 | 29 | 18 | 30 | 29 | 18 | 30 |
| 2013 | 33 | 21 | 35 | 35 | 22 | 36 | 37 | 23 | 38 |
| 2014 | 35 | 23 | 37 | 39 | 25 | 40 | 42 | 27 | 44 |
| 2015 | 37 | 24 | 38 | 42 | 27 | 44 | 48 | 32 | 51 |
| 2016 | 38 | 25 | 40 | 45 | 30 | 49 | 53 | 37 | 60 |
| 2017 | 39 | 26 | 42 | 47 | 33 | 54 | 58 | 43 | 69 |
| 2018 | 40 | 27 | 45 | 50 | 37 | 60 | 64 | 49 | 80 |

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.[499] The average emission factor for 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 tanks. Since many mid-stream facilities are located near well sites, any storage tank that emits more than 6 tons/year must reduce VOC emissions by 95 percent for all new projected mid-stream facilities built after 2014.

Table 8-16 shows midstream source emissions by source type for 2011 and 2012, while Table 8-17 lists projected mid-stream sources for 2015 and 2018. The largest source of $NO_X$ emissions is compressor engines: 6.75 tons per ozone season day in 2012. The largest source of VOC emissions are condensate tanks, 5.25 tons per ozone season day, follow by crude storage tanks, 1.48 tons per ozone season day, and compressor engines, 1.27 tons per ozone season day.

[499] *Ibid*.

Table 8-16: Ozone Season Daily $NO_X$ and VOC Emissions from Mid-Stream Sources in Eagle Ford by source category, 2011 and 2012.

| Year | Source | VOC | $NO_X$ | CO |
|---|---|---|---|---|
| 2011 | Heater/ Boiler | 0.02 | 0.21 | 0.19 |
| | Glycol Dehydration | 0.50 | 0.00 | 0.06 |
| | Amine Unit | 0.02 | 0.00 | 0.00 |
| | Compressor Engine | 1.27 | 6.75 | 11.18 |
| | Pumps | 0.00 | 0.00 | 0.00 |
| | Gas Cooler Engine | 0.03 | 0.02 | 0.17 |
| | Crude Storage Tanks | 1.48 | 0.00 | 0.00 |
| | Produced Water Storage Tanks | 0.29 | 0.00 | 0.00 |
| | Condensate Tank | 5.25 | 0.00 | 0.00 |
| | Oil Loading Facility | 0.06 | 0.00 | 0.00 |
| | Produced Water Loading Facility | 0.10 | 0.00 | 0.00 |
| | Condensate Loading | 0.08 | 0.00 | 0.00 |
| | Flare/ Combustor | 0.02 | 0.09 | 1.27 |
| | Fugitives | 0.56 | 0.00 | 0.00 |
| | Other | 0.41 | 0.25 | 0.76 |
| | Total | 10.09 | 7.33 | 13.62 |
| 2012 | Heater/ Boiler | 0.06 | 0.69 | 1.04 |
| | Glycol Dehydration | 1.11 | 0.00 | 0.13 |
| | Amine Unit | 0.07 | 0.00 | 0.02 |
| | Compressor Engine | 3.12 | 16.61 | 22.81 |
| | Pumps | 0.01 | 0.00 | 0.00 |
| | Gas Cooler Engine | 0.06 | 0.04 | 0.20 |
| | Crude Storage Tanks | 7.00 | 0.00 | 0.00 |
| | Produced Water Storage Tanks | 0.81 | 0.00 | 0.00 |
| | Condensate Tank | 13.15 | 0.00 | 0.00 |
| | Oil Loading Facility | 0.21 | 0.00 | 0.00 |
| | Produced Water Loading Facility | 0.30 | 0.00 | 0.00 |
| | Condensate Loading | 0.16 | 0.00 | 0.00 |
| | Flare/ Combustor | 0.09 | 0.38 | 4.53 |
| | Fugitives | 1.48 | 0.00 | 0.00 |
| | Other | 1.00 | 0.61 | 0.94 |
| | Total | 28.61 | 18.32 | 29.67 |

Table 8-17: Ozone Season Projected Daily $NO_X$ and VOC Emissions from Mid-Stream Sources in Eagle Ford by source category for the Three Scenarios 2015.

| Year | Source | Low Development | | | Moderate Development | | | High Development | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | VOC | $NO_X$ | CO | VOC | $NO_X$ | CO | VOC | $NO_X$ | CO |
| 2015 | Heater/ Boiler | 0.08 | 0.89 | 1.35 | 0.09 | 1.03 | 1.56 | 0.11 | 1.19 | 1.80 |
| | Glycol Dehydration | 1.43 | 0.00 | 0.17 | 1.66 | 0.00 | 0.19 | 1.91 | 0.00 | 0.22 |
| | Amine Unit | 0.08 | 0.00 | 0.02 | 0.10 | 0.00 | 0.03 | 0.11 | 0.00 | 0.03 |
| | Compressor Engine | 4.04 | 21.46 | 29.54 | 4.67 | 24.81 | 34.15 | 5.39 | 28.66 | 39.45 |
| | Pumps | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 |
| | Gas Cooler Engine | 0.08 | 0.05 | 0.26 | 0.09 | 0.05 | 0.30 | 0.10 | 0.06 | 0.35 |
| | Crude Storage Tanks | 9.05 | 0.00 | 0.00 | 10.46 | 0.00 | 0.00 | 12.08 | 0.00 | 0.00 |
| | Produced Water Storage Tanks | 1.04 | 0.00 | 0.00 | 1.20 | 0.00 | 0.00 | 1.39 | 0.00 | 0.00 |
| | Condensate Tanks | 16.81 | 0.00 | 0.00 | 19.20 | 0.00 | 0.00 | 21.91 | 0.00 | 0.00 |
| | Oil Loading Facility | 0.27 | 0.00 | 0.00 | 0.31 | 0.00 | 0.00 | 0.36 | 0.00 | 0.00 |
| | Produced Water Loading Facility | 0.39 | 0.00 | 0.00 | 0.45 | 0.00 | 0.00 | 0.52 | 0.00 | 0.00 |
| | Condensate Loading | 0.21 | 0.00 | 0.00 | 0.25 | 0.00 | 0.00 | 0.28 | 0.00 | 0.00 |
| | Flare/ Combustor | 0.11 | 0.49 | 5.86 | 0.13 | 0.57 | 6.78 | 0.15 | 0.66 | 7.83 |
| | Fugitives | 1.80 | 0.00 | 0.00 | 2.08 | 0.00 | 0.00 | 2.41 | 0.00 | 0.00 |
| | Other | 1.29 | 0.78 | 1.22 | 1.50 | 0.90 | 1.41 | 1.73 | 1.05 | 1.63 |
| | Total | 36.69 | 23.67 | 38.42 | 42.18 | 27.36 | 44.42 | 48.47 | 31.61 | 51.31 |
| 2018 | Heater/ Boiler | 0.09 | 1.03 | 1.56 | 0.13 | 1.39 | 2.10 | 0.17 | 1.86 | 2.81 |
| | Glycol Dehydration | 1.66 | 0.00 | 0.19 | 2.23 | 0.00 | 0.26 | 2.99 | 0.00 | 0.35 |
| | Amine Unit | 0.10 | 0.00 | 0.03 | 0.13 | 0.00 | 0.04 | 0.18 | 0.00 | 0.05 |
| | Compressor Engine | 4.69 | 24.93 | 34.31 | 6.29 | 33.45 | 46.04 | 8.43 | 44.83 | 61.70 |
| | Pumps | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 |
| | Gas Cooler Engine | 0.09 | 0.05 | 0.31 | 0.12 | 0.07 | 0.41 | 0.16 | 0.10 | 0.55 |
| | Crude Storage Tanks | 10.51 | 0.00 | 0.00 | 14.10 | 0.00 | 0.00 | 18.90 | 0.00 | 0.00 |
| | Produced Water Storage Tanks | 1.21 | 0.00 | 0.00 | 1.62 | 0.00 | 0.00 | 2.18 | 0.00 | 0.00 |
| | Condensate Tanks | 16.92 | 0.00 | 0.00 | 19.46 | 0.00 | 0.00 | 22.36 | 0.00 | 0.00 |
| | Oil Loading Facility | 0.31 | 0.00 | 0.00 | 0.42 | 0.00 | 0.00 | 0.57 | 0.00 | 0.00 |
| | Produced Water Loading Facility | 0.45 | 0.00 | 0.00 | 0.60 | 0.00 | 0.00 | 0.81 | 0.00 | 0.00 |
| | Condensate Loading | 0.25 | 0.00 | 0.00 | 0.33 | 0.00 | 0.00 | 0.44 | 0.00 | 0.00 |
| | Flare/ Combustor | 0.13 | 0.57 | 6.81 | 0.17 | 0.77 | 9.13 | 0.23 | 1.03 | 12.24 |
| | Fugitives | 2.09 | 0.00 | 0.00 | 2.81 | 0.00 | 0.00 | 3.76 | 0.00 | 0.00 |
| | Other | 1.50 | 0.91 | 1.42 | 2.02 | 1.22 | 1.91 | 2.70 | 1.63 | 2.55 |
| | Total | 40.02 | 27.49 | 44.63 | 50.45 | 36.89 | 59.88 | 63.89 | 49.44 | 80.25 |

Figure 8-19: Ozone Season Projected $NO_X$ Emissions from Mid-Stream Sources in Eagle Ford for the Three Scenarios

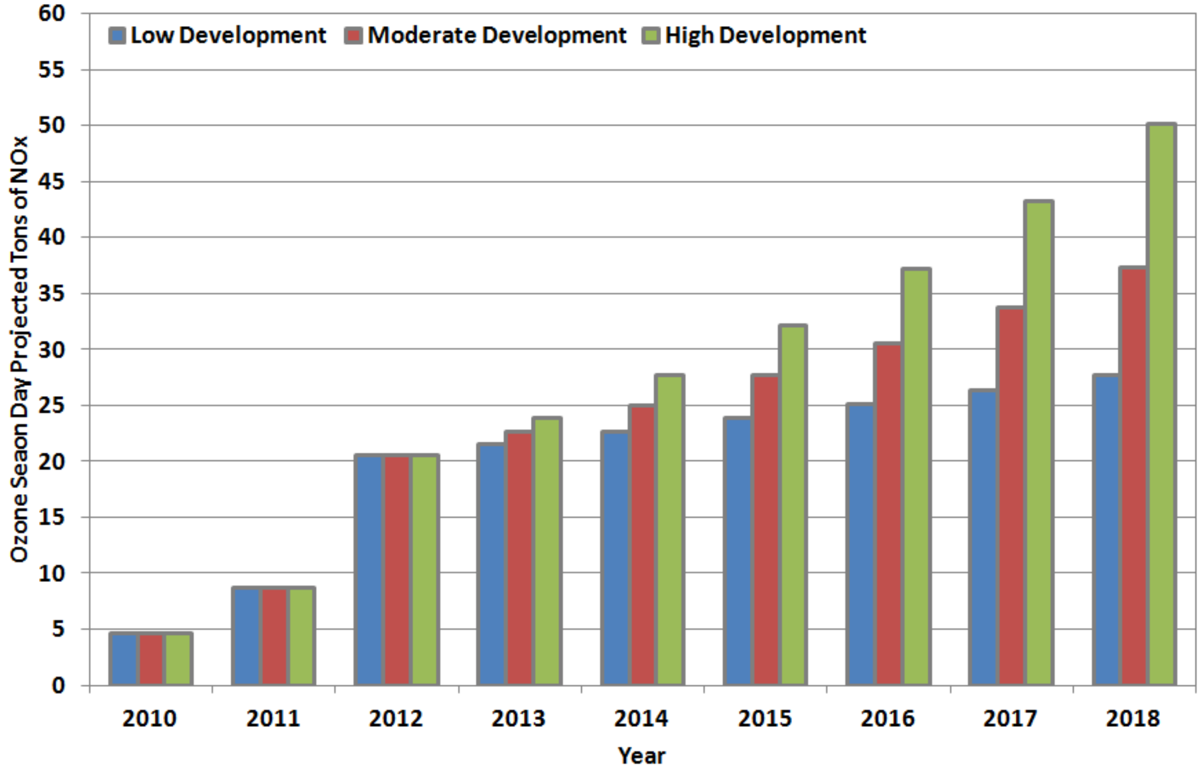
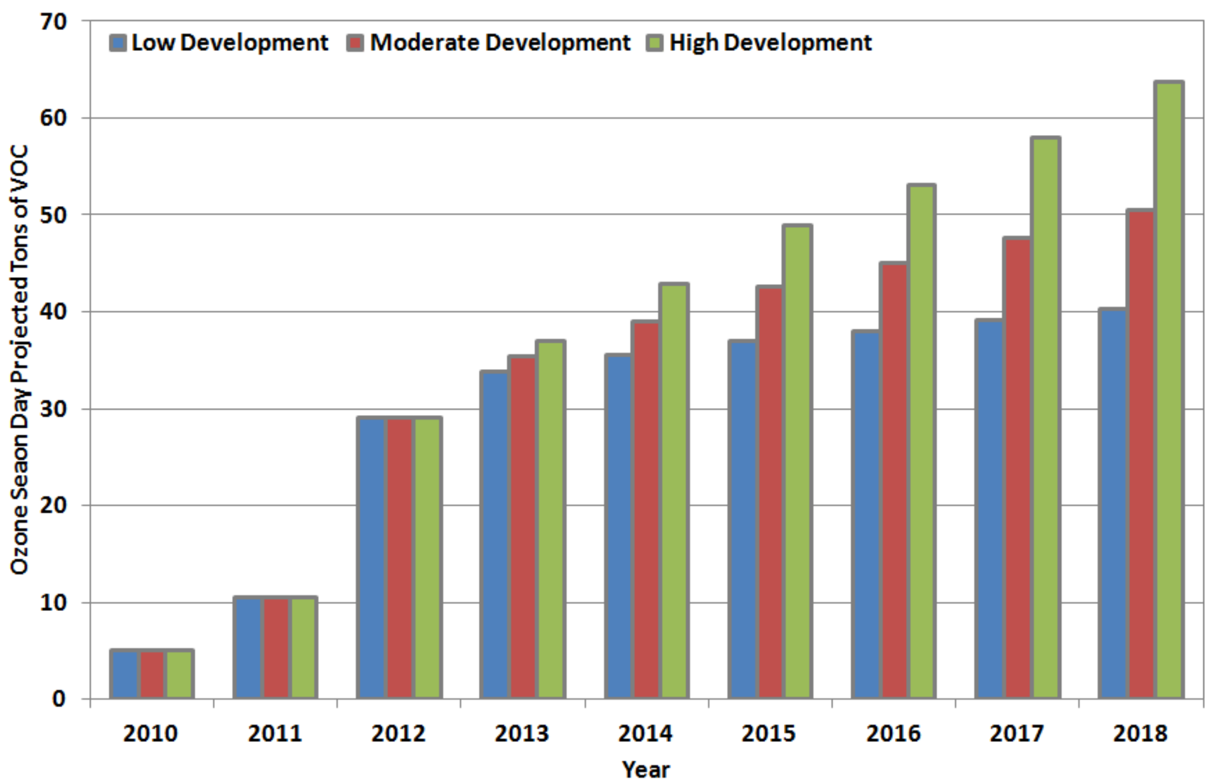



Figure 8-20: Ozone Season Projected VOC Emissions from Mid-Stream Sources in Eagle Ford for the Three Scenarios



# 9 SUMMARY

## 9.1 Emissions from the Eagle Ford

Production in the Eagle Ford emitted 66 tons of $NO_X$ and 101 tons of VOC per ozone season day in 2011 (Table 9-1). For the 2012 photochemical model projection year, emissions increase to 111 tons of $NO_X$ and 229 tons of VOC per ozone season day. $NO_X$ emissions increase slightly for the low development scenario in 2018 (113 tons per day). $NO_X$ emissions also increase under the 2018 moderate scenario (146 tons per day) and the high scenario (188 tons per day). By 2018, VOC emissions are expected to increase significantly to 338 tons per ozone season day under the low development scenario and to 872 tons per ozone season day under the high development scenario

Table 9-1: Emissions Summary for the Eagle Ford, 2011, 2012, 2015, and 2018.

| Year | Low Development Scenario | | | Moderate Development Scenario | | | High Development Scenario | | |
|---|---|---|---|---|---|---|---|---|---|
| | VOC | $NO_X$ | CO | VOC | $NO_X$ | CO | VOC | $NO_X$ | CO |
| 2011 | 101 | 66 | 50 | 101 | 66 | 50 | 101 | 66 | 50 |
| 2012 | 229 | 111 | 92 | 229 | 111 | 92 | 229 | 111 | 92 |
| 2015 | 347 | 108 | 113 | 417 | 121 | 130 | 512 | 140 | 154 |
| 2018 | 338 | 113 | 113 | 544 | 146 | 160 | 872 | 188 | 226 |

The majority of $NO_X$ emissions from oil and gas operations in the Eagle Ford in 2012 were emitted by drill rigs and well hydraulic pump engines (47% from Figure 9-1). By 2018, these sources are expected to account for only 9% of the $NO_X$ emissions from the Eagle Ford as equipment turnover replaces older engines with those that meet TIER4 standards. In contrast, compressors and mid-stream sources accounted for 39% of the $NO_X$ emissions in 2012, but are projected to increase to 77% of total $NO_X$ emissions under the 2018 moderate development scenario because of the significant increase in oil and gas production that's expected in the region (Figure 9-2). As shown in Figure 9-2 the majority of VOC emissions in 2018 are from storage tanks (47%) and loading loss (32%). Other significant sources of VOC emissions are midstream sources (7%), pneumatic devices (5%), and fugitives (4%). Table 9-1 provides a detailed breakdown of $NO_X$ and VOC emissions for each projection year scenario.

Figure 9-1: $NO_X$ Emissions by Source Category, Eagle Ford Moderate Scenario

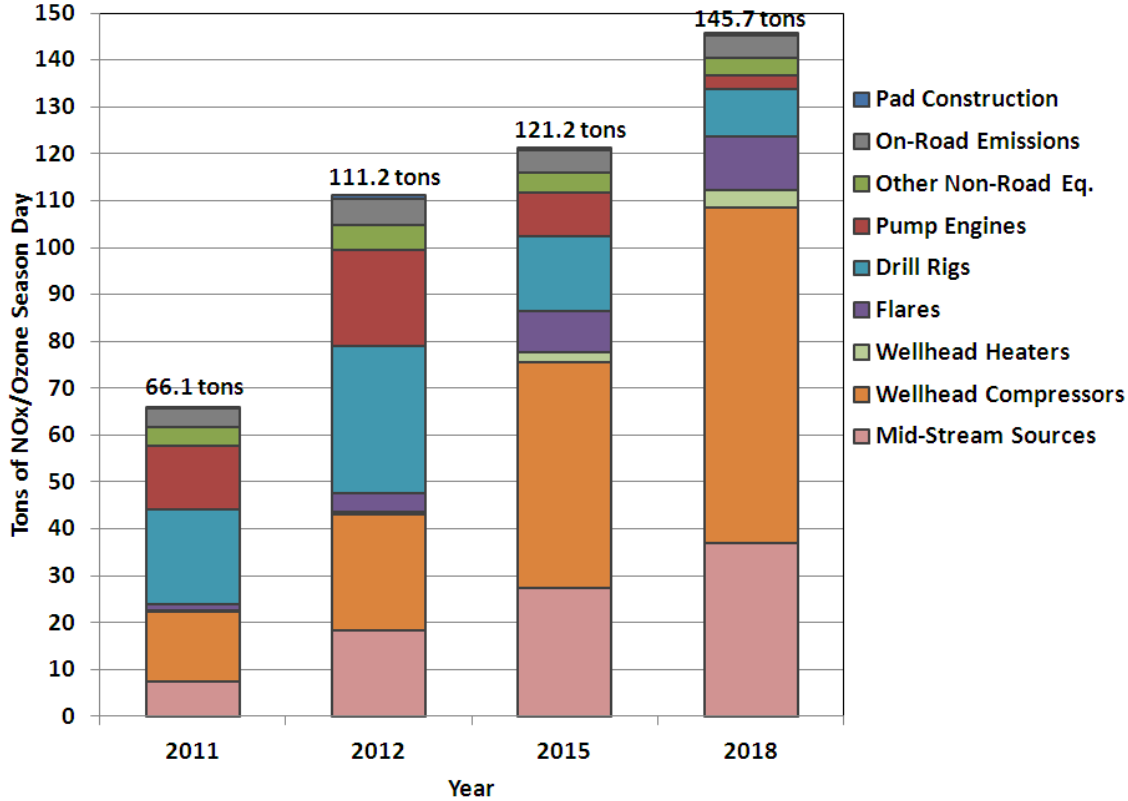



Figure 9-2: VOC Emissions by Source Category, Eagle Ford Moderate Scenario

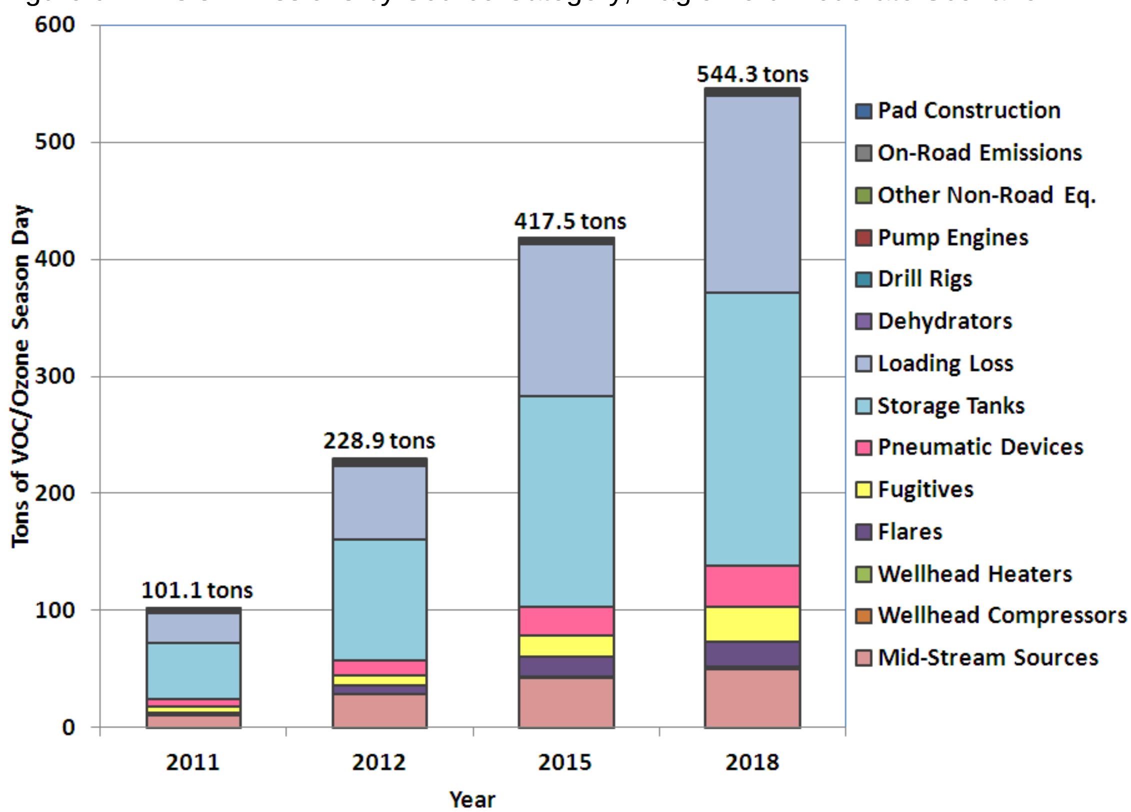
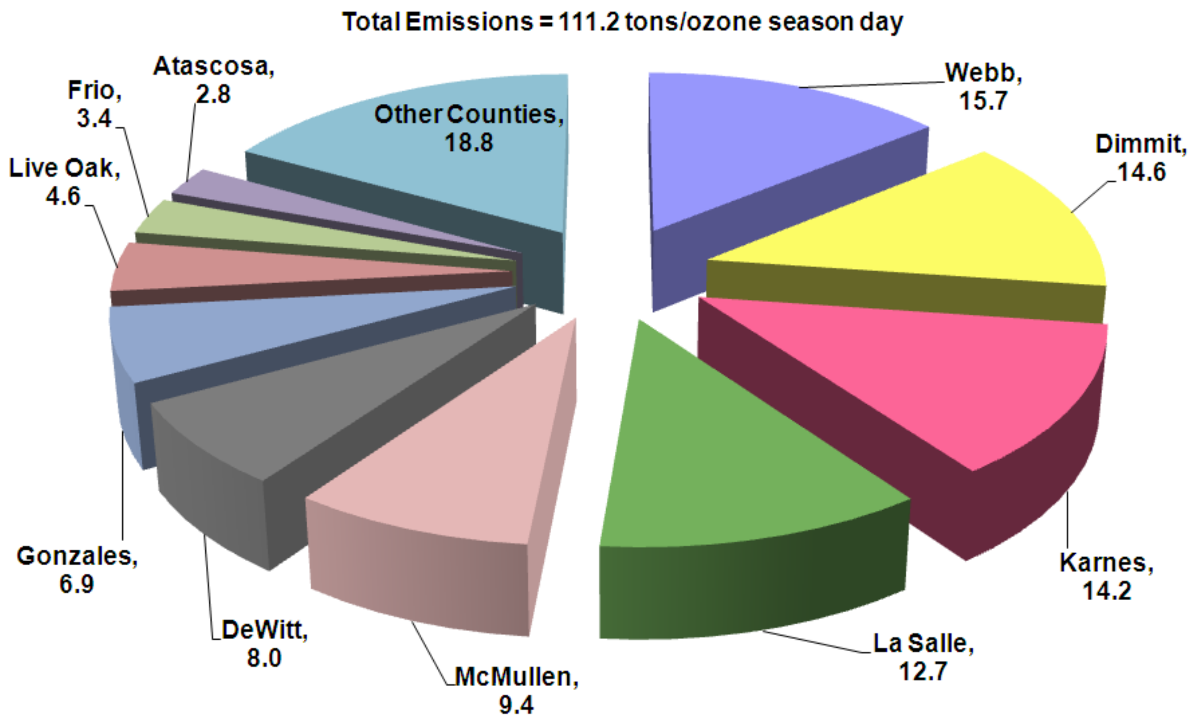


Table 9-2: Emissions by Source in the Eagle Ford, 2011, 2012, 2015, and 2018.

| Source | 2011 | | 2012 | | 2015 Low | | 2015 Moderate | | 2015 High | | 2018 Low | | 2018 Moderate | | 2018 High | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ |
| Seismic Trucks | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Pad Construction Non-Road | 0.04 | 0.49 | 0.06 | 0.70 | 0.04 | 0.39 | 0.05 | 0.46 | 0.06 | 0.59 | 0.03 | 0.21 | 0.05 | 0.33 | 0.06 | 0.47 |
| Pad Construction On-Road | 0.03 | 0.22 | 0.04 | 0.31 | 0.03 | 0.17 | 0.04 | 0.21 | 0.05 | 0.27 | 0.02 | 0.10 | 0.03 | 0.17 | 0.05 | 0.24 |
| Drill Rigs | 1.10 | 20.15 | 1.75 | 31.32 | 1.01 | 14.24 | 1.13 | 15.85 | 1.34 | 18.87 | 0.73 | 7.43 | 1.00 | 10.21 | 1.19 | 12.15 |
| Drilling Non-Road | 0.05 | 0.59 | 0.07 | 0.86 | 0.07 | 0.86 | 0.06 | 0.75 | 0.07 | 0.89 | 0.04 | 0.53 | 0.06 | 0.73 | 0.06 | 0.77 |
| Drilling On-Road | 0.08 | 0.62 | 0.11 | 0.86 | 0.08 | 0.50 | 0.10 | 0.59 | 0.12 | 0.77 | 0.05 | 0.30 | 0.08 | 0.49 | 0.12 | 0.69 |
| Pump Engines | 0.74 | 13.72 | 1.11 | 20.45 | 0.71 | 7.71 | 0.85 | 9.25 | 1.10 | 11.98 | 0.71 | 2.72 | 0.78 | 2.97 | 1.11 | 4.24 |
| Hydraulic Fract. Non-Road | 0.43 | 3.21 | 0.60 | 4.55 | 0.39 | 2.87 | 0.46 | 3.44 | 0.60 | 4.45 | 0.26 | 1.83 | 0.42 | 2.96 | 0.60 | 4.23 |
| Hydraulic Fract. On-Road | 0.35 | 2.82 | 0.47 | 3.95 | 0.34 | 2.35 | 0.41 | 2.81 | 0.53 | 3.64 | 0.22 | 1.47 | 0.35 | 2.38 | 0.50 | 3.39 |
| Completion Flares | 0.00 | 0.32 | 0.00 | 0.47 | 0.00 | 0.37 | 0.00 | 0.44 | 0.00 | 0.57 | 0.00 | 0.29 | 0.00 | 0.47 | 0.00 | 0.67 |
| Wellhead Compressors | 0.31 | 14.91 | 0.51 | 24.75 | 0.93 | 44.88 | 1.00 | 48.21 | 1.08 | 51.93 | 1.24 | 59.56 | 1.49 | 71.67 | 1.83 | 88.10 |
| Wellhead Heaters | 0.01 | 0.25 | 0.04 | 0.66 | 0.12 | 2.09 | 0.12 | 2.16 | 0.13 | 2.30 | 0.18 | 3.29 | 0.21 | 3.76 | 0.24 | 4.44 |
| Production Flares | 2.42 | 1.16 | 7.08 | 3.44 | 14.43 | 7.10 | 17.07 | 8.39 | 20.96 | 10.30 | 13.36 | 6.59 | 22.03 | 10.86 | 35.10 | 17.28 |
| Dehydrators | 0.85 | 0.00 | 1.57 | 0.00 | 1.40 | 0.00 | 1.77 | 0.00 | 2.24 | 0.00 | 0.92 | 0.00 | 1.70 | 0.00 | 3.06 | 0.00 |
| Storage Tanks | 48.02 | 0.00 | 103.24 | 0.00 | 144.68 | 0.00 | 180.17 | 0.00 | 227.69 | 0.00 | 129.48 | 0.00 | 233.69 | 0.00 | 406.25 | 0.00 |
| Fugitives | 4.33 | 0.00 | 7.84 | 0.00 | 16.51 | 0.00 | 17.52 | 0.00 | 18.78 | 0.00 | 23.21 | 0.00 | 27.44 | 0.00 | 33.27 | 0.00 |
| Loading Loss | 24.97 | 0.00 | 61.89 | 0.00 | 106.83 | 0.00 | 129.20 | 0.00 | 160.74 | 0.00 | 97.95 | 0.00 | 168.04 | 0.00 | 278.64 | 0.00 |
| Well Blowdowns | 0.42 | 0.00 | 0.70 | 0.00 | 1.27 | 0.00 | 1.37 | 0.00 | 1.47 | 0.00 | 1.69 | 0.00 | 2.03 | 0.00 | 2.50 | 0.00 |
| Pneumatic Devices | 6.80 | 0.00 | 13.07 | 0.00 | 21.77 | 0.00 | 23.77 | 0.00 | 26.06 | 0.00 | 28.11 | 0.00 | 34.47 | 0.00 | 43.34 | 0.00 |
| Production On-Road | 0.06 | 0.30 | 0.10 | 0.56 | 0.22 | 1.22 | 0.23 | 1.27 | 0.25 | 1.35 | 0.28 | 1.55 | 0.33 | 1.80 | 0.39 | 2.14 |
| Mid-Stream Sources | 10.09 | 7.33 | 28.61 | 18.32 | 36.61 | 23.67 | 42.16 | 27.36 | 48.43 | 31.61 | 39.80 | 27.49 | 50.13 | 36.89 | 63.35 | 49.44 |
| Total | 101.11 | 66.09 | 228.87 | 111.19 | 347.45 | 108.42 | 417.47 | 121.20 | 511.72 | 139.52 | 338.27 | 113.37 | 544.32 | 145.68 | 871.65 | 188.25 |

As show in Figure 9-3, over 51% of $NO_X$ emissions from oil and gas operations in the Eagle Ford were produced in only 4 counties: Webb, Dimmit, Karnes, and La Salle. Eagle Ford operations in Webb County emitted 15.7 tons of $NO_X$ per ozone season day, while operations in Dimmit emitted 14.6 tons, operations in Karnes emitted 14.2 tons, and operations in La Salle emitted 12.8 tons in 2012. Other counties that produce significant emissions from Eagle Ford oil and gas production included McMullen, DeWitt, Gonzales, Live Oak, Frio, and Atascosa counties.

Figure 9-3: $NO_X$ Emissions by County from Eagle Ford, 2012




Under the 2018 moderate development scenario, oil and natural gas operations are projected to emit, on an ozone season day, 26.4 tons of $NO_X$ in Webb County , 17.9 tons of $NO_X$ in Dimmit , 16.8 tons of $NO_X$ in La Salle, , and 15.1 tons of $NO_X$ in Karnes. A similar pattern occurs with VOC emissions under the 2018 moderate scenario in which ozone season daily emissions are expected to be: 84.6 tons in Webb County 71.5 tons in Dimmit , 66.1 tons in La Salle emitted, and 64.8 tons in Karnes (Table 9-3).

Table 9-3: Emissions by County in the Eagle Ford, 2011, 2012, 2015, and 2018.

| County | 2011 | | 2012 | | 2015 Low | | 2015 Moderate | | 2015 High | | 2018 Low | | 2018 Moderate | | 2018 High | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ | VOC | $NO_X$ |
| Atascosa | 2.05 | 1.72 | 5.22 | 2.78 | 8.37 | 2.51 | 9.98 | 2.80 | 12.19 | 3.25 | 8.16 | 2.49 | 12.98 | 3.23 | 20.48 | 4.20 |
| Bee | 0.89 | 0.43 | 1.44 | 0.70 | 1.82 | 0.89 | 2.18 | 1.01 | 2.61 | 1.15 | 1.86 | 1.04 | 2.74 | 1.35 | 4.13 | 1.78 |
| Brazos | 1.96 | 0.88 | 4.57 | 2.46 | 7.99 | 2.04 | 9.52 | 2.28 | 11.68 | 2.68 | 7.68 | 1.91 | 12.49 | 2.50 | 19.98 | 3.26 |
| Burleson | 1.06 | 0.43 | 2.73 | 1.51 | 5.03 | 1.17 | 5.94 | 1.31 | 7.26 | 1.56 | 4.85 | 1.03 | 7.76 | 1.38 | 12.21 | 1.82 |
| DeWitt | 9.82 | 6.27 | 20.10 | 7.98 | 26.80 | 9.10 | 32.61 | 10.14 | 40.08 | 11.46 | 26.28 | 10.36 | 42.46 | 13.07 | 68.95 | 16.69 |
| Dimmit | 10.41 | 7.13 | 28.67 | 14.58 | 46.16 | 13.58 | 55.02 | 15.25 | 67.14 | 17.72 | 45.07 | 13.75 | 71.48 | 17.91 | 112.60 | 23.38 |
| Fayette | 0.63 | 0.46 | 1.68 | 1.45 | 3.04 | 1.32 | 3.59 | 1.50 | 4.37 | 1.76 | 2.95 | 1.31 | 4.67 | 1.75 | 7.28 | 2.32 |
| Frio | 2.28 | 1.68 | 6.37 | 3.41 | 10.72 | 2.90 | 12.69 | 3.26 | 15.42 | 3.83 | 10.50 | 2.76 | 16.41 | 3.63 | 25.44 | 4.77 |
| Gonzales | 3.79 | 3.56 | 10.35 | 6.94 | 20.07 | 4.96 | 23.63 | 5.56 | 28.85 | 6.65 | 19.29 | 4.08 | 30.89 | 5.50 | 48.41 | 7.28 |
| Grimes | 1.24 | 0.64 | 2.43 | 1.21 | 3.55 | 1.29 | 4.28 | 1.45 | 5.26 | 1.66 | 3.46 | 1.42 | 5.59 | 1.82 | 9.02 | 2.36 |
| Houston | 0.29 | 0.17 | 0.62 | 0.37 | 1.07 | 0.33 | 1.27 | 0.37 | 1.55 | 0.44 | 1.04 | 0.32 | 1.66 | 0.43 | 2.62 | 0.56 |
| Karnes | 10.13 | 7.66 | 24.48 | 14.23 | 41.64 | 12.08 | 49.59 | 13.52 | 60.72 | 15.82 | 40.22 | 11.52 | 64.81 | 15.09 | 103.02 | 19.68 |
| La Salle | 12.24 | 8.07 | 28.39 | 12.74 | 42.19 | 12.50 | 50.74 | 13.95 | 62.16 | 16.01 | 41.20 | 13.16 | 66.06 | 16.82 | 105.64 | 21.64 |
| Lavaca | 0.77 | 0.61 | 1.48 | 1.29 | 2.26 | 1.44 | 2.67 | 1.64 | 3.23 | 1.90 | 2.25 | 1.59 | 3.42 | 2.10 | 5.20 | 2.79 |
| Lee | 0.69 | 0.32 | 1.67 | 0.86 | 2.93 | 0.69 | 3.49 | 0.77 | 4.29 | 0.90 | 2.81 | 0.63 | 4.59 | 0.82 | 7.38 | 1.06 |
| Leon | 2.53 | 1.74 | 4.62 | 2.29 | 6.28 | 2.63 | 7.63 | 2.96 | 9.39 | 3.36 | 6.13 | 2.98 | 9.96 | 3.82 | 16.21 | 4.93 |
| Live Oak | 5.36 | 3.14 | 11.17 | 4.64 | 14.88 | 5.24 | 18.05 | 5.85 | 22.11 | 6.63 | 14.67 | 5.92 | 23.40 | 7.51 | 37.59 | 9.63 |
| Madison | 0.81 | 0.56 | 2.13 | 1.31 | 3.86 | 1.07 | 4.57 | 1.20 | 5.60 | 1.42 | 3.71 | 0.98 | 5.98 | 1.30 | 9.48 | 1.72 |
| McMullen | 9.49 | 5.82 | 20.65 | 9.38 | 29.67 | 9.64 | 35.88 | 10.75 | 44.08 | 12.28 | 28.91 | 10.42 | 46.83 | 13.25 | 75.73 | 17.01 |
| Maverick | 1.37 | 0.65 | 2.83 | 1.28 | 4.21 | 1.36 | 5.05 | 1.53 | 6.18 | 1.75 | 4.13 | 1.48 | 6.56 | 1.90 | 10.41 | 2.47 |
| Milam | 0.07 | 0.05 | 0.16 | 0.25 | 0.27 | 0.17 | 0.32 | 0.17 | 0.40 | 0.17 | 0.26 | 0.13 | 0.42 | 0.14 | 0.67 | 0.15 |
| Washington | 0.63 | 0.41 | 1.11 | 0.66 | 1.52 | 0.78 | 1.83 | 0.88 | 2.24 | 1.00 | 1.50 | 0.88 | 2.38 | 1.15 | 3.80 | 1.50 |
| Webb | 20.52 | 12.08 | 40.06 | 15.68 | 52.60 | 18.27 | 64.45 | 20.30 | 79.70 | 22.84 | 51.14 | 21.05 | 84.55 | 26.36 | 139.95 | 33.49 |
| Wilson | 0.65 | 0.66 | 2.43 | 1.41 | 4.52 | 1.02 | 5.30 | 1.15 | 6.42 | 1.38 | 4.41 | 0.85 | 6.85 | 1.15 | 10.47 | 1.53 |
| Zavala | 1.43 | 0.93 | 3.53 | 1.78 | 6.02 | 1.44 | 7.17 | 1.60 | 8.79 | 1.88 | 5.81 | 1.33 | 9.39 | 1.72 | 14.98 | 2.23 |
| Total | 101.11 | 66.09 | 228.87 | 111.19 | 347.45 | 108.42 | 417.47 | 121.20 | 511.72 | 139.52 | 338.27 | 113.37 | 544.32 | 145.68 | 871.65 | 188.25 |

### 9.2 Spatial Allocation of Emissions

Emissions were geo-coded based on the locations of wells in each county. Development of the input files for photochemical model emission processing was 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 with these parameters, the results can be used for any future TCEQ photochemical model.

The locations of producing oil and gas wells are displayed in Figure 9-4[500], while Figure 9-5 contains the locations of Eagle Ford disposal wells drilled in 2011[501]. The largest concentrations of oil wells are located in northern Karnes County and the far northern section of Live Oak County and the 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 the 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 were geo-coded to the location of all permitted Eagle Ford wells. Emissions from natural gas production were geo-coded to the location of natural gas wells in the Eagle Ford, while emissions from oil production were geo-coded to the location of oil wells. Emissions from condensate production were geo-coded to natural gas wells located in the condensate window. Emissions from pad construction and drilling of disposal wells were allocated to the location of disposal wells.

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[500] Railroad Commission of Texas, 2012. "Digital Map Information". Austin, Texas.
[501] *Ibid*.

Figure 9-4: Locations of Wells Drilled in the Eagle Ford Shale Play, 2012

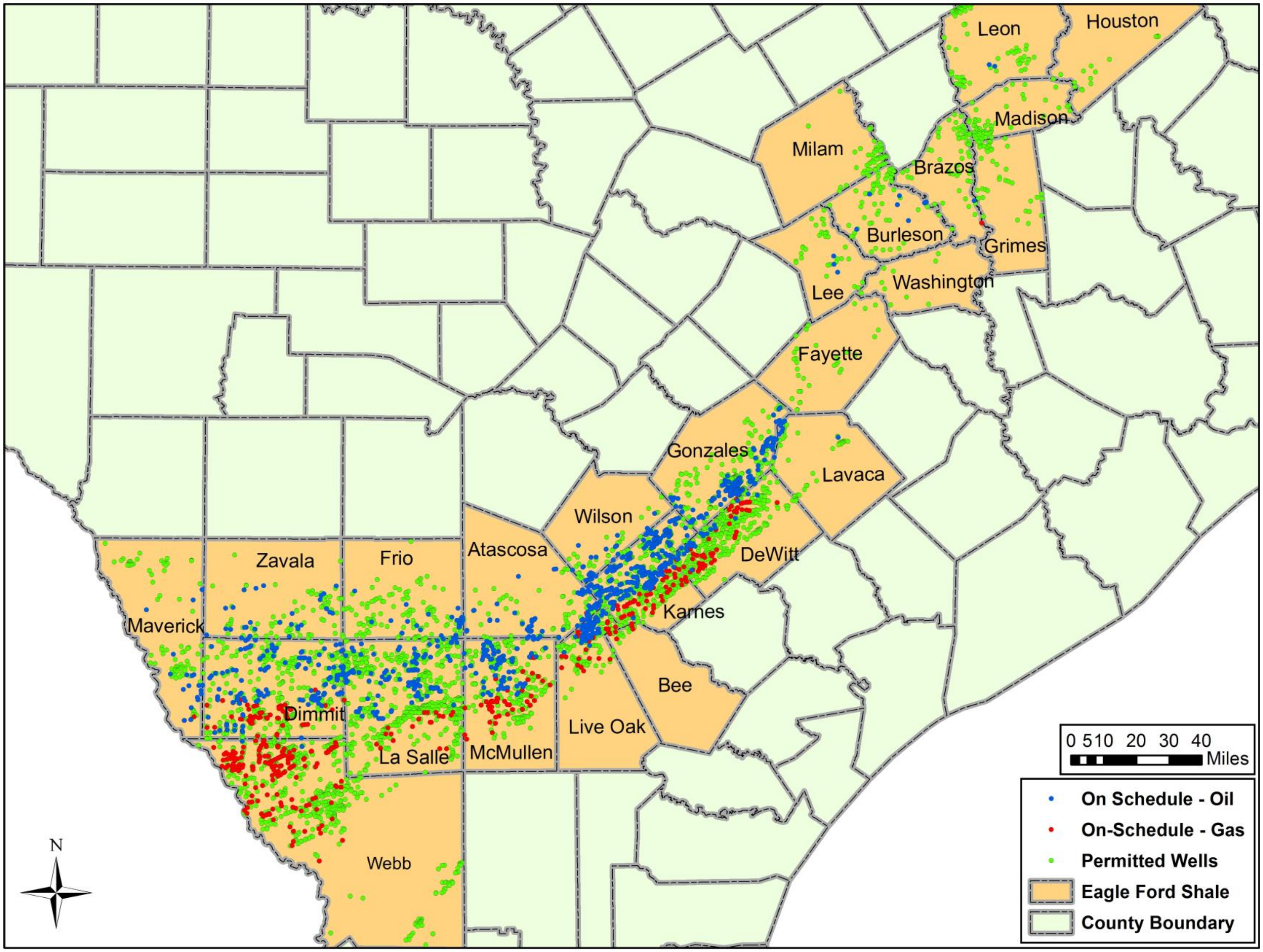
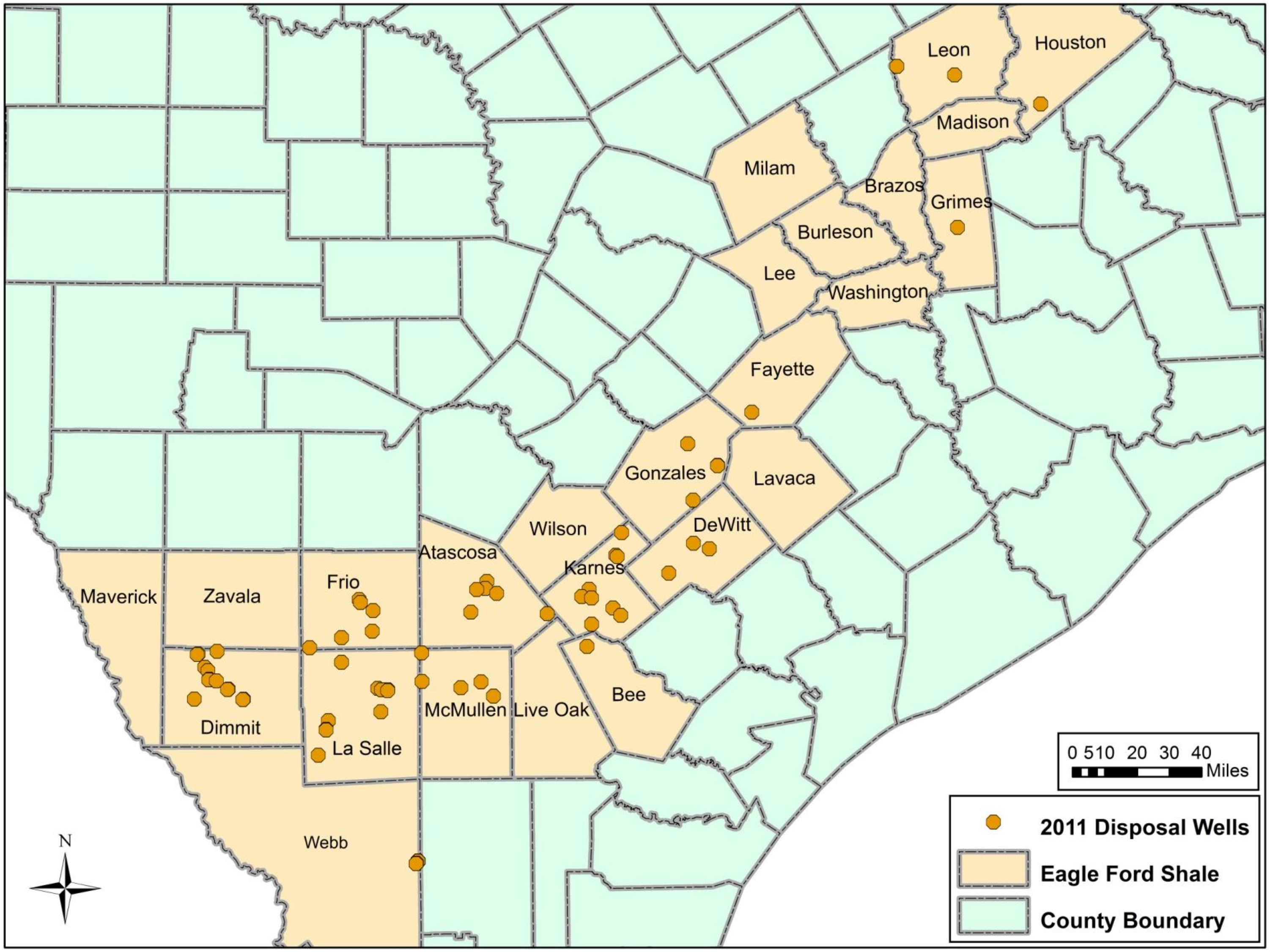


Figure 9-5: Locations of 2011 Disposal Wells in the Eagle Ford Shale Play



# 10 FUTURE IMPROVEMENTS

Several improvements to the Eagle Ford emission inventory were not completed in time for this report. Future Eagle Ford emission inventories will include the updates listed below.

## 10.1 Drill Rig and Hydraulic Pump Survey

In the summer of 2013, AACOG conducted surveys of drill rigs and well pad hydraulic pump engines from oil and gas activity in the Eagle Ford. The surveys requested 2012 data on number of engines, hours of use, fuel consumption, controls on engines, total annual depth that drills rigs drilled, average percentage of time ancillary equipment was operated at drill sites, and the replacement rate of engines to meet Tier 4 standards. As part of the survey process, AACOG requested the drill rig and well pad hydraulic pump engines inventory from each company. The survey forms on the following pages represented collaboration between AACOG and oil and gas industry representatives from the Eagle Ford emission inventory working group.

A total of 9 companies responded to the survey including most of the major operators in the Eagle Ford. These companies reported on 94 drill rigs that represented 48 percent of the drill rigs operating in the Eagle Ford. For the questions about well pad hydraulic pump engines, the survey results included data on 340 engines that hydraulically fractured 1,289 wells in the Eagle Ford in 2012 (37 percent of the wells drilled).

There was not enough time to incorporate these survey results in the Eagle Ford emission inventory, but when the Eagle Ford emission inventory is updated during the 2014-2015 biennium, the survey results will be included in the emission inventory calculations.

## 10.2 Projection of Mid-Stream Sources

The projections of mid-stream sources for 2018 will be revised in future Eagle Ford emission inventories with updated equipment counts from TCEQ's permit database.[502] Current projections are based on all permitted mid-stream sources between 2008 and April 2012. Since this inventory was completed, new mid-stream sources have been issued permits to start operating in the Eagle Ford. Mid-stream sources continue to expand rapidly in the Eagle Ford and may represent a larger emission source then what is reported in this emission inventory.

## 10.3 Stack Parameters of Mid Stream Sources

Stack parameters used in the June 2006 photochemical modeling episode for mid-stream sources were based on similar facilities in TCEQ's point source emission inventory.[503] Eagle Ford mid-stream sources were split into crude petroleum &and natural gas, natural gas liquids, natural gas transmission, and petroleum bulk stations and terminals. For each type, average stack height, stack diameter, temperature, and velocity were calculated from TCEQ's existing point source database. Future Eagle Ford emissions inventories will have separate parameters for each process at an individual facility instead of average stack parameters for all processes at the facility.

[502] 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.
[503] TCEQ, Nov. 28, 2012. "afs.osd_2006_STARS_extract_for_CB06_cat_so2_lcpRPO.v2.gz". Available online: ftp://amdaftp.tceq.texas.gov/pub/Rider8/ei/basecase/point/AFS/. Accessed 03/08/2013.

**Eagle Ford - Drill Rigs Survey, 2012**

Thank you for participating in our survey! Your responses are important for our study and for assessing drill rig emissions in the Eagle Ford. Data is needed for all fields in the Eagle Ford for 2012.

1. Company Name: ____________________
2. How many wells did you drill in the Eagle Ford (2012)? ____________________

**Combustion Engine Driven Electric Drill Rigs**

3. How many Electric Drill Rigs do you operate in the Eagle Ford (2012)? ____________________
4. What are the total annual hours these Electric Drill Rigs operated in the Eagle Ford (2012)?

   ____________________

5. What is the total cumulative depth drilled by all Electric Drill Rigs for all wells (end-to-end) in the Eagle Ford (2012)? ____________________
6. What controls are on each Electric Drill Rigs (How many are Tier 1, Tier 2, Tier 4, SNCR, etc.)?

   ____________________

   ____________________

7. What type of fuel (Diesel, CNG, etc.) and how many gallons of each fuel type did you use for the Electric Drill Rigs, 2012?

   ____________________

8. What is the average percentage of time did ancillary equipment (cement pumps, excavators, cranes, etc.) operated at each well site during drilling? ____________________
9. We are interesting in the implementation of Tier 4 engines by 2015 and 2018. Please estimate what percentage of your drill rig generators will be replaced with Tier 4 engines per year (i.e. turnover rate of engines)?

   ____________________

**Mechanical Drill Rigs**

10. How many Mechanical Drill Rigs do you operate in the Eagle Ford (2012)? ____________________
11. What are the total annual hours these Mechanical Drill Rigs operated in the Eagle Ford (2012)?

    ____________________

12. What is the total cumulative depth drilled by all Mechanical Drill Rigs for all wells (end-to-end) in the Eagle Ford (2012)? ____________________
13. What controls are on each Mechanical Drill Rigs (How many are Tier 1, Tier 2, Tier 4, SNCR, etc.)?

    ____________________

    ____________________

14. What type of fuel (Diesel, CNG, etc.) and how many gallons of each type of fuel did you use for the Mechanical Drill Rigs, 2012?

    ____________________

15. How many, horsepower, engine model year, make and model of the generators or engines on each Electric or Mechanical Drill Rig (Please attached additional paper or electronic database if needed)?

| Electric or Mechanical and Operator | Number of Engines | Horsepower of Each Engine | Engines Model Year | Engine Make and Models |
|---|---|---|---|---|
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Please return completed survey to:
AACOG – Attn: Steven Smeltzer
8700 Tesoro Dr., Suite 700,
San Antonio, TX 78217
Phone: 210-362-5266 – Fax 210-225-5937
ssmeltzer@aacog.com

**Eagle Ford – Well Pad Hydraulic Pump Engine Survey, 2012**

Thank you for participating in our survey! Your responses will be important for our study and for assessing well pad hydraulic pump engines emissions in the Eagle Ford. Data is needed for all fields in the Eagle Ford in 2012.

1. Company Name: ______
2. How many well pad Hydraulic Pumps do you operate in the Eagle Ford? ______
3. What are the total annual hours these Hydraulic Pumps operated in the Eagle Ford (2012)?
4. ______
5. How many wells did you hydraulic fractured in the Eagle Ford (2012)?
6. ______
7. What controls are on each well pad Hydraulic Pump Engine (How many are Tier 1, Tier 2, Tier 4, SNCR, etc.)?
8. ______
9. ______
10. What type of fuel (Diesel, CNG, etc.) and how many gallons of each fuel type did you use for the well pad Hydraulic Pump Engines, 2012?
11. ______
12. What is the average percentage of time did ancillary equipment (blender trucks, forklifts, bulldozers, small generators, etc.) operated at each well site during hydraulic fracturing?
13. ______
14. We are interesting in the implementation of Tier 4 engines by 2015 and 2018. Please estimate what percentage of your well pad hydraulic pump engines will be replaced with Tier 4 engines per year (i.e. turnover rate of engines)?

    ______

16. What are the horsepower, model year, make, and model of the well pad Hydraulic Pump Engines (Please attached additional paper or electronic database if needed)?

| Hydraulic Pump Engine and Operator | Horsepower of Engine | Engine Model Year | Make and Model of Engine |
|---|---|---|---|
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Please return completed survey to:
AACOG – Attn: Steven Smeltzer
8700 Tesoro Dr., Suite 700,
San Antonio, TX 78217
Phone: 210-362-5266 – Fax 210-225-5937
ssmeltzer@aacog.com

## 10.4 TCEQ's Pneumatic Survey

As part of TCEQ's ongoing efforts to improve the area source oil and gas emissions inventory, the TCEQ requested "data associated with pneumatic devices operating at active gas well sites outside of the 23-county Barnett Shale area for calendar year 2011."[504] TCEQ requested "information regarding the total component count of pneumatic devices categorized according to type and bleed rate. This data will be used to evaluate volatile organic compounds (VOC) emissions estimates from pneumatic devices on the county-level."[505] TCEQ categorized component count of pneumatic devices according to type and bleed rate.[506]

The current methodology to calculate emissions from pneumatic devices are based on ERG's Texas emission inventory for oil and gas. The results of TCEQ's Pneumatic Survey were not available in time for the Eagle Ford emission inventory and are not included. When the data become available from TCEQ, future Eagle Ford emissions inventories will be updated with the results from the survey.

## 10.5 TxDOT On-Road Traffic Counts

TxDOT collected short term traffic count data for 2012 in districts that are being impacted by oil, gas, and wind energy expansion activities.[507] Traffic count data was collected for 26 sites in the Eagle Ford from the TxDOT districts of Corpus, Laredo, Pharr, San Antonio, and Yoakum. Most of the 15 minute traffic counts were collected over one or two days. The data collected included data counts by vehicle classification for each traffic lane. By using this data, future inventories will account for temporal profiles collected by TXDOT for traffic in the Eagle Ford for each vehicle classification.

## 10.6 Barnett Shale Special Inventory Final Results

TCEQ conducted a two-phase ozone precursor emission survey of Barnett Shale operations. 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."[508]

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 draft survey results were used to calculate emissions from production sources for this emission inventory. Although the draft results account for a 99 percent reporting level, future Eagle Ford emission inventory calculations will be updated based on information that reflects the final results from the Barnett Shale special inventory.

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[504] TCEQ. "Area Source Emissions: Statewide Pneumatic Devices Survey". Austin, Texas. Available online: http://www.tceq.texas.gov/airquality/areasource/ASEI.html. Accessed 10/22/2013.
[505] *Ibid*.
[506] Keith Sheedy, P.E. Technical Advisor, Office of Air , TCEQ. "Statewide Update 2012". Austin, Texas. p. 31. Available online: www.tceq.texas.gov/assets/public/permitting/air/info/statewide-update.pptx. Accessed: 10/22/2013.
[507] Lorri Pavliska, Texas Department of Transportation, SAT District. San Antonio, Texas.
[508] *Ibid*.

## 10.7 Updated Spatial Allocation of Emissions

Pad construction, drilling operations, and hydraulic fracturing emissions were geo-coded to the location of all permitted Eagle Ford wells. Emissions from natural gas production were geo-coded to the location of natural gas wells in the Eagle Ford, while emissions from oil production were geo-coded to the location of oil wells. Emissions from condensate production were geo-coded to natural gas wells located in the condensate window.[509] Future improvements can include updating the spatial allocation as new wells are permitted by the Railroad Commission of Texas.

## 10.8 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.[510] The construction of larger midstream sources, such as production facilities, can take up even more land area and involve significant amounts of heavy equipment.

Figure 10-1 shows an aerial image of the construction of a mid-stream facility in Karnes County. In this image, there are 2 dozers, 1 scraper, 3 graders, 4 tractors, and 4 rollers for a site that is 35.8 acres.[511] Little data was available on construction of mid-stream sources when this emission inventory was completed. As new data becomes available, these sources could be included in future updates.

Figure 10-1: Midstream Construction Aerial Imagery


Karnes County - 28.7532°, -98.0134°, April 20, 2012

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[509] Railroad Commission of Texas, 2012. "Digital Map Information". Austin, Texas.

[510] 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.

[511] "Google Earth". Available online: http://www.google.com/earth/index.html. Accessed 07/23/2012.

## 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[512] | 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 |

[512] Patterson-UTI Drilling Company. "Rigs". Available online: http://patdrilling.com/rigs. Accessed: 04/01/2012.

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 539 | Electric | | | | 3 | 1,000 | Diesel | | | | | | |
| Lantern Drilling[513] | 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[514] | 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[515] | 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[516] | 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[517] | 1 | Electric | | | | 2 | 1,215 | Diesel | | | | | | |
| | 2 | Electric | | | | 2 | 1,215 | Diesel | | | | | | |
| | 4 | Electric | | | | 3 | 1,500 | Diesel | | | | | | |
| | 7 | Electric | | | | 3 | 1,500 | Diesel | | | | | | |

[513] Lantern Drilling, Rigs. Available online: http://lanterndrilling.com/index.cfm/ID/2/Rigs/. Accessed: 04/01/2012.
[514] 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.
[515] Ensign Energy Service Inc. “Ensign RigFinder”, Available online: http://www.ensignenergy.com/_layouts/ensign.rigfinder/rigfinder.aspx. Accessed: 2/8/2012.
[516] Unison Drilling Inc. “Rig List”. Available online: http://www.unisondrilling.com/riglist.html. Accessed: 04/09/2012.
[517] Pioneer Drilling Company. “Rig Fleet”. Available online: http://www.pioneerdrlg.com/rig-fleet.aspx?id=1. Accessed: 04/09/2012.

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 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[518] | 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.[519] | 1 | Electric | | | | 3 | 1,500 | Diesel | | | | | | |
| | 2 | Electric | | | | 3 | 1,500 | Diesel | | | | | | |
| | 4 | Electric | | | | 4 | 1,500 | Diesel | | | | | | |
| | 5 | Electric | | | | 4 | 1,500 | Diesel | | | | | | |

[518] Trinidad Drilling. "Rig Fleet". Available online: http://www.trinidaddrilling.com/Services/RigFleet.aspx. Accessed: 04/10/2012.
[519] 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.

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | Electric | | | | 4 | 760 | Diesel | | | | | | |
| Justiss Oil Co.[520] | 56 | Mechanical | 2 | 550 | Diesel | 2 | 515 | Diesel | 2 | 1,000 | Diesel | | | |
| Keen Drilling[521] | 22 | Electric | | | | 3 | 1,500 | Diesel | | | | | | |
| Scan Drilling[522] | 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[523] | 439 | Electric | | | | 2 | 630 | Diesel | | | | | | |
| Unit[524] | 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[525] | Rig-5 | Mechanical | | | | 2 | 540 | Diesel | 1 | 1,215 | Diesel | | | |

[520] Justiss Oil Company, Inc. “Drilling Rigs”. Available online: http://justissoil.com/MyWebs5/drilling_rigs.htm. Accessed: 04/01/2012
[521] KeenEnergy Services. “Rigs”. Available online: http://keenenergyservices.com.dnnmax.com/Rigs.aspx. Accessed: 04/10/2012
[522] Scandrill Inc. “Rig Specifications”. Available online: http://www.scandrill.com/rig-specifications.htm. Accessed: 04/13/2012.
[523] Savana Energy Service Corp. “Savana US Drilling Rigs”. Available online: http://www.savannaenergy.com/default.asp?id=104. Accessed: 04/13/2012
[524] Unit Corporation, Golf Coast Division. Available online: http://www.unitcorp.com/houston.html. Accessed: 04/13/2012.
[525] 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 | 1.01 | 1.39 | 12.99 |
| | | | 2015 | 0.80 | 1.10 | 10.91 |
| | | | 2018 | 0.63 | 0.87 | 9.32 |
| | | Diesel | 2011 | 0.47 | 3.91 | 3.09 |
| | | | 2015 | 0.32 | 2.90 | 2.39 |
| | | | 2018 | 0.22 | 2.24 | 2.03 |
| | Light Commercial Trucks | Gasoline | 2011 | 1.06 | 1.52 | 14.17 |
| | | | 2015 | 0.84 | 1.23 | 12.11 |
| | | | 2018 | 0.66 | 1.00 | 10.54 |
| | | Diesel | 2011 | 0.61 | 4.68 | 3.81 |
| | | | 2015 | 0.44 | 3.65 | 3.02 |
| | | | 2018 | 0.32 | 2.84 | 2.48 |
| | Average Light Duty Vehicle | Gasoline and Diesel | 2011 | 1.00 | 1.55 | 12.85 |
| | | | 2015 | 0.79 | 1.23 | 10.83 |
| | | | 2018 | 0.62 | 0.97 | 9.29 |
| Heavy Duty Vehicle (35 mph) | Combination Short Haul Trucks | Diesel | 2011 | 0.52 | 8.43 | 2.64 |
| | | | 2015 | 0.37 | 5.65 | 1.84 |
| | | | 2018 | 0.26 | 3.73 | 1.26 |

## APPENDIX C: UPDATED TexN INPUTS

| Category | SCC | SCC Description | Mim HP | Average HP | Population Estimate[526] |
|---|---|---|---|---|---|
| Exploration | 2270002051 | Diesel Off-highway Trucks | 100 | 160 | 0 |
| | | | 175 | 244 | 0 |
| | | | 300 | 400 | 100 |
| | | | 600 | 688 | 0 |
| | | | 750 | 868 | 0 |
| | | | 1000 | 1047 | 0 |
| | | | 1200 | 1787 | 0 |
| | | | 2000 | 2424 | 0 |
| Pad Construction | 2270002018 | Diesel Scrapers | 50 | 66 | 0 |
| | | | 100 | 161 | 0 |
| | | | 175 | 247 | 0 |
| | | | 300 | 363 | 0 |
| | | | 600 | 700 | 100 |
| | | | 750 | 760 | 0 |
| | 2270002048 | Diesel Graders | 50 | 60 | 0 |
| | | | 75 | 84 | 0 |
| | | | 100 | 141 | 0 |
| | | | 175 | 250 | 100 |
| | | | 300 | 342 | 0 |
| | | | 600 | 750 | 0 |
| | 2270002069 | Diesel Crawler Tractor/Dozers | 50 | 66 | 0 |
| | | | 75 | 99 | 100 |
| | | | 100 | 136 | 0 |
| | | | 175 | 223 | 0 |
| | | | 300 | 493 | 0 |
| | | | 600 | 707 | 0 |
| | | | 750 | 923 | 0 |
| Drilling | 2270006010 | Diesel Cement Pumps | 1 | 3 | 0 |
| | | | 3 | 5 | 0 |
| | | | 6 | 8 | 0 |
| | | | 11 | 14 | 0 |
| | | | 16 | 22 | 0 |
| | | | 25 | 34 | 0 |
| | | | 40 | 45 | 0 |
| | | | 50 | 62 | 0 |
| | | | 75 | 86 | 0 |
| | | | 100 | 132 | 0 |
| | | | 175 | 243 | 0 |
| | | | 300 | 400 | 100 |
| | | | 600 | 687 | 0 |
| | | | 750 | 860 | 0 |
| | | | 1000 | 1200 | 0 |
| | | | 1200 | 1633 | 0 |
| | | | 2000 | 2373 | 0 |
| Hydraulic Fracturing | 2270010010 | Diesel Blender Truck | 6 | 9 | 0 |
| | | | 16 | 20 | 0 |
| | | | 25 | 37 | 0 |
| | | | 40 | 44 | 0 |
| | | | 50 | 63 | 0 |
| | | | 75 | 88 | 0 |

[526] Note: All equipment was based on a total population of 100 to calculate emission factors

| | | | | | |
|---|---|---|---|---|---|
| | | | 100 | 137 | 0 |
| | | | 175 | 255 | 0 |
| | | | 300 | 402 | 0 |
| | | | 600 | 634 | 100 |
| | | | 750 | 887 | 0 |
| | | | 1000 | 1110 | 0 |
| | | | 1200 | 1492 | 0 |
| | | | 2000 | 2268 | 0 |
| | 2270006005 | Diesel Generators | 3 | 5 | 0 |
| | | | 6 | 8 | 0 |
| | | | 11 | 14 | 0 |
| | | | 16 | 21 | 0 |
| | | | 25 | 33 | 0 |
| | | | 40 | 45 | 0 |
| | | | 50 | 60 | 0 |
| | | | 75 | 87 | 100 |
| | | | 100 | 136 | 0 |
| | | | 175 | 238 | 0 |
| | | | 300 | 419 | 0 |
| | | | 600 | 682 | 0 |
| | | | 750 | 887 | 0 |
| | | | 1000 | 1112 | 0 |
| | | | 1200 | 1655 | 0 |
| | | | 2000 | 2401 | 0 |
| | 2270006010 | Diesel Water Pumps | 1 | 3 | 0 |
| | | | 3 | 5 | 0 |
| | | | 6 | 8 | 0 |
| | | | 11 | 14 | 0 |
| | | | 16 | 22 | 0 |
| | | | 25 | 34 | 0 |
| | | | 40 | 45 | 0 |
| | | | 50 | 62 | 0 |
| | | | 75 | 86 | 0 |
| | | | 100 | 132 | 0 |
| | | | 175 | 243 | 0 |
| | | | 300 | 384 | 100 |
| | | | 600 | 687 | 0 |
| | | | 750 | 860 | 0 |
| | | | 1000 | 1200 | 0 |
| | | | 1200 | 1633 | 0 |
| | | | 2000 | 2373 | 0 |
| | 2270003020 | Diesel Forklifts | 11 | 15 | 0 |
| | | | 16 | 25 | 0 |
| | | | 25 | 35 | 0 |
| | | | 40 | 47 | 0 |
| | | | 50 | 62 | 0 |
| | | | 75 | 85 | 0 |
| | | | 100 | 110 | 100 |
| | | | 175 | 220 | 0 |
| | | | 300 | 354 | 0 |
| | 2270002045 | Diesel Cranes (Large) | 25 | 39 | 0 |
| | | | 40 | 42 | 0 |
| | | | 50 | 64 | 0 |
| | | | 75 | 88 | 0 |
| | | | 100 | 145 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| | | | 175 | 238 | 0 |
| | | | 300 | 517 | 100 |
| | | | 600 | 669 | 0 |
| | | | 750 | 883 | 0 |
| | | | 1000 | 1071 | 0 |
| | 2270010010 | Sand Kings | 6 | 9 | 0 |
| | | | 16 | 20 | 0 |
| | | | 25 | 37 | 0 |
| | | | 40 | 44 | 0 |
| | | | 50 | 63 | 0 |
| | | | 75 | 78 | 100 |
| | | | 100 | 137 | 0 |
| | | | 175 | 255 | 0 |
| | | | 300 | 402 | 0 |
| | | | 600 | 634 | 0 |
| | | | 750 | 887 | 0 |
| | | | 1000 | 1110 | 0 |
| | | | 1200 | 1492 | 0 |
| | | | 2000 | 2268 | 0 |
| | 2270010010 | Blow Out Control System | 6 | 9.2 | 50 |
| | | | 16 | 16 | 50 |
| | | | 25 | 37 | 0 |
| | | | 40 | 44 | 0 |
| | | | 50 | 63 | 0 |
| | | | 75 | 88 | 0 |
| | | | 100 | 137 | 0 |
| | | | 175 | 255 | 0 |
| | | | 300 | 402 | 0 |
| | | | 600 | 634 | 0 |
| | | | 750 | 887 | 0 |
| | | | 1000 | 1110 | 0 |
| | | | 1200 | 1492 | 0 |
| | | | 2000 | 2268 | 0 |
| | 2270010010 | High Pressure Water Cannon | 6 | 9 | 0 |
| | | | 16 | 20 | 0 |
| | | | 25 | 37 | 0 |
| | | | 40 | 44 | 0 |
| | | | 50 | 63 | 0 |
| | | | 75 | 88 | 0 |
| | | | 100 | 137 | 0 |
| | | | 175 | 200 | 100 |
| | | | 300 | 402 | 0 |
| | | | 600 | 634 | 0 |
| | | | 750 | 887 | 0 |
| | | | 1000 | 1110 | 0 |
| | | | 1200 | 1492 | 0 |
| | | | 2000 | 2268 | 0 |

## APPENDIX D: 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 | Heirholzer 1 | No | Pop | 2 | 1 | - | 1 | - | - | - | 1 | 5 | - | 1 | 1 | 1 | 1 | - | 13 |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | EF LLC | Production Facility | | 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 |
| 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 | Doering Ranch | No | Pop | 1 | 1 | - | 3 | - | - | - | - | 1 | - | - | - | 1 | 1 | - | 8 |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Petroleum Management, LLC | Production Facility | | 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 |
| 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 & | Pickens B 2H | No | Pop | 2 | - | - | 1 | - | - | - | 4 | 10 | - | 1 | 1 | 1 | 1 | - | 21 |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Gas Corporation | Production Facility | | 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 |
| 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 | George 1 | No | Pop | 2 | 1 | - | 1 | - | - | - | - | - | - | 1 | 1 | 1 | 1 | - | 7 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Company | Production Facility | | 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 |
| 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 | Rancho Grande 1 | No | Pop | 2 | 1 | 1 | 1 | - | - | - | 1 | 5 | - | 1 | 1 | 1 | 1 | - | 13 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | EF LLC | Production Facility | | 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 |
| 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 | Casares | No | Pop | 2 | - | - | - | - | - | 5 | 1 | - | 1 | 1 | - | 1 | 1 | - | 11 |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Resources, Inc. | Production Facility | | 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 |
| 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 |

## APPENDIX E: NUMBER OF WELLS AND PRODUCTION IN THE EAGLE FORD

Number of Natural Gas Wells Drilled and Calculated Production in the Eagle Ford, 2008-2012

| County | FIPS Code | Natural Gas Wells Drilled | | | | | Calculated Natural Gas Production by County (BCF) | | | | | Calculated Condensate Production by County (bbl) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2008 | 2009 | 2010 | 2011 | 2012 | 2008 | 2009 | 2010 | 2011 | 2012 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Atascosa | 48013 | 0 | 1 | 11 | 21 | 12 | - | 0.1 | 1.6 | 6.6 | 12.2 | - | 0.0 | 0.1 | 0.5 | 1.0 |
| Bee | 48025 | 3 | 1 | 4 | 3 | 4 | 0.0 | 0.3 | 1.1 | 2.2 | 4.1 | - | 0.0 | 0.1 | 0.2 | 0.3 |
| Brazos | 48041 | 4 | 7 | 13 | 2 | 10 | 0.0 | 0.8 | 3.2 | 5.2 | 9.6 | 0.0 | 0.0 | 0.2 | 0.4 | 0.8 |
| Burleson | 48051 | 2 | 1 | 5 | 1 | 3 | 0.0 | 0.2 | 1.1 | 1.8 | 3.3 | 0.1 | 0.0 | 0.1 | 0.1 | 0.3 |
| DeWitt | 48123 | 27 | 12 | 29 | 156 | 84 | 0.1 | 2.8 | 9.1 | 45.0 | 82.8 | - | 0.1 | 0.6 | 3.4 | 6.6 |
| Dimmit | 48127 | 3 | 14 | 41 | 118 | 66 | 0.0 | 1.2 | 7.8 | 35.4 | 65.1 | 0.1 | 0.1 | 0.5 | 2.7 | 5.2 |
| Fayette | 48149 | 2 | 0 | 2 | 1 | 2 | 0.0 | 0.1 | 0.5 | 1.0 | 1.8 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 |
| Frio | 48163 | 1 | 3 | 11 | 11 | 10 | 0.0 | 0.3 | 2.0 | 5.2 | 9.6 | 0.0 | 0.0 | 0.1 | 0.4 | 0.8 |
| Gonzales | 48177 | 1 | 2 | 10 | 6 | 7 | 0.0 | 0.2 | 1.7 | 3.8 | 7.0 | - | 0.0 | 0.1 | 0.3 | 0.6 |
| Grimes | 48185 | 4 | 8 | 7 | 4 | 9 | 0.0 | 0.9 | 2.5 | 4.6 | 8.5 | 0.0 | 0.0 | 0.2 | 0.4 | 0.7 |
| Houston | 48225 | 0 | 1 | 0 | 2 | 1 | - | 0.1 | 0.1 | 0.6 | 1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| Karnes | 48255 | 10 | 15 | 51 | 64 | 53 | 0.1 | 1.8 | 10.2 | 28.1 | 51.8 | - | 0.1 | 0.6 | 2.2 | 4.1 |
| La Salle | 48283 | 1 | 20 | 73 | 149 | 91 | 0.0 | 1.5 | 12.6 | 48.8 | 89.8 | - | 0.1 | 0.8 | 3.7 | 7.2 |
| Lavaca | 48285 | 6 | 0 | 1 | 0 | 3 | 0.0 | 0.4 | 0.9 | 1.4 | 2.6 | - | 0.0 | 0.1 | 0.1 | 0.2 |
| Lee | 48287 | 0 | 0 | 9 | 1 | 4 | - | - | 1.2 | 2.0 | 3.7 | 0.0 | - | 0.1 | 0.2 | 0.3 |
| Leon | 48289 | 6 | 7 | 20 | 18 | 19 | 0.0 | 0.9 | 4.4 | 10.2 | 18.9 | - | 0.0 | 0.3 | 0.8 | 1.5 |
| Live Oak | 48297 | 4 | 5 | 30 | 78 | 44 | 0.0 | 0.6 | 5.2 | 23.5 | 43.3 | - | 0.0 | 0.3 | 1.8 | 3.5 |
| Madison | 48313 | 4 | 1 | 2 | 2 | 3 | 0.0 | 0.4 | 0.9 | 1.8 | 3.3 | 0.0 | 0.0 | 0.1 | 0.1 | 0.3 |
| McMullen | 48311 | 2 | 3 | 17 | 1 | 9 | 0.0 | 0.4 | 3.0 | 4.6 | 8.5 | 0.1 | 0.0 | 0.2 | 0.4 | 0.7 |
| Maverick | 48323 | 2 | 15 | 71 | 115 | 76 | 0.0 | 1.2 | 11.8 | 40.8 | 75.0 | 0.0 | 0.1 | 0.7 | 3.1 | 6.0 |
| Milam | 48331 | 0 | 0 | 1 | 0 | 0 | - | - | 0.1 | 0.2 | 0.4 | - | - | 0.0 | 0.0 | 0.0 |
| Washington | 48477 | 2 | 1 | 5 | 3 | 4 | 0.0 | 0.2 | 1.1 | 2.2 | 4.1 | - | 0.0 | 0.1 | 0.2 | 0.3 |
| Webb | 48479 | 24 | 33 | 135 | 313 | 189 | 0.1 | 4.1 | 25.8 | 101.5 | 186.7 | 0.0 | 0.2 | 1.6 | 7.8 | 14.9 |
| Wilson | 48493 | 0 | 0 | 2 | 0 | 1 | - | - | 0.3 | 0.4 | 0.7 | - | - | 0.0 | 0.0 | 0.1 |
| Zavala | 48507 | 1 | 0 | 8 | 12 | 8 | 0.0 | 0.1 | 1.2 | 4.2 | 7.8 | 0.0 | 0.0 | 0.1 | 0.3 | 0.6 |
| Total | | 109 | 150 | 558 | 1,081 | 712 | 0.5 | 18.5 | 109.6 | 381.3 | 701.7 | 0.1 | 0.8 | 6.9 | 29.2 | 56.0 |

Number of Oil Wells Drilled and Calculated Production in the Eagle Ford, 2008-2012

| County | FIPS Code | Oil Wells Drilled | | | | | Calculated Oil Production by County (MMbbl) | | | | | Calculated Casinghead Production by County (BCF) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2008 | 2009 | 2010 | 2011 | 2012 | 2008 | 2009 | 2010 | 2011 | 2012 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Atascosa | 48013 | 0 | 0 | 4 | 47 | 81 | - | - | 0.0 | 1.4 | 4.2 | - | - | 0.1 | 2.0 | 6.1 |
| Bee | 48025 | 0 | 0 | 1 | 0 | 2 | - | - | 0.0 | 0.0 | 0.1 | - | - | 0.0 | 0.0 | 0.1 |
| Brazos | 48041 | 7 | 15 | 19 | 21 | 99 | 0.0 | 0.0 | 0.5 | 1.7 | 5.2 | 0.0 | 0.1 | 0.7 | 2.4 | 7.4 |
| Burleson | 48051 | 13 | 3 | 15 | 12 | 69 | 0.0 | 0.0 | 0.4 | 1.2 | 3.6 | 0.0 | 0.0 | 0.5 | 1.7 | 5.1 |
| DeWitt | 48123 | 0 | 0 | 10 | 50 | 96 | - | - | 0.1 | 1.6 | 5.0 | - | - | 0.2 | 2.3 | 7.1 |
| Dimmit | 48127 | 12 | 9 | 52 | 209 | 450 | 0.0 | 0.0 | 0.8 | 7.6 | 23.5 | 0.0 | 0.1 | 1.2 | 10.8 | 33.5 |
| Fayette | 48149 | 3 | 3 | 6 | 13 | 40 | 0.0 | 0.0 | 0.1 | 0.7 | 2.1 | 0.0 | 0.0 | 0.2 | 1.0 | 3.0 |
| Frio | 48163 | 4 | 4 | 11 | 55 | 118 | 0.0 | 0.0 | 0.2 | 2.0 | 6.2 | 0.0 | 0.0 | 0.3 | 2.8 | 8.8 |
| Gonzales | 48177 | 0 | 0 | 29 | 160 | 302 | - | - | 0.3 | 5.1 | 15.7 | - | - | 0.5 | 7.3 | 22.4 |
| Grimes | 48185 | 1 | 1 | 6 | 7 | 24 | 0.0 | 0.0 | 0.1 | 0.4 | 1.2 | 0.0 | 0.0 | 0.1 | 0.6 | 1.8 |
| Houston | 48225 | 6 | 0 | 1 | 1 | 13 | 0.0 | 0.0 | 0.1 | 0.2 | 0.7 | 0.0 | 0.0 | 0.1 | 0.3 | 0.9 |
| Karnes | 48255 | 0 | 1 | 53 | 247 | 480 | - | 0.0 | 0.6 | 8.1 | 25.1 | - | 0.0 | 0.9 | 11.6 | 35.7 |
| La Salle | 48283 | 0 | 1 | 37 | 155 | 308 | - | 0.0 | 0.4 | 5.2 | 16.1 | - | 0.0 | 0.6 | 7.4 | 22.9 |
| Lavaca | 48285 | 0 | 0 | 0 | 11 | 18 | - | - | - | 0.3 | 0.9 | - | - | - | 0.4 | 1.3 |
| Lee | 48287 | 8 | 3 | 1 | 11 | 37 | 0.0 | 0.0 | 0.1 | 0.6 | 1.9 | 0.0 | 0.0 | 0.2 | 0.9 | 2.7 |
| Leon | 48289 | 0 | 0 | 4 | 13 | 27 | - | - | 0.0 | 0.5 | 1.4 | - | - | 0.1 | 0.7 | 2.0 |
| Live Oak | 48297 | 0 | 2 | 16 | 14 | 51 | - | 0.0 | 0.2 | 0.9 | 2.7 | - | 0.0 | 0.3 | 1.2 | 3.8 |
| Madison | 48313 | 5 | 2 | 5 | 20 | 51 | 0.0 | 0.0 | 0.1 | 0.9 | 2.7 | 0.0 | 0.0 | 0.2 | 1.2 | 3.8 |
| McMullen | 48311 | 22 | 7 | 7 | 10 | 73 | 0.0 | 0.1 | 0.4 | 1.2 | 3.8 | 0.0 | 0.1 | 0.6 | 1.8 | 5.5 |
| Maverick | 48323 | 1 | 2 | 6 | 80 | 142 | 0.0 | 0.0 | 0.1 | 2.4 | 7.4 | 0.0 | 0.0 | 0.1 | 3.4 | 10.6 |
| Milam | 48331 | 0 | 0 | 0 | 2 | 3 | - | - | - | 0.1 | 0.2 | - | - | - | 0.1 | 0.2 |
| Washington | 48477 | 0 | 3 | 0 | 1 | 6 | - | 0.0 | 0.0 | 0.1 | 0.3 | - | 0.0 | 0.0 | 0.2 | 0.5 |
| Webb | 48479 | 1 | 2 | 46 | 56 | 168 | 0.0 | 0.0 | 0.6 | 2.8 | 8.7 | 0.0 | 0.0 | 0.8 | 4.0 | 12.5 |
| Wilson | 48493 | 0 | 0 | 4 | 35 | 62 | - | - | 0.0 | 1.1 | 3.2 | - | - | 0.1 | 1.5 | 4.6 |
| Zavala | 48507 | 6 | 5 | 4 | 29 | 70 | 0.0 | 0.0 | 0.2 | 1.2 | 3.7 | 0.0 | 0.0 | 0.2 | 1.7 | 5.2 |
| Total | | 89 | 63 | 337 | 1,259 | 2,789 | 0.1 | 0.3 | 5.5 | 47.2 | 145.6 | 0.2 | 0.4 | 7.9 | 67.2 | 207.5 |

# 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 | 2,435,107 | 3,424,369 | 1,863,951 | 23,299,389 | 2,435,107 | 3,424,369 | 1,863,951 | 23,299,389 | 2,435,107 | 3,424,369 | 1,863,951 | 23,299,389 |
| | 2nd | 3,432,534 | 4,827,001 | 2,627,432 | 32,842,894 | 3,432,534 | 4,827,001 | 2,627,432 | 32,842,894 | 3,432,534 | 4,827,001 | 2,627,432 | 32,842,894 |
| | 3rd | 3,826,871 | 5,381,537 | 2,929,276 | 36,615,951 | 3,826,871 | 5,381,537 | 2,929,276 | 36,615,951 | 3,826,871 | 5,381,537 | 2,929,276 | 36,615,951 |
| | 4th | 1,604,914 | 2,256,910 | 1,228,481 | 15,356,007 | 1,604,914 | 2,256,910 | 1,228,481 | 15,356,007 | 1,604,914 | 2,256,910 | 1,228,481 | 15,356,007 |
| | 5th | 787,400 | 1,107,281 | 602,715 | 7,533,932 | 787,400 | 1,107,281 | 602,715 | 7,533,932 | 787,400 | 1,107,281 | 602,715 | 7,533,932 |
| | 6th | 446,691 | 628,159 | 341,919 | 4,273,990 | 446,691 | 628,159 | 341,919 | 4,273,990 | 446,691 | 628,159 | 341,919 | 4,273,990 |
| | 7th | 278,936 | 392,253 | 213,511 | 2,668,889 | 278,936 | 392,253 | 213,511 | 2,668,889 | 278,936 | 392,253 | 213,511 | 2,668,889 |
| | 8th | 138,379 | 194,596 | 105,922 | 1,324,029 | 138,379 | 194,596 | 105,922 | 1,324,029 | 138,379 | 194,596 | 105,922 | 1,324,029 |
| | 9th | 119,490 | 168,032 | 91,463 | 1,143,291 | 119,490 | 168,032 | 91,463 | 1,143,291 | 119,490 | 168,032 | 91,463 | 1,143,291 |
| | 10th | 105,185 | 147,916 | 80,514 | 1,006,423 | 105,185 | 147,916 | 80,514 | 1,006,423 | 105,185 | 147,916 | 80,514 | 1,006,423 |
| | 11th | 93,965 | 132,138 | 71,925 | 899,065 | 93,965 | 132,138 | 71,925 | 899,065 | 93,965 | 132,138 | 71,925 | 899,065 |
| 2009 Wells | 1st | 1,723,727 | 2,423,991 | 2,565,070 | 32,063,379 | 1,723,727 | 2,423,991 | 2,565,070 | 32,063,379 | 1,723,727 | 2,423,991 | 2,565,070 | 32,063,379 |
| | 2nd | 2,429,772 | 3,416,866 | 3,615,731 | 45,196,643 | 2,429,772 | 3,416,866 | 3,615,731 | 45,196,643 | 2,429,772 | 3,416,866 | 3,615,731 | 45,196,643 |
| | 3rd | 2,708,909 | 3,809,403 | 4,031,114 | 50,388,923 | 2,708,909 | 3,809,403 | 4,031,114 | 50,388,923 | 2,708,909 | 3,809,403 | 4,031,114 | 50,388,923 |
| | 4th | 1,136,063 | 1,597,588 | 1,690,570 | 21,132,120 | 1,136,063 | 1,597,588 | 1,690,570 | 21,132,120 | 1,136,063 | 1,597,588 | 1,690,570 | 21,132,120 |
| | 5th | 557,373 | 783,805 | 829,424 | 10,367,797 | 557,373 | 783,805 | 829,424 | 10,367,797 | 557,373 | 783,805 | 829,424 | 10,367,797 |
| | 6th | 316,197 | 444,652 | 470,531 | 5,881,638 | 316,197 | 444,652 | 470,531 | 5,881,638 | 316,197 | 444,652 | 470,531 | 5,881,638 |
| | 7th | 197,449 | 277,662 | 293,823 | 3,672,782 | 197,449 | 277,662 | 293,823 | 3,672,782 | 197,449 | 277,662 | 293,823 | 3,672,782 |
| | 8th | 97,954 | 137,748 | 145,765 | 1,822,058 | 97,954 | 137,748 | 145,765 | 1,822,058 | 97,954 | 137,748 | 145,765 | 1,822,058 |
| | 9th | 84,583 | 118,944 | 125,867 | 1,573,337 | 84,583 | 118,944 | 125,867 | 1,573,337 | 84,583 | 118,944 | 125,867 | 1,573,337 |
| | 10th | 74,457 | 104,705 | 110,799 | 1,384,986 | 74,457 | 104,705 | 110,799 | 1,384,986 | 74,457 | 104,705 | 110,799 | 1,384,986 |
| 2010 Wells | 1st | 9,220,573 | 12,966,431 | 9,542,062 | 119,275,771 | 9,220,573 | 12,966,431 | 9,542,062 | 119,275,771 | 9,220,573 | 12,966,431 | 9,542,062 | 119,275,771 |
| | 2nd | 12,997,349 | 18,277,522 | 13,450,521 | 168,131,513 | 12,997,349 | 18,277,522 | 13,450,521 | 168,131,513 | 12,997,349 | 18,277,522 | 13,450,521 | 168,131,513 |
| | 3rd | 14,490,511 | 20,377,281 | 14,995,744 | 187,446,794 | 14,490,511 | 20,377,281 | 14,995,744 | 187,446,794 | 14,490,511 | 20,377,281 | 14,995,744 | 187,446,794 |
| | 4th | 6,077,034 | 8,545,829 | 6,288,919 | 78,611,487 | 6,077,034 | 8,545,829 | 6,288,919 | 78,611,487 | 6,077,034 | 8,545,829 | 6,288,919 | 78,611,487 |
| | 5th | 2,981,502 | 4,192,737 | 3,085,456 | 38,568,203 | 2,981,502 | 4,192,737 | 3,085,456 | 38,568,203 | 2,981,502 | 4,192,737 | 3,085,456 | 38,568,203 |
| | 6th | 1,691,402 | 2,378,534 | 1,750,375 | 21,879,692 | 1,691,402 | 2,378,534 | 1,750,375 | 21,879,692 | 1,691,402 | 2,378,534 | 1,750,375 | 21,879,692 |
| | 7th | 1,056,194 | 1,485,273 | 1,093,020 | 13,662,750 | 1,056,194 | 1,485,273 | 1,093,020 | 13,662,750 | 1,056,194 | 1,485,273 | 1,093,020 | 13,662,750 |
| | 8th | 523,975 | 736,840 | 542,244 | 6,778,056 | 523,975 | 736,840 | 542,244 | 6,778,056 | 523,975 | 736,840 | 542,244 | 6,778,056 |
| | 9th | 452,450 | 636,257 | 468,225 | 5,852,813 | 452,450 | 636,257 | 468,225 | 5,852,813 | 452,450 | 636,257 | 468,225 | 5,852,813 |

| 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 | 34,447,185 | 48,441,354 | 18,485,607 | 231,070,087 | 34,447,185 | 48,441,354 | 18,485,607 | 231,070,087 | 34,447,185 | 48,441,354 | 18,485,607 | 231,070,087 |
| | 2nd | 48,556,863 | 68,283,089 | 26,057,371 | 325,717,142 | 48,556,863 | 68,283,089 | 26,057,371 | 325,717,142 | 48,556,863 | 68,283,089 | 26,057,371 | 325,717,142 |
| | 3rd | 54,135,172 | 76,127,585 | 29,050,894 | 363,136,172 | 54,135,172 | 76,127,585 | 29,050,894 | 363,136,172 | 54,135,172 | 76,127,585 | 29,050,894 | 363,136,172 |
| | 4th | 22,703,223 | 31,926,407 | 12,183,372 | 152,292,145 | 22,703,223 | 31,926,407 | 12,183,372 | 152,292,145 | 22,703,223 | 31,926,407 | 12,183,372 | 152,292,145 |
| | 5th | 11,138,608 | 15,663,667 | 5,977,380 | 74,717,254 | 11,138,608 | 15,663,667 | 5,977,380 | 74,717,254 | 11,138,608 | 15,663,667 | 5,977,380 | 74,717,254 |
| | 6th | 6,318,918 | 8,885,978 | 3,390,960 | 42,387,002 | 6,318,918 | 8,885,978 | 3,390,960 | 42,387,002 | 6,318,918 | 8,885,978 | 3,390,960 | 42,387,002 |
| | 7th | 3,945,842 | 5,548,840 | 2,117,481 | 26,468,518 | 3,945,842 | 5,548,840 | 2,117,481 | 26,468,518 | 3,945,842 | 5,548,840 | 2,117,481 | 26,468,518 |
| | 8th | 1,957,522 | 2,752,765 | 1,050,477 | 13,130,965 | 1,957,522 | 2,752,765 | 1,050,477 | 13,130,965 | 1,957,522 | 2,752,765 | 1,050,477 | 13,130,965 |
| 2012 Wells | 1st | 76,309,133 | 107,309,718 | 12,784,311 | 144,584,465 | 80,124,590 | 112,675,204 | 13,423,526 | 151,813,689 | 83,940,046 | 118,040,690 | 14,062,742 | 159,042,912 |
| | 2nd | 107,565,600 | 151,264,125 | 18,020,806 | 203,806,730 | 112,943,880 | 158,827,332 | 18,921,846 | 213,997,066 | 118,322,160 | 166,390,538 | 19,822,886 | 224,187,403 |
| | 3rd | 119,922,950 | 168,641,648 | 20,091,071 | 227,220,451 | 125,919,097 | 177,073,730 | 21,095,625 | 238,581,473 | 131,915,245 | 185,505,813 | 22,100,179 | 249,942,496 |
| | 4th | 50,293,319 | 70,724,980 | 8,425,799 | 95,291,774 | 52,807,985 | 74,261,228 | 8,847,089 | 100,056,362 | 55,322,651 | 77,797,477 | 9,268,379 | 104,820,951 |
| | 5th | 24,674,803 | 34,698,942 | 4,133,848 | 46,751,851 | 25,908,543 | 36,433,889 | 4,340,540 | 49,089,443 | 27,142,283 | 38,168,836 | 4,547,233 | 51,427,036 |
| | 6th | 13,997,984 | 19,684,665 | 2,345,127 | 26,522,264 | 14,697,883 | 20,668,898 | 2,462,383 | 27,848,378 | 15,397,782 | 21,653,131 | 2,579,639 | 29,174,491 |
| | 7th | 8,741,026 | 12,292,068 | 1,464,412 | 16,561,800 | 9,178,077 | 12,906,671 | 1,537,632 | 17,389,890 | 9,615,129 | 13,521,275 | 1,610,853 | 18,217,980 |
| 2013 Wells | 1st | 63,228,340 | 88,914,853 | 12,053,779 | 123,277,281 | 69,509,395 | 97,747,587 | 14,732,396 | 150,672,232 | 75,782,855 | 106,569,640 | 17,678,875 | 180,806,679 |
| | 2nd | 89,126,872 | 125,334,664 | 16,991,045 | 173,772,054 | 97,980,668 | 137,785,315 | 20,766,833 | 212,388,066 | 106,823,757 | 150,220,908 | 24,920,200 | 254,865,679 |
| | 3rd | 99,365,944 | 139,733,359 | 18,943,010 | 193,735,332 | 109,236,882 | 153,614,365 | 23,152,568 | 236,787,627 | 119,095,882 | 167,478,584 | 27,783,082 | 284,145,153 |
| | 4th | 41,672,116 | 58,601,413 | 7,944,325 | 81,248,775 | 45,811,793 | 64,422,834 | 9,709,730 | 99,304,059 | 49,946,463 | 70,237,213 | 11,651,676 | 119,164,870 |
| | 5th | 20,445,087 | 28,750,903 | 3,897,628 | 39,862,104 | 22,476,086 | 31,606,996 | 4,763,768 | 48,720,350 | 24,504,629 | 34,459,635 | 5,716,521 | 58,464,420 |
| | 6th | 11,598,471 | 16,310,350 | 2,211,119 | 22,613,720 | 12,750,655 | 17,930,608 | 2,702,479 | 27,638,991 | 13,901,444 | 19,548,906 | 3,242,975 | 33,166,790 |
| 2014 Wells | 1st | 63,336,805 | 89,067,383 | 11,341,510 | 104,785,689 | 77,398,568 | 108,841,737 | 16,102,144 | 148,769,805 | 97,937,973 | 137,725,275 | 22,024,932 | 203,491,220 |
| | 2nd | 89,279,766 | 125,549,670 | 15,987,029 | 147,706,246 | 109,101,272 | 153,423,664 | 22,697,634 | 209,706,398 | 138,053,684 | 194,137,993 | 31,046,415 | 286,841,882 |
| | 3rd | 99,536,402 | 139,973,065 | 17,823,651 | 164,675,032 | 121,635,042 | 171,049,278 | 25,305,183 | 233,797,885 | 153,913,564 | 216,440,950 | 34,613,089 | 319,794,846 |
| | 4th | 41,743,603 | 58,701,942 | 7,474,887 | 69,061,459 | 51,011,337 | 71,734,692 | 10,612,494 | 98,050,220 | 64,548,312 | 90,771,064 | 14,516,047 | 134,115,648 |
| | 5th | 20,480,159 | 28,800,224 | 3,667,314 | 33,882,789 | 25,027,075 | 35,194,325 | 5,206,680 | 48,105,194 | 31,668,558 | 44,533,910 | 7,121,832 | 65,799,539 |
| 2015 Wells | 1st | 59,785,960 | 84,074,006 | 10,651,157 | 88,759,642 | 83,115,540 | 116,881,229 | 17,532,769 | 146,106,407 | 124,554,096 | 175,154,198 | 27,225,468 | 226,878,899 |
| | 2nd | 84,274,482 | 118,510,991 | 15,013,905 | 125,115,879 | 117,159,934 | 164,756,157 | 24,714,248 | 205,952,064 | 175,571,857 | 246,897,923 | 38,377,108 | 319,809,229 |
| | 3rd | 93,956,102 | 132,125,768 | 16,738,733 | 139,489,439 | 130,619,500 | 183,683,671 | 27,553,469 | 229,612,245 | 195,741,899 | 275,262,046 | 42,785,946 | 356,549,547 |
| | 4th | 39,403,335 | 55,410,940 | 7,019,894 | 58,499,118 | 54,779,241 | 77,033,307 | 11,555,381 | 96,294,845 | 82,090,290 | 115,439,471 | 17,943,581 | 149,529,845 |

| 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 | 56,077,320 | 78,858,731 | 9,985,460 | 74,890,948 | 89,028,497 | 125,196,324 | 19,024,272 | 142,682,038 | 144,799,053 | 203,623,668 | 33,424,124 | 250,680,927 |
| | 2nd | 79,046,771 | 111,159,522 | 14,075,536 | 105,566,523 | 125,494,857 | 176,477,143 | 26,816,675 | 201,125,062 | 204,109,213 | 287,028,580 | 47,114,753 | 353,360,644 |
| | 3rd | 88,127,821 | 123,929,748 | 15,692,562 | 117,694,214 | 139,911,955 | 196,751,186 | 29,897,428 | 224,230,708 | 227,557,684 | 320,002,992 | 52,527,389 | 393,955,415 |
| 2017 Wells | 1st | 52,128,033 | 73,305,047 | 9,346,390 | 62,908,397 | 95,137,438 | 133,787,023 | 20,576,652 | 138,496,698 | 157,847,587 | 221,973,169 | 40,786,344 | 274,523,468 |
| | 2nd | 73,479,844 | 103,331,031 | 13,174,702 | 88,675,879 | 134,106,040 | 188,586,619 | 29,004,916 | 195,225,394 | 222,502,468 | 312,894,096 | 57,492,562 | 386,969,168 |
| 2018 Wells | 1st | 48,149,564 | 67,710,324 | 8,735,280 | 52,573,446 | 101,442,364 | 142,653,325 | 22,189,911 | 133,550,388 | 170,835,656 | 240,237,641 | 49,502,464 | 297,931,496 |