

Draft Report**DEVELOPMENT OF EMISSIONS INVENTORIES
FOR NATURAL GAS EXPLORATION AND
PRODUCTION ACTIVITY IN THE
HAYNESVILLE SHALE**

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August 31, 2009

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EXECUTIVE SUMMARY

The Haynesville Shale is a rock formation that lies at depths of 10,000 to 13,000 feet below the surface and straddles the border between Northeast Texas and Northwest Louisiana near Shreveport. This formation is estimated to contain very large recoverable reserves of natural gas, and during the two years since the drilling of the first highly productive wells, has been the focus of intensive exploration and leasing activity. The development of natural gas resources within the Haynesville Shale is likely to be an important driver of local economic growth, but may also generate significant emissions of ozone precursors in a region that is often immediately upwind of the 5-county area of Northeast Texas on high ozone days. Three of these five counties have been recommended to the U.S. Environmental Protection Agency by the state of Texas as potential ozone non-attainment areas. Northeast Texas Air Care (NETAC; www.netac.org), a local stakeholder group comprised of representatives of local government, business and industry, the general public, and environmental interest groups, has therefore undertaken this study to investigate how development in the Haynesville Shale may impact future ozone air quality in Northeast Texas.

Based on well production data from state regulatory agencies and a review of the available literature, projections of future year Haynesville Shale natural gas production for 2009-2020 were derived for three scenarios corresponding to limited, moderate, and aggressive development. These production estimates were then used to develop an inventory of potential emissions from future natural gas exploration and production in the Haynesville Shale for all three scenarios. Estimates of 2012 NO_x emissions in Northeast Texas and Northwest Louisiana due to development in the Haynesville Shale ranged from 61 tons/day in the limited development scenario to 82 tons/day in the moderate scenario to 140 tons/day in the aggressive scenario. Results for the moderate scenario indicate that by 2020, development in the Haynesville Shale results in more than 120 tons/day of additional NO_x emitted in Northeast Texas and Northwest Louisiana. There is significant uncertainty associated with the emissions estimates since development in the Haynesville Shale is still in its initial stages. The assumptions used in the development of the inventories – particularly the minimal usage of wellhead compressors – indicate that these inventories represent a lower bound of the potential emissions from these scenarios. Analysis of the emission inventories suggests that if the development of the Haynesville Shale proceeds at even a relatively slow pace, emissions from exploration and production activities will be sufficiently large that their potential impacts on ozone levels in Northeast Texas should be evaluated.

1.0 INTRODUCTION

The Haynesville Shale is an Upper Jurassic-era layer of sedimentary rock that was discovered 60 years ago near the town of Haynesville in Claiborne Parish, Louisiana. The Haynesville Shale is approximately 300 feet thick and lies at depths of 10,000 to 13,000 feet below the surface in Northeast Texas and Northwest Louisiana. The Haynesville Shale is sometimes referred to as the Bossier Shale in Texas. The region was once covered by water and the shale formed as sediments were deposited on the sea floor and were compacted as subsequent layers formed overhead. The natural gas present within the rock is the result of the deposition of organic material along with the sediment and the chemical transformation of this material from the resulting heat and pressure of the overlying layers.

Shale rock has very low permeability, making it difficult for gas to be produced from the rock. Until recent technological advances, it was not considered economically feasible to develop natural gas reserves in shale. Over the last two decades, increased demand for domestic sources of energy and the development of horizontal drilling techniques and advances in hydraulic rock fracturing (fracing) methods have made it profitable to extract natural gas from shale layers.

In a conventional well, a single vertical well bore is drilled. A horizontal well is shown in Figure 1. Initially, the well is drilled vertically, but once the formation of interest has been reached, the drill bit is angled so the well turns and runs horizontally along the formation. This increases the well's exposure to the formation, enhancing production. Next, the rock surrounding the well bore is fractured hydraulically in order to stimulate production. Water and proppants such as sand or ceramic beads are pumped into the well bore under high pressure and create cracks in the rock through which natural gas can flow into the well bore. The purpose of the proppant is to keep the cracks open so that gas continues to flow to the well.

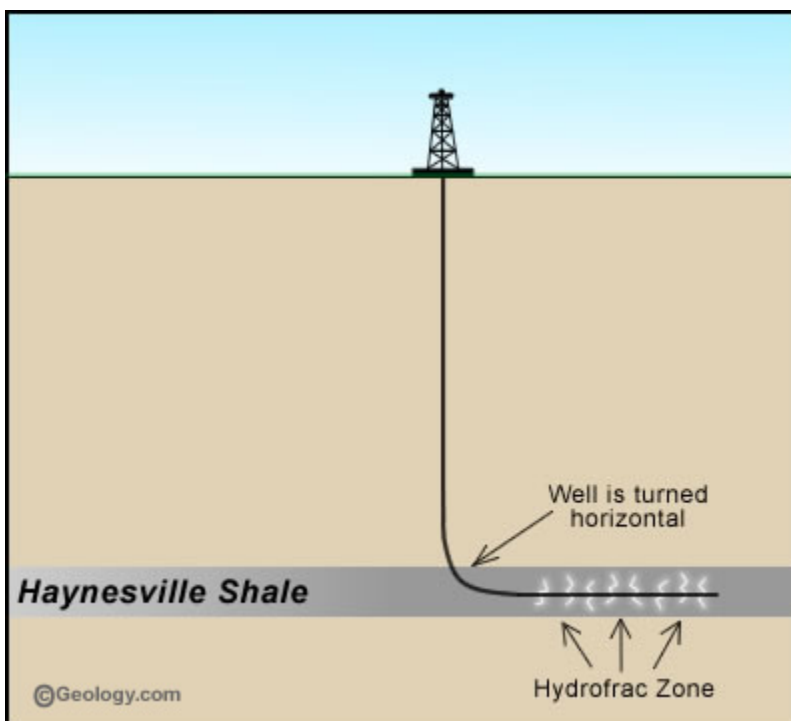


Figure 1. Schematic of a Haynesville Shale well showing horizontal drilling and hydraulic fracturing techniques. Image from <http://geology.com/articles/haynesville-shale.shtml>.

The Barnett Shale in the Dallas-Fort Worth area of Texas is a shale play that has benefitted from these advances. The Barnett Shale has been an area of intensive natural gas development over the last decade, with large increases in production coming after the widespread adoption of improved drilling and fracing methods. The Haynesville Shale is similar to the Barnett Shale in terms of required gas extraction techniques, but the Haynesville is potentially a much larger resource (Groundwater Resources Council et al., 2009). Exploratory wells drilled in the Haynesville Shale area in 2007-8 were determined to be highly productive, and the Haynesville Shale was touted as a significant new energy resource. For example, a 2008 report in the Wall Street Journal indicated that as many as 15,000 new wells were planned for the Haynesville Shale area (Wall Street Journal, 2008). Development has just begun and is expected to grow rapidly in the next few years (Nossiter, 2008), even allowing for the current economic slowdown and the drop in natural gas prices between 2008 and 2009. According to some estimates (Groundwater Resources Council et al., 2009), the Haynesville Shale formation may contain as much as 250 trillion cubic feet (TCF) of recoverable gas, and several major energy companies have begun activities to develop this formation.

The development of the Haynesville Shale will require both significant exploration (i.e. drilling) activities and, as the field develops, construction of production and gathering/transmission infrastructure. Each of these activities will result in a significant population of equipment operating in the region, potentially contributing to emissions of ozone precursors. Because the field is deep (13,000 feet at some points) and requires significant rock fracturing to stimulate production, nitrogen oxide (NO_x) emissions from drilling and well completion activities are expected to be high relative to development of shallow wells. In addition, volatile organic compound (VOC) emissions from completion activities and emissions from other initial activities such as fracturing and well pad construction will be relatively high. As the field develops, production and gathering/transmission infrastructure will be built, and related emissions will grow. Given the potential level of activity in the Haynesville Shale, the development of the formation could result in significant emissions and impacts to local air quality. The Haynesville Shale lies in the same geographic area as the Louisiana-Mississippi Salt Basins and the East Texas Basin, areas that already have significant oil and gas development.

The development of natural gas resources within the Haynesville Shale is an important driver of local economic growth, but is likely to generate significant emissions of ozone precursors in a region that is often immediately upwind of Northeast Texas on high ozone days. In 2008, the U.S. Environmental Protection Agency (EPA) promulgated a new National Ambient Air Quality Standard for ozone of 0.075 ppm and the level of the standard is currently under review by the new EPA Administrator. In March, 2009, Texas Governor Perry recommended to the EPA that Smith, Gregg, and Rusk Counties in Northeast Texas be designated in non-attainment of the 2008 ozone standard pending analysis of data from the 2009 ozone season. A projected increase in ozone precursors and transported ozone in and near Northeast Texas is therefore cause for concern, and the potential air quality impacts of proposed development in the Haynesville Shale region must be assessed. Northeast Texas Air Care (NETAC; www.netac.org), a local stakeholder group comprised of representatives of local government, business and industry, the general public, and environmental interest groups, has therefore undertaken this study to investigate how development in the Haynesville Shale may impact future ozone air quality in Northeast Texas.

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. Emissions from the three Haynesville Shale scenarios were then compared to existing emission inventories for Northeast Texas and Northwest Louisiana to assess the potential significance of the Haynesville emissions.

In Section 2 of this report, we describe the data used in the study and methods used to determine the spatial extent of the Haynesville Shale. In Section 3, the methods for obtaining activity and production projections for the Haynesville Shale are discussed, and results of projections of future year production are presented and compared with estimates of available reserves in the formation. In Section 4, methods for development of the emission inventory are given, and the emission inventory results are discussed. Section 5 is a discussion of the significance of the results, the uncertainties in the study, and suggestions for future work.

2.0 DATA AND METHODS

Exploration and production in the Haynesville Shale have been going on for only two years, therefore peer-reviewed published information is extremely limited. Basic information, such as the geographic extent and recoverable reserves of the Haynesville Shale, are not yet known. The strategy in developing estimates of future year activity and emissions was therefore to gather the best available information and cross-check among different sources of data where possible.

2.1 Data

The Texas Commission on Environmental Quality (TCEQ), Texas Railroad Commission (RRC) and the Louisiana Department of Natural Resources (LDNR) were contacted regarding production and activity within the Haynesville Shale. The RRC and LDNR were able to provide some data, but recommended that the best source of estimates of future year activity and equipment use would be the producers active in the area, so ENVIRON attempted to enlist the cooperation of the producers in the projection of the future activity and emission inventory development.

A survey was sent out to the producers identified on their company web pages, stockholder reports or venture capital firm reports as being major leaseholders in the Haynesville Shale as of March, 2009. The survey and cover letter that accompanied its transmittal to the producers are shown in Appendix A. The companies contacted were XTO Energy Inc., Chesapeake Energy Corp., Petrohawk Energy Corp., EOG resources, Inc., EnCana Corp., Shell, BP America, Devon Energy, and El Paso Corp. The energy companies all declined to participate in the survey.

ENVIRON therefore assembled available data from the state regulatory agencies and the available literature to determine the recoverable reserves as well as to derive future year activity projections. The emission inventory development was based on WRAP Phase III (Bar-Ilan et al., 2009) and CENRAP oil and gas emission inventories (Bar-Ilan et al., 2008).

2.2 Temporal Scope of the Study

This study considers a base year of 2009 for the purpose of estimating present-day Haynesville Shale emissions and projects emissions for each year from 2010 – 2020. A 2008 base year was considered in order to be consistent with the 2008 National Emission Inventory year, but exploration and production in the Haynesville Shale were just beginning in 2008. 2009 is the first year for which sufficient production data from wells drilled in the Haynesville Shale are available for well decline curve and production projections. All emissions estimations are presented on a daily basis, but it should be noted that this analysis assumes continuous exploration and production activity throughout the year so that annual emissions can be directly estimated from the daily emissions without the use of weighting factors for seasonal activity. Given the temperate climate of the Northeast Texas-Northeast Louisiana region, it is reasonable to assume that exploration and production can proceed year-round without major changes in emissions due to the seasonal cycle.

2.3 Pollutants

The most important air quality issue for Northeast Texas is ozone. Therefore, the focus of the emission inventory is on the major ozone precursors; emissions of NO_x, VOC, and CO are estimated.

2.4 Geographic Extent of the Haynesville Shale

The Haynesville Shale straddles the border of Texas and Louisiana and encompasses areas in northwest Louisiana, eastern Texas, and possibly southern Arkansas. The drilling activity to date has been concentrated in Texas and Louisiana and this study is therefore restricted to those states. Exploration of the Haynesville play is still in its infancy and therefore the full spatial extent of the play is not yet known. Neither the U.S. Geological Survey (USGS) nor the Louisiana Geologic Survey has published studies defining the extent of the Haynesville Shale. Many of the operators drilling in the Haynesville Shale have developed maps outlining their estimates of the boundaries of the formation, but these boundaries vary by operator.

Both the Texas RRC and the LDNR maintain Haynesville Shale-specific websites that summarize the information gathered by these agencies on the Haynesville Shale and track the progress of its development (<http://www.rrc.state.tx.us/bossierplay/index.php>; <http://dnr.louisiana.gov/haynesvilleshale/>). Both the RRC and LDNR have published maps delineating the geographic extent of the Haynesville Shale based on exploration to date. Figures 2 and 3 show the Haynesville Shale regional maps developed by the RRC for Texas and by the LDNR for Louisiana as of March 17, 2009.

Significant oil and gas exploration and production in formations unrelated to the Haynesville Shale are present in both Northeast Texas and northwest Louisiana. The identification of specific wells as accessing the Haynesville Shale formation was made by the state agencies through a combination of information; this includes the drilling depth, the composition of the gas produced, and, if available, core samples indicating that a well has accessed the stratigraphic interval consisting of shale below the base of the deepest Cotton Valley sands and above the top of the Smackover Formation; this region is defined to be the Haynesville Shale (<http://dnr.louisiana.gov/cons/notices/20090601-shale.pdf>). It was beyond the scope of this effort to evaluate these criteria or develop any additional analysis to determine the extent of the Haynesville, and the definitions presented by the RRC and LDNR were used directly.

As of March, 2009, the RRC identified three core and two non-core counties in Texas as Haynesville/Bossier counties, and the LDNR reported six parishes with Haynesville Shale drilling activity in Louisiana. For the purposes of this study, these 11 counties/parishes were defined to be Haynesville Shale region counties and parishes. The counties/parishes that comprise the geographic scope of this analysis are listed below in Table 1.

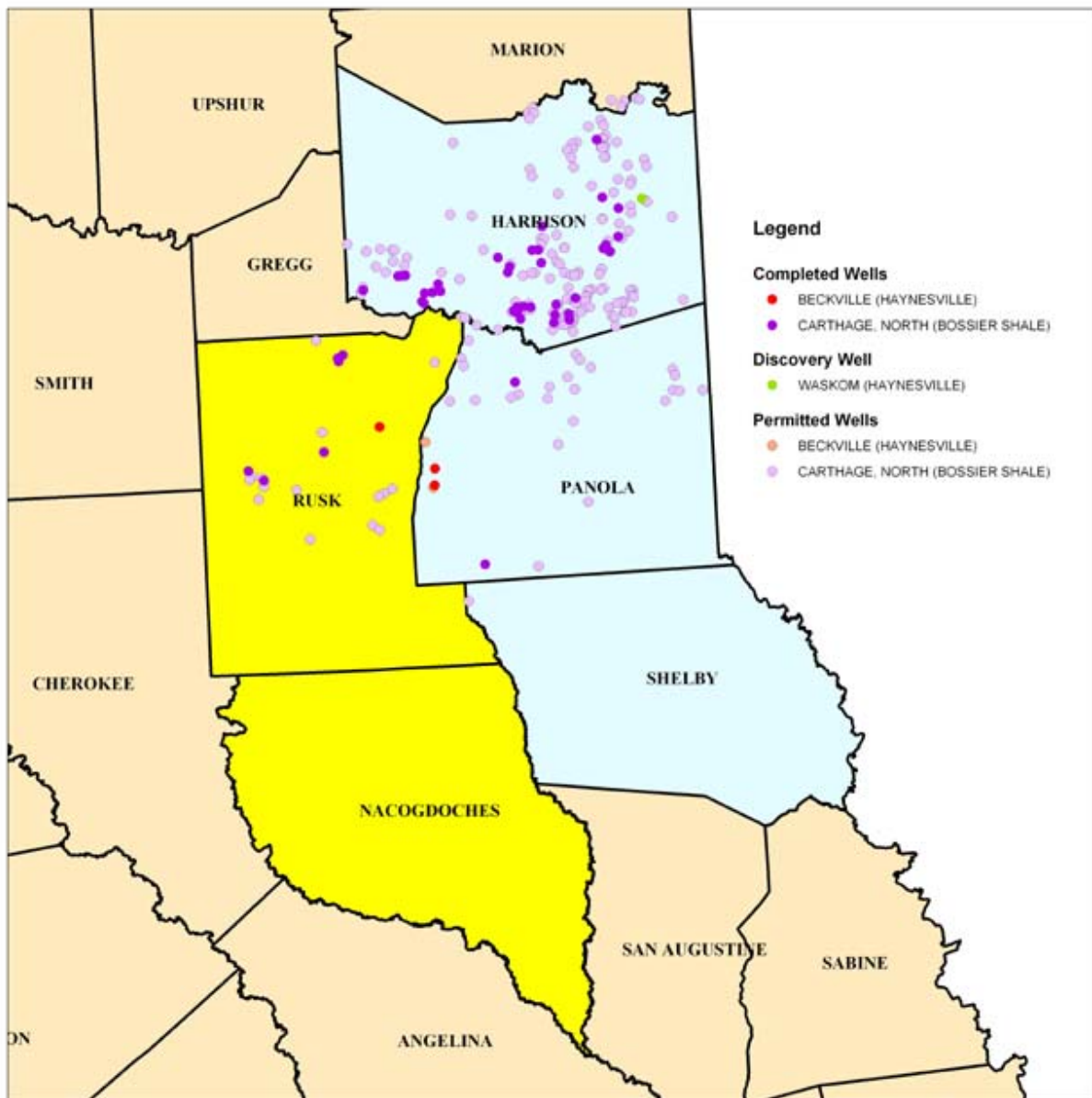


Figure 2. March 17, 2009 extent of the Haynesville Shale in East Texas including specific counties where gas exploration is occurring. (Source: Texas RRC <http://www.rrc.state.tx.us/bossierplay/index.php>).

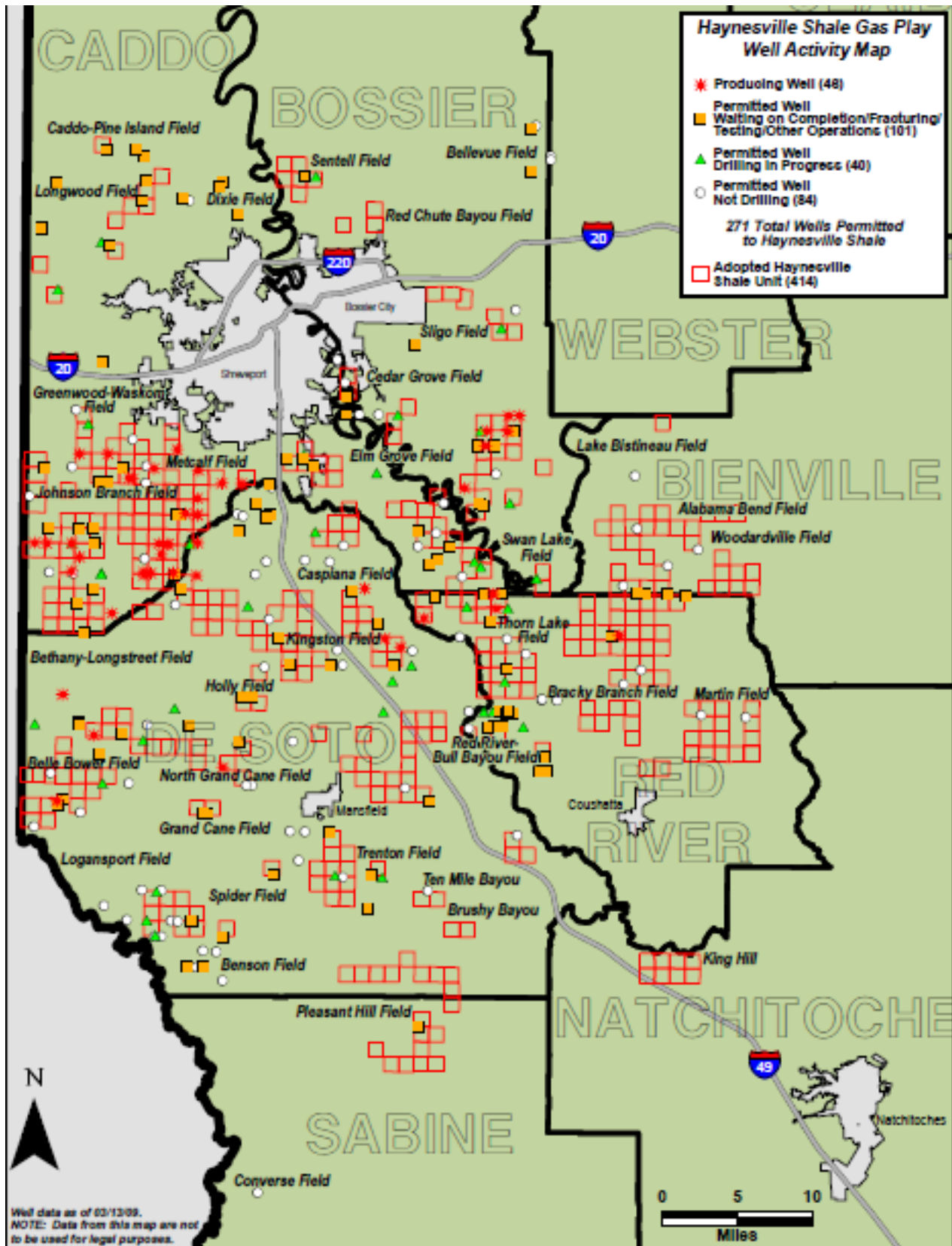


Figure 3. Extent of the Haynesville Shale in Northwest Louisiana including specific parishes where gas exploration is occurring. (Source: LDNR <http://dnr.louisiana.gov/haynesvilleshale/>).

Table 1. Counties in Texas and parishes in Louisiana considered part of the Haynesville Shale core development area (well sites).

Texas Counties	Louisiana Parishes
Harrison (core)	Caddo
Panola (core)	Bossier
Shelby (core)	Webster
Rusk (non-core)	Bienville
Nacogdoches (non-core)	De Soto
	Red River

Figure 4 below shows the extent of the Haynesville Shale including counties and parishes in both Texas and Louisiana. Between the beginning of this study March 2009 and the writing of this report in August 2009, the RRC has included Marion and Saint Augustine Counties in Texas as part of the non-core area based on additional wells drilled between March and August (3 in Marion and 1 well in Saint Augustine). Because the number of wells in these counties is small and the wells are located near the borders of counties that are included in the non-core area, this should not have a significant effect on the results of this study.

These counties were considered in this study to form the geographic extent of the Haynesville Shale for exploration and some production activities. All source categories associated with the development and operation of well sites were assumed to occur within these counties for all future years.



Figure 4. Spatial extent of the Haynesville Shale in Texas and Louisiana as defined in this study.

An expanded geographic domain was considered for emissions sources associated with gas transmission and processing, specifically central compressor stations and gas processing facilities. These facilities are often not owned and operated by the same companies that own and operate the wells and produce the gas, and are collectively referred to in this analysis as “midstream” facilities. It was expected that gas produced in the Haynesville Shale region would be gathered and processed at nearby midstream facilities, but pipelines could carry produced gas to facilities located farther from the core of the Haynesville Shale development area. This is particularly true for gas processing plants which may not be located directly within a development area. Through a review of the TCEQ permit database, it was determined that no new major natural gas processing plants are permitted within the Texas portion of the Haynesville Shale region as of July 2009. Comparable data were not readily available for Louisiana. Because data on base year gas plant throughput were unavailable, the emission inventory calculation method was not predicated on detailed information regarding future year gas plants, and no further effort was made to project the construction of new major gas processing facilities as a result of the Haynesville Shale development. This is discussed in more detail in the section below on the emissions inventory development. New pipelines are planned for the purpose of transporting the Haynesville Shale natural gas to markets (EIA, 2009; Will Brackett, personal communication, 2009), but it is beyond the scope of this study to assess how this new construction would impact the development of an emissions inventory for the Haynesville.

The locations of midstream facilities operating within the Haynesville Shale and surrounding regions were extracted from emission inventory databases maintained separately by the Texas Commission on Environmental Quality (TCEQ) and the Louisiana Department of Environmental Quality (LADEQ). A subset of the midstream sources were identified which lie within or near the periphery of the Haynesville Shale region. Although efforts were made to specifically identify where gas produced from the Haynesville Shale was gathered and processed by contacting various production companies, this information was not readily available. Midstream facilities in the region surrounding the Haynesville Shale which might potentially process gas from the Haynesville Shale were identified. In selecting the midstream facilities to be included in the study, consideration was given to the modeling domain of NETAC’s ozone model (Kemball-Cook et al., 2008) because modeling large point sources of ozone precursor emissions within the high-resolution 4 km modeling domain provides a more accurate simulation of their ozone impacts. Figure 5 shows a map of their locations and the boundaries of the region in which midstream facilities were considered as well as the location of the 4 km domain of the NETAC ozone model. Table 2 lists the counties and parishes for which emissions from midstream sources were used in the inventory development.

Table 2. Counties in Texas and parishes in Louisiana considered part of the Haynesville Shale midstream gas gathering and processing area.

Texas Counties	Louisiana Parishes
Anderson	Bienville
Camp	Bossier
Cass	Caddo
Cherokee	Claiborne
Franklin	De Soto
Gregg	Jackson
Harrison	Lincoln
Henderson	Natchitoches
Hopkins	Red River
Marion	Sabine
Morris	Webster
Nacogdoches	Winn
Panola	
Rains	
Rusk	
Sabine	
San Augustine	
Shelby	
Smith	
Titus	
Upshur	
Van Zandt	
Wood	

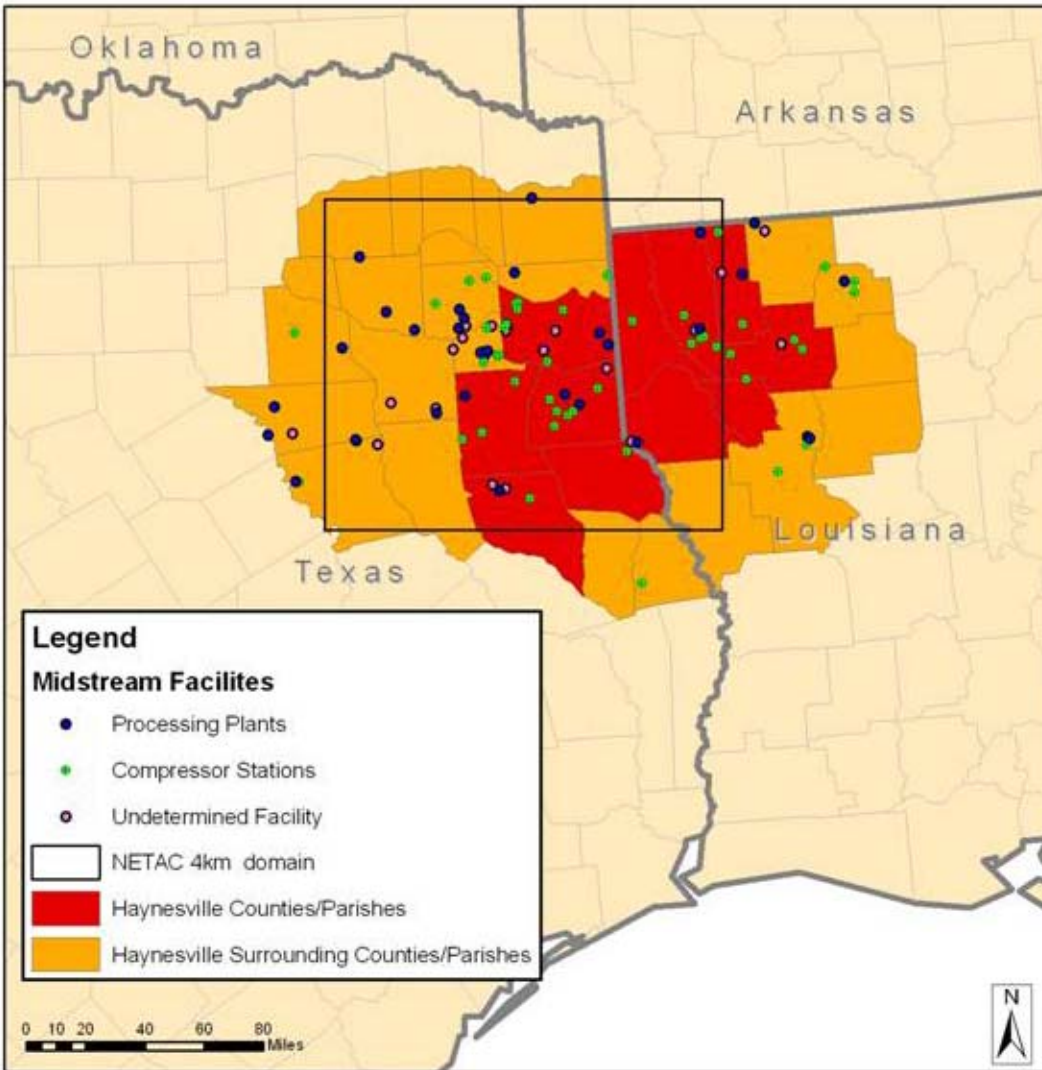


Figure 5. Midstream facilities in Texas and Louisiana (identified from state emission inventory databases) in the region surrounding the Haynesville Shale that considered in this analysis. The 4 km modeling domain for the NETAC ozone model is shown in black.

A more detailed description of the procedure used to estimate midstream facility emissions is provided in the section below on the emissions inventory development methodology.

3.0 ACTIVITY AND PRODUCTION PROJECTIONS

Projections of exploration activity and gas production in the Haynesville Shale were developed for each year in the period 2010-2020. These projections form the basis for scaling the base year emissions inventory to all future years, using one of the various activity factors as a projection surrogate. The projections were developed for three scenarios: (1) a moderate (medium) growth scenario; (2) a low growth scenario; and (3) an aggressive (high) development scenario. These scenarios were developed to cover a range of possible future levels of gas exploration and production activity in the Haynesville Shale. There is a wide array of factors that can affect the future levels of exploration and production, and these are listed in the next section. Chief among these is the price of natural gas which is, in turn, affected by the state of the global economy as well as the natural gas supply from other formations in the U.S. Another important variable is the productivity of wells within the Haynesville Shale. This is measured for an individual well using a well decline curve, which tracks the amount of natural gas produced by the well as a function of time. Typically, a well will have its maximum production immediately after drilling and then productivity decreases with time as the gas 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.

The projection scenarios were constructed for each future year using two factors: (1) the number of new wells drilled (spuds) in each year; and (2) production estimates for each new active well (derived from well decline curves). From these two factors, formation-wide spuds, well counts, and gas production were estimated considering a number of assumptions. The methodology for generating the activity projection scenarios is described in detail below. Each scenario was constructed considering a number of assumptions, and it should be noted that these are “best-guess” projections which are highly uncertain.

3.1 Drilling and Well Count Estimates

The number of new wells that will be drilled in the Haynesville Shale in the period 2009-2020 will depend on a broad range of economic factors, some affecting the natural gas industry as a whole and some specific to the Haynesville Shale, but all of which ultimately influence the profitability of development of the formation. The economic factors include: natural gas prices; natural gas demand; natural gas supply from other sources; productivity of Haynesville Shale wells compared with other natural gas formations; natural gas transportation infrastructure; cost of drilling in the Haynesville Shale as compared to other formations; drill rig availability; land leasing costs; and other factors. The Haynesville Shale region has experienced a significant increase in drilling activity since March 2008, when very high initial production rates were reported for some early test wells. Operators in this area were optimistic about profitability of drilling in the Haynesville Shale and planned aggressive development of the formation. Chesapeake Energy alone, for example, planned on operating 60 rigs in the Haynesville Shale by the end of 2010 (Scandinavian Oil and Gas Magazine, 2008). Since March 2008, the global economic downturn has affected natural gas prices and it appears that some operators are scaling back their drilling operations, although this may not be the case for all operators. Some operators seem to consider development of the Haynesville Shale as a continuing strong development opportunity in the current economic climate, and therefore are concentrating their operations in the Haynesville Shale over other formations (e.g. Wall Street Journal, 2009). Since

production estimates in this study are projected for the long-term (through 2020), and predicting the duration of the economic downturn is impossible, production estimates are based on available data that incorporates some effects of the economic downturn. This analysis does not attempt to predict future economic conditions, but attempts to take future economic variability into account by providing a range of potential future activity estimates.

In developing estimates of future activity in the Haynesville Shale, the most direct source of information is the producers, who were queried about their development plans in the survey sent out by ENVIRON (Appendix A). Since the producers declined to respond to the survey, the historical development of the Barnett Shale near Dallas-Fort Worth, Texas was used as a surrogate for modeling growth in drilling activity the Haynesville Shale. Figure 6 shows a plot of the counties within the Barnett Shale. The Barnett Shale was used for this purpose because it is a shale formation in the same geographic region as the Haynesville Shale; the Barnett Shale has been active before and since the development of the improved drilling and fracturing techniques that have made extraction of shale gas economically feasible. A comparison of some of the physical characteristics of the Haynesville Shale and Barnett Shale is shown in Table 3. The comparison to the Barnett Shale was made to determine a reasonable growth rate in development activity (determined by drilling counts per year) that can be assumed for the Haynesville Shale. For example, examination of historical data from the Barnett Shale can be used to constrain the speed with which drill rigs can be diverted from other regions into a more profitable area as well as indicate how quickly new infrastructure can be built to handle the increased gas production from a newly discovered formation.

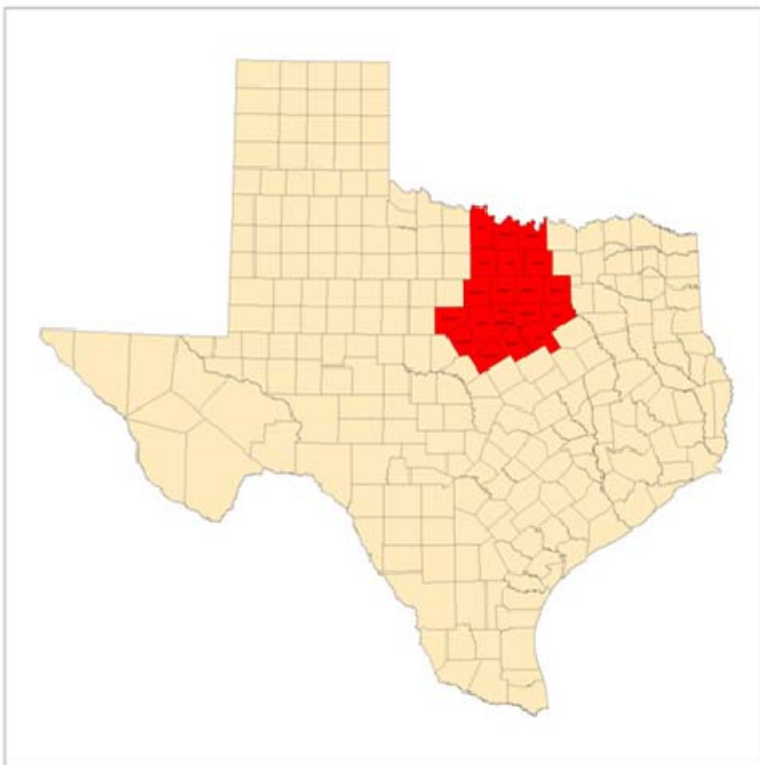


Figure 6. Counties comprising the Barnett Shale development area in North Central Texas.
Source: Texas RRC (<http://www.rrc.state.tx.us/barnettshale/images/countyproducing.jpg>)

Table 3. Comparison of production and physical characteristics of the Barnett and Haynesville Shales.

Comparison of Data For Gas Shales*		
Gas Shale	Barnett	Haynesville
Estimated Formation Area [sq. mi]	5,000	9,000
Depth [ft]	6,500-8,500	10,500-13,500
Net Thickness [ft]	100-600	200-300
Technically Recoverable Resources [TCF]	44	251

Source: DOE 2009 Shale Gas Primer (http://www.netl.doe.gov/technologies/oil-gas/publications/EPreports/Shale_Gas_Primer_2009.pdf)

Figure 7 shows the drill rig count in the Barnett Shale from 1996 through 2008. Development of the Barnett Shale accelerated rapidly in 2001 due to a number of factors, including improved horizontal drilling technology and hydraulic fracturing, and rising natural gas prices. The average year-over-year increase in the number of drill rigs in operation between 2001 and 2008 in the Barnett Shale was 25. Figure 7 shows a reduction in the number of drill rigs in 2008 likely due to decreased development resulting from the economic downturn and falling natural gas prices.

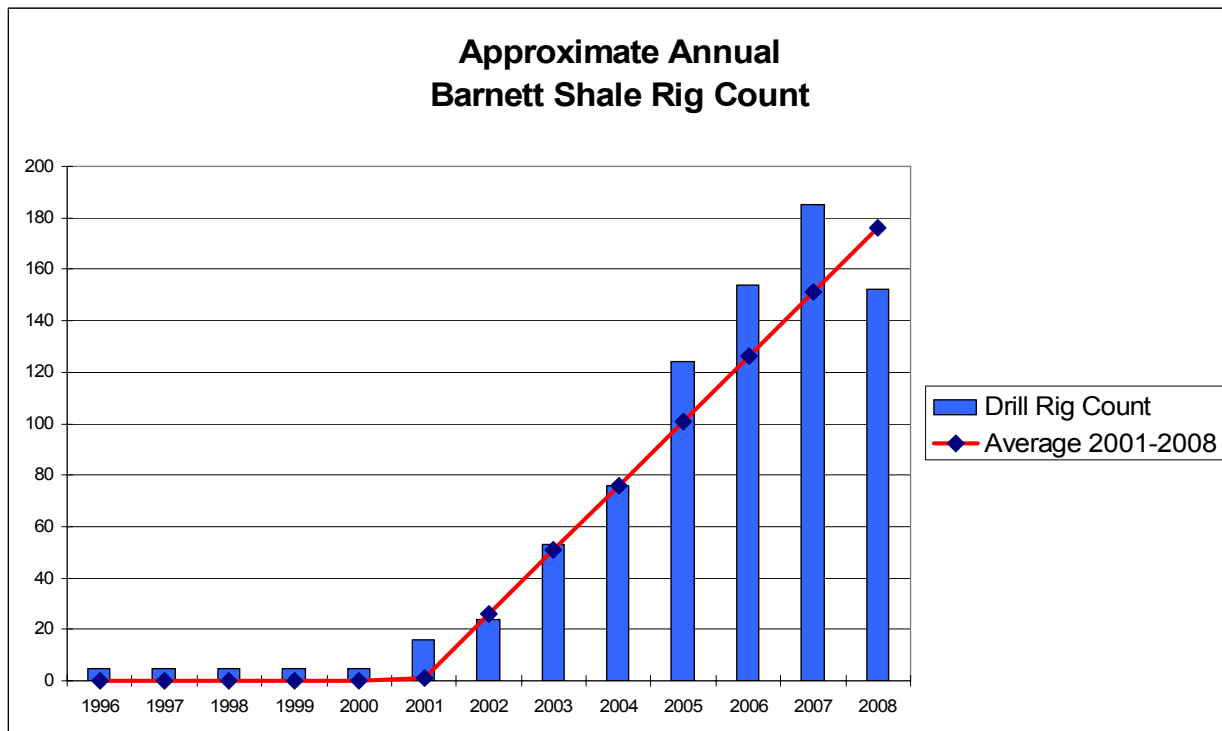


Figure 7. Barnett Shale Historical Rig Count Growth Curve. Source: Pickering Energy Partners Inc. (2005) and Barnett Shale News (2009).

It is reasonable to assume that the Haynesville Shale could experience the same level of development as the Barnett Shale if Haynesville well economics are favorable and well productivity in the Haynesville is comparable to that in the Barnett Shale. Historical development of the Barnett Shale was therefore used to model the aggressive growth scenario for the Haynesville Shale by assuming that the development of the Barnett represents a scenario in

which sufficient available infrastructure and a favorable pricing and supply environment will exist for the Haynesville Shale. The rig count growth curve in Barnett from 2001-2008 was used to estimate the rig count growth curve for the aggressive scenario in the Haynesville Shale. In the aggressive scenario, 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. Table 4 summarizes the annual drill rig growth for the three development scenarios.

Table 4. Annual increase in the drill rig count in the Haynesville Shale for the three development scenarios.

Scenario	Annual Increase in Drill Rig Count
Low development	0
Moderate development	12
Aggressive development	25

To determine the number of drill rigs currently in operation in the Haynesville Shale region, the Baker-Hughes database was examined (<http://gis.bakerhughesdirect.com/RigCounts/default2.aspx>). Baker-Hughes maintains a real-time interactive geographical database of rigs in the United States. The database was queried to determine the number of rigs drilling in the Haynesville Shale region by selecting rigs drilling for gas that were development wells at depths between 10,000ft and 15,000 in this region. Figure 8 shows a sample of the database query result for rigs operating in the Haynesville Shale region at the time of the query.



Figure 8. Drilling rigs currently operating in the Haynesville Shale region as of March 2009. Source: Barnett Shale News (2009).

In March 2009, the results of a query of the Baker Hughes database yielded 95 active drill rigs within the Haynesville Shale. For each of the three scenarios, the 2009 baseline drill rig count was set to 95. In order to avoid predicting an unreasonably large number of rigs to be operating in the Haynesville Shale in future years, the number of rigs operating in this region at any one time was capped at 200 for this analysis. This number is close to the maximum number of drill rigs that were ever in operation in the Barnett Shale, and is approximately ten percent of the entire U.S. fleet of drilling rigs (which numbers approximately 2000 rigs). Based on these assumptions the total number of drill rigs in operation in the Haynesville Shale for the three scenarios for the period 2009-2020 is shown in Figure 9.

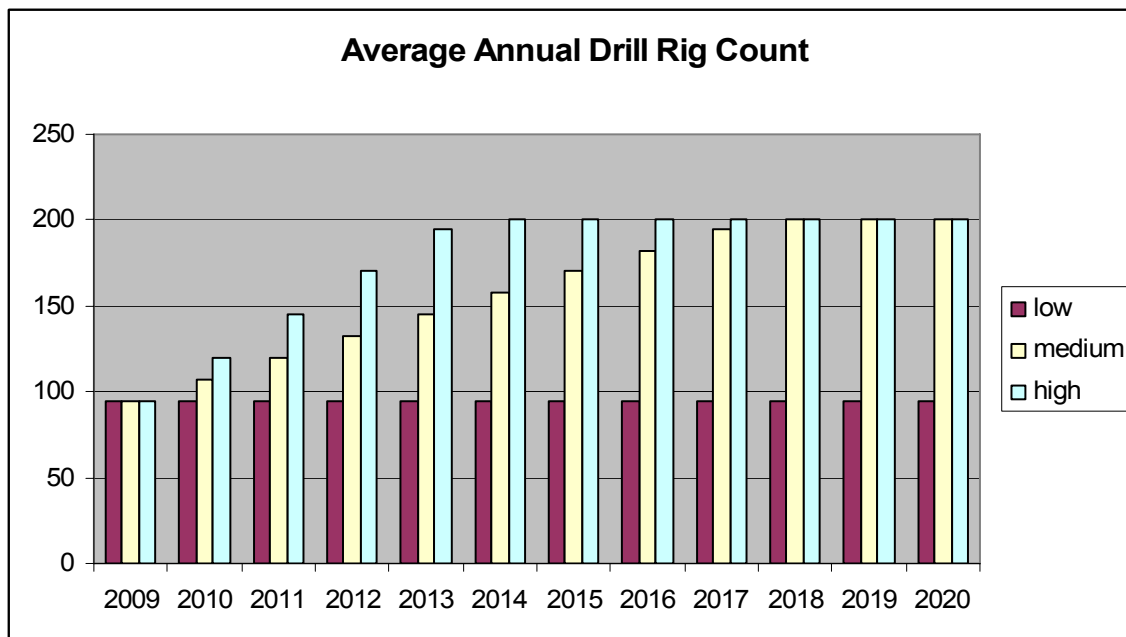


Figure 9. Total annual drill rig count in the Haynesville Shale predicted for the three development scenarios in the period 2009-2020.

The drill rig count was used to determine the number of new wells drilled per year. Drilling records from the LDNR Strategic Online Natural Resources Information System (SONRIS) database (http://sonris-www.dnr.state.la.us/www_root/sonris_portal_1.htm) were used to determine an average drilling duration of 63 days spuds occurring in the Haynesville Shale. Therefore, one drill rig was assumed to be able to drill a total of 5.8 wells in one year. The current 2009 baseline drilling success factor was determined from the LDNR wells database for the Haynesville Shale region to be 55%, which was determined to be the percentage of new active wells added to the region relative to the number of recorded spuds. With assumed technological improvements and better definition of the formation boundaries as exploration proceeds, the analysis assumes that the drilling success factor would improve to 100% by 2018, and would increase linearly between 2009 and 2018. Based on these assumptions the number of new active wells for each year in each scenario is shown below in Figure 10.

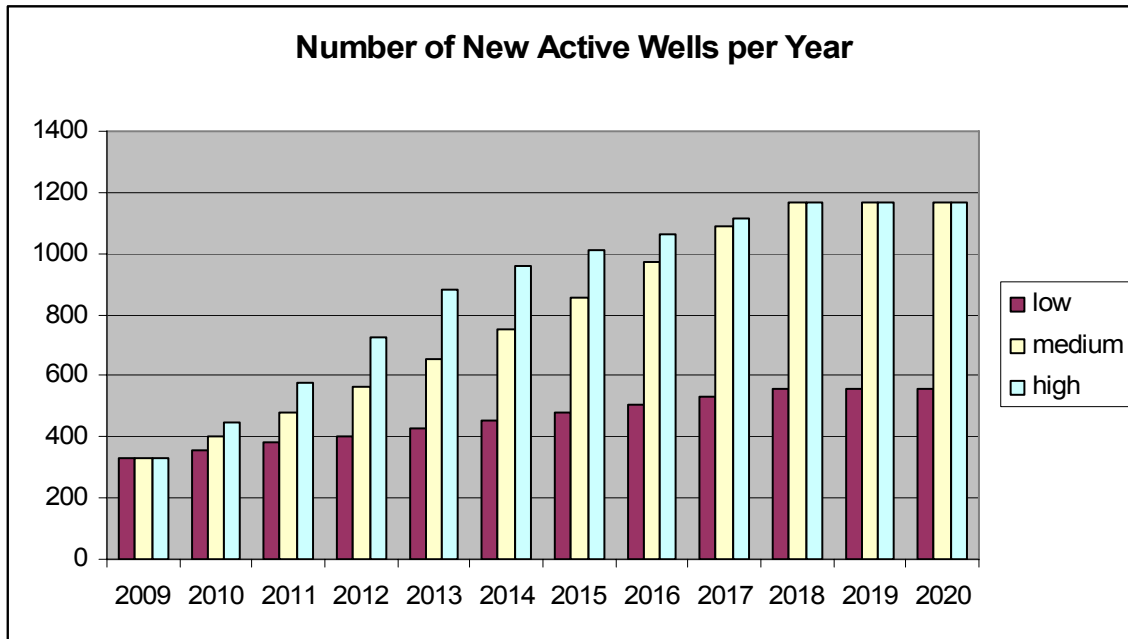


Figure 10. Number of new active wells added in each year in the Haynesville Shale in the period 2009-2020 for the three development scenarios considered in this analysis.

Based on the assumptions described above, the cumulative number of natural gas producing wells over the period 2009-2020 in the Haynesville Shale region for the three scenarios is shown in Figure 11. Table 5 summarizes the spud count and active well count estimates for each of the three scenarios considered in this analysis.

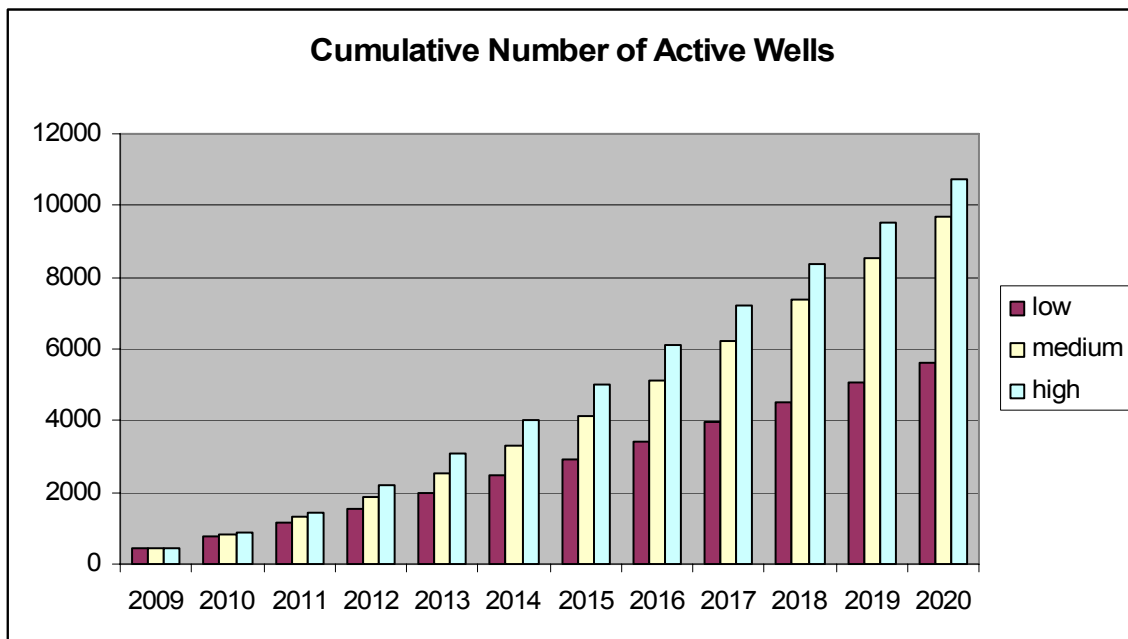


Figure 11. Cumulative number of new active wells in the Haynesville Shale in the period 2009-2020 for the three development scenarios considered in this analysis.

Table 5. Summary of spud counts and total active well counts by year in the period 2009-2020 for each of the three scenarios considered in this analysis.

Year	Annual Spud Count			Total Number of Producing Wells		
	Low	Moderate	Aggressive	Low	Moderate	Aggressive
2009	555	555	555	428	428	428
2010	555	628	701	783	830	877
2011	555	701	847	1163	1310	1457
2012	555	774	993	1568	1875	2181
2013	555	847	1139	1998	2531	3064
2014	555	920	1168	2453	3285	4022
2015	555	993	1168	2933	4144	5032
2016	555	1066	1168	3438	5114	6095
2017	555	1139	1168	3968	6202	7210
2018	555	1168	1168	4523	7370	8378
2019	555	1168	1168	5077	8538	9546
2020	555	1168	1168	5632	9706	10714

3.2 Production Estimates

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. This 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. Haynesville Shale wells have been producing gas for a very limited time period (approximately 1 year at the time the analysis was conducted), therefore long-term yearly production rates were unknown. To estimate long-term production rates, eight wells with the longest production periods were identified and the production rates analyzed for the total time period during which these wells have been active. The locations of the producing wells with the longest production history are presented in Figure 12. These 8 wells were used to derive a representative decline curve for all Haynesville Shale wells. It should be noted that there is significant uncertainty in this estimate, but that development of the Haynesville Shale region is so recent that a more robust well decline data set was not available.

The LDNR well serial numbers of wells used in the decline curve analysis were: 236242, 237022, 237111, 237078, 236237, 237457, 236110, and 237384. For these eight wells, monthly production data were available from LDNR. These data were extrapolated to the year 2020 by finding the best fit power law function for each well, and then averaging over the eight wells to calculate a derived decline curve. The power law function was chosen as a representative fit based on other historical well decline curves. Figure 13 shows a detailed example of extrapolation for a single well (well number 237022), and Figure 14 shows the extrapolated well decline curves for all 8 wells.

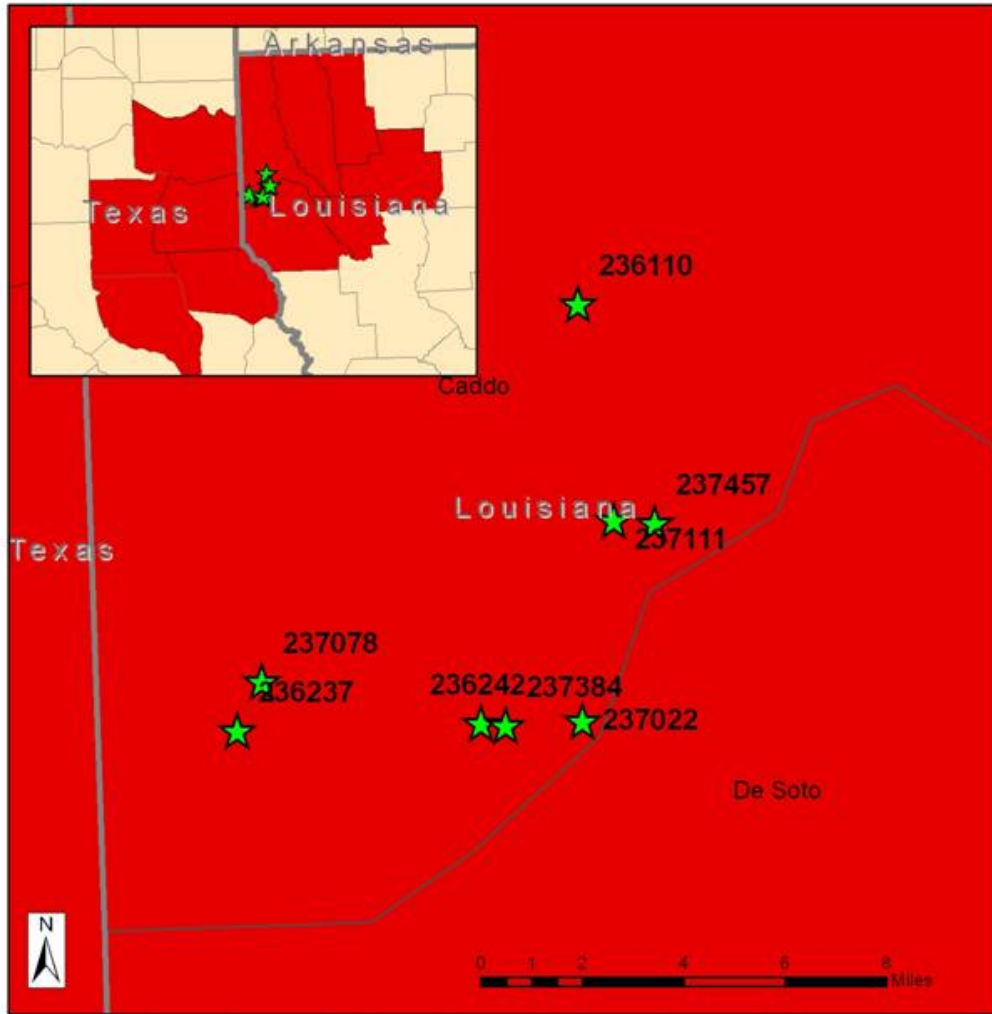


Figure 12. Eight representative wells used to determine gas production decline curves in the Haynesville Shale.

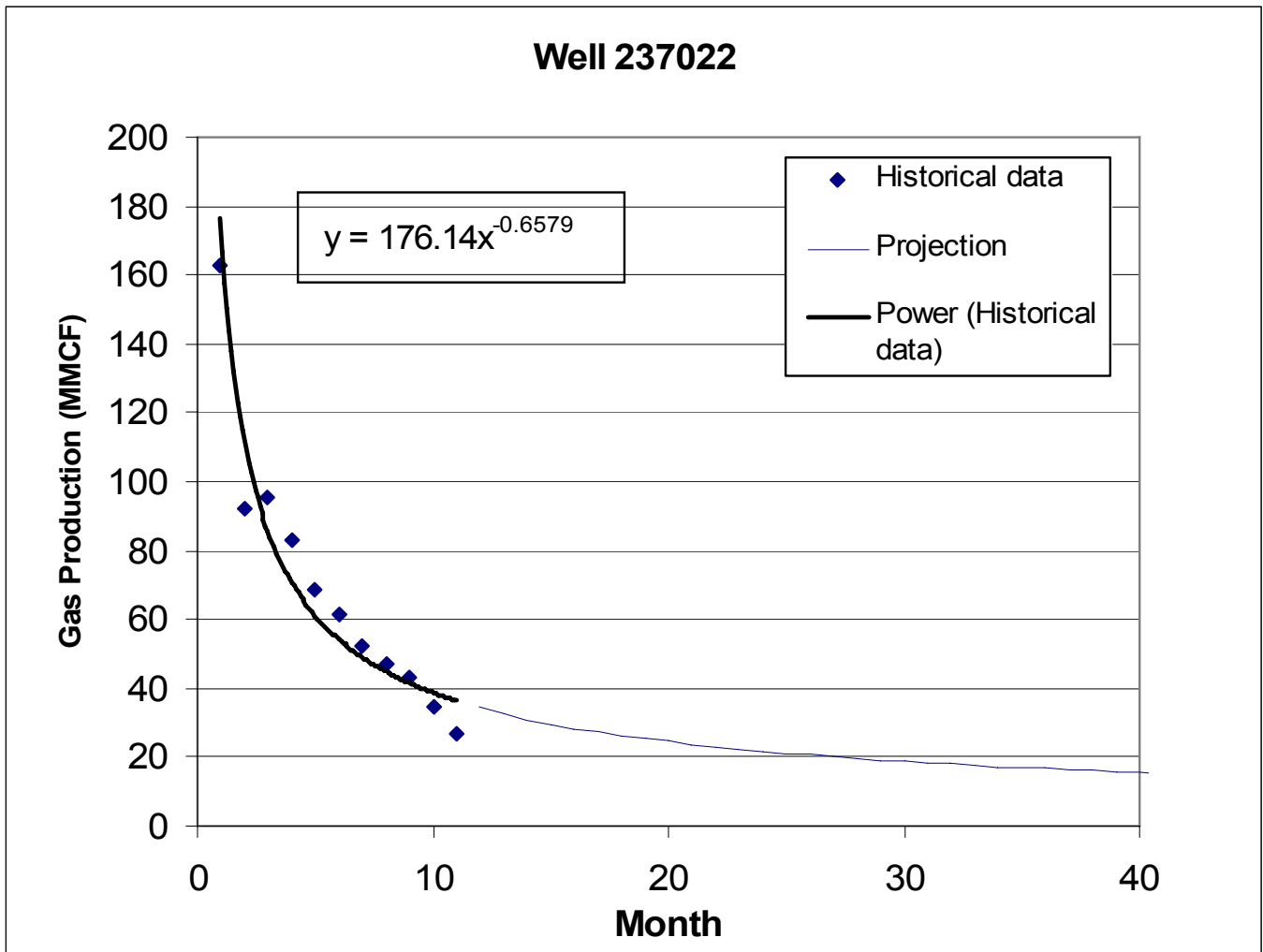


Figure 13. Extrapolated production decline curve for a single example Haynesville Shale well in Louisiana.

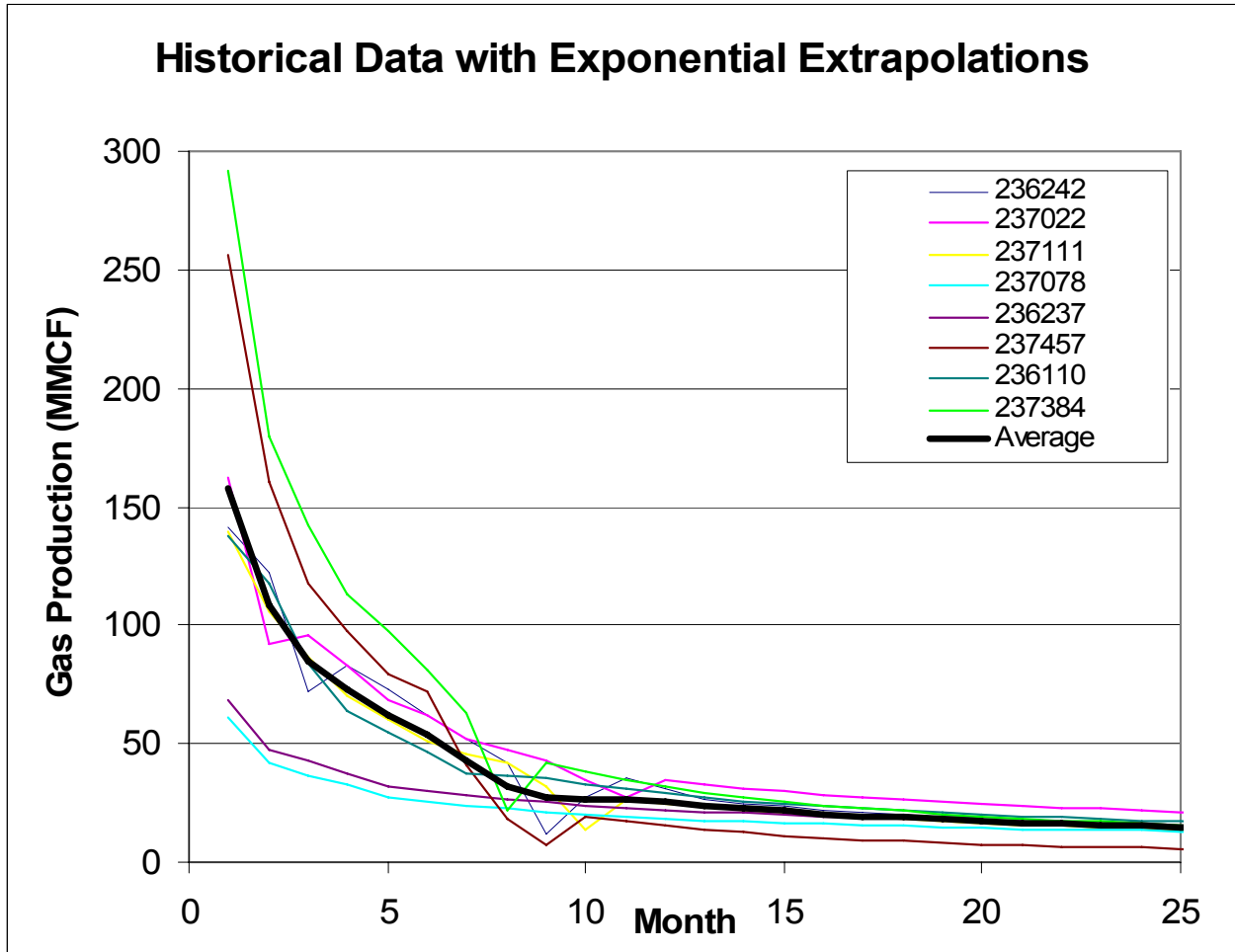


Figure 14. Summary results for power law extrapolations of production well decline curves for all 8 representative Haynesville Shale wells in Louisiana.

The derived decline curves for all 8 wells were averaged and extrapolated such that yearly well production could be determined for an “average” Haynesville Shale well. The results of this analysis are presented below in Figure 15.

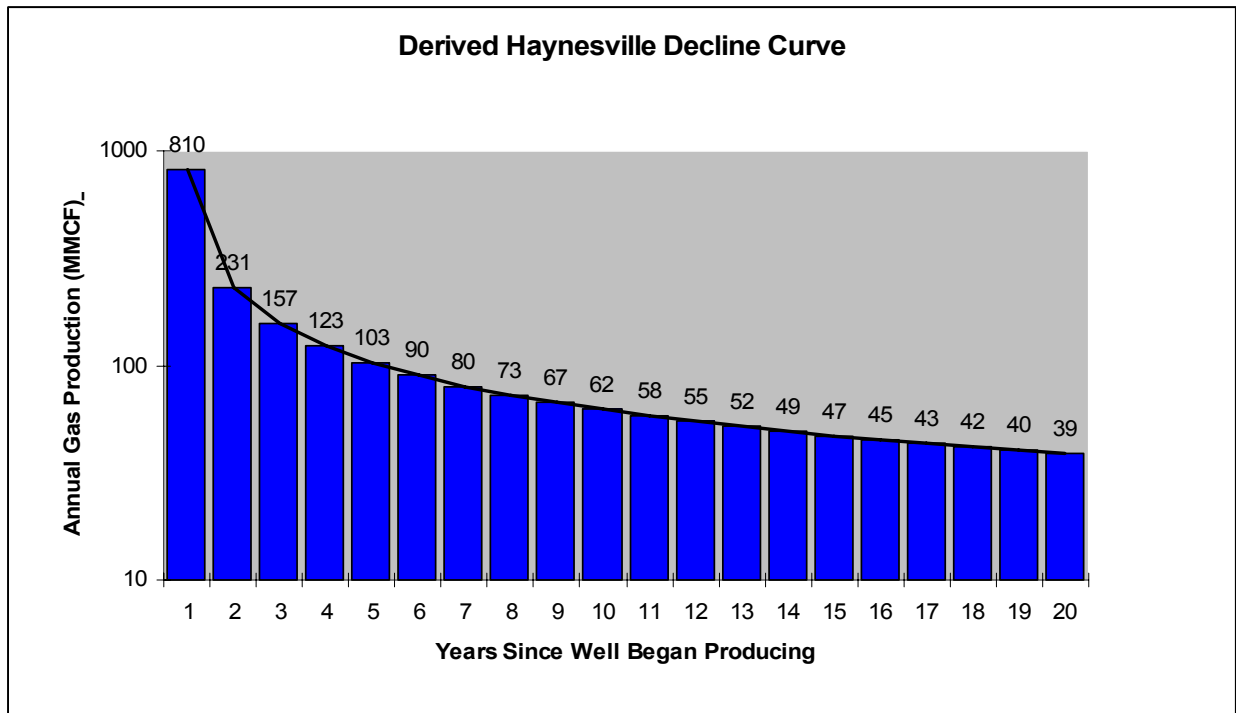


Figure 15. Average Haynesville Shale well production decline derived in this analysis

A separate literature search was conducted to determine the availability of additional published Haynesville Shale well decline curves from any other sources. Two venture capital reports on the Haynesville Shale from Tristone Venture Capital (Tristone Venture Capital, 2008) and Southern Star (<http://www.ssenergyinc.com>) contained well decline curves for the Haynesville Shale for a number of individual wells. These reported decline curves from these two sources were averaged together to develop a single reported well decline curve. Figure 16 shows the reported well decline curve and the derived well decline curve from the analysis described above. The total cumulative per-well production from the reported curves is 5.2 billion cubic feet (bcf), compared to 1.9 bcf for the derived well decline curves. This analysis assumes that the lower, derived well decline curve is representative of the low and moderate development scenarios, and the reported well decline curve obtained from the venture capital reports is representative of the aggressive development scenario.

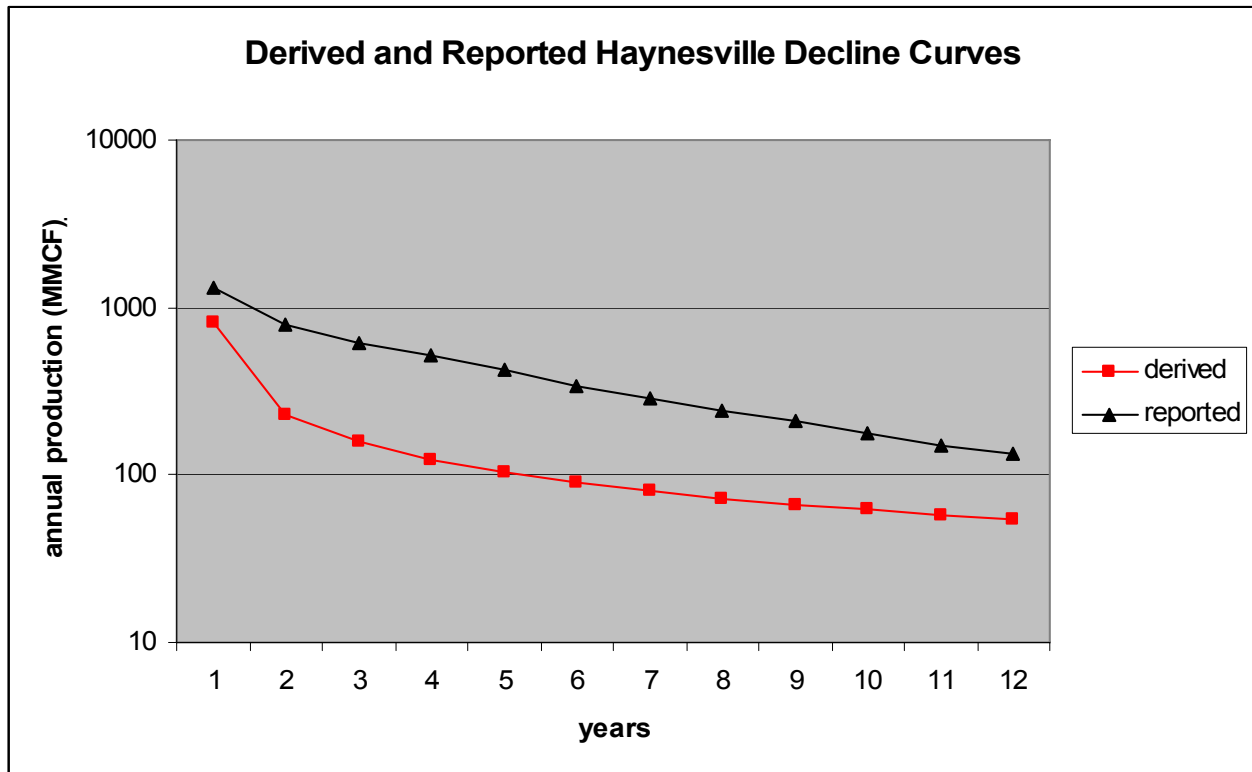
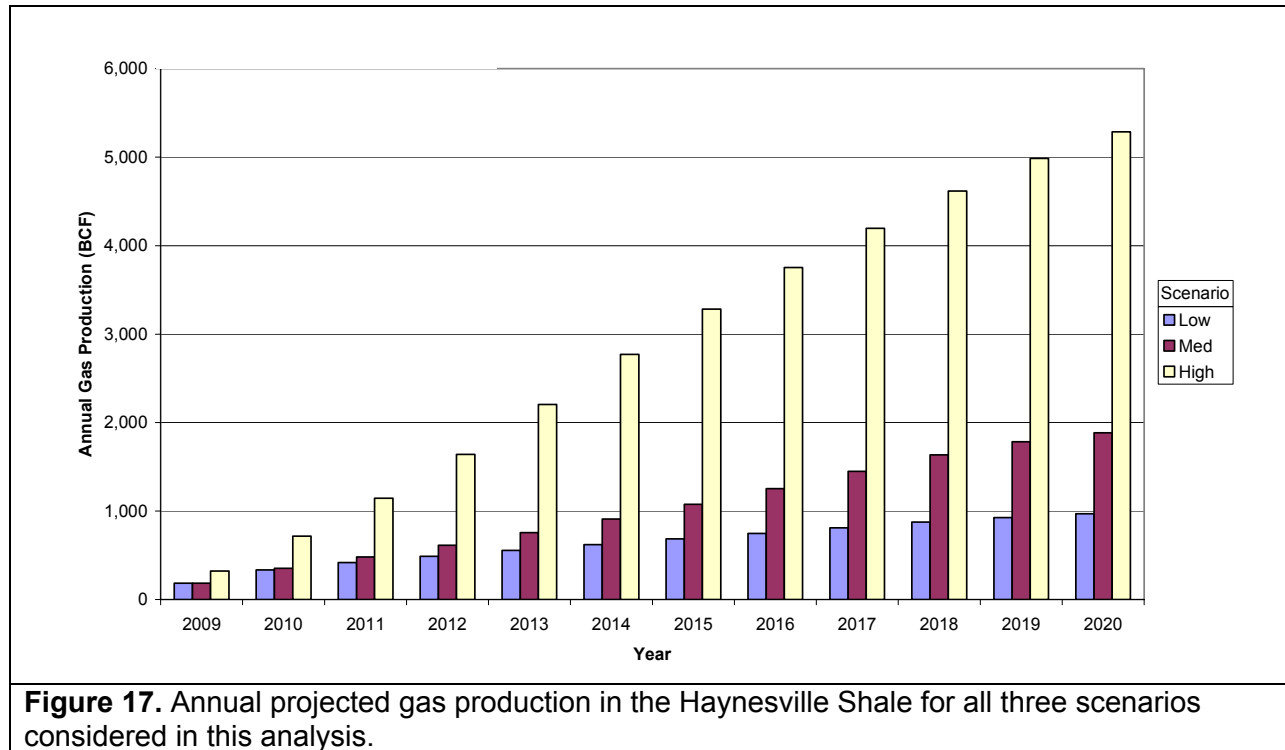


Figure 16. Well production decline curve derived from the analysis in this study, and a second reported well decline curve obtained from published venture capital reports on the Haynesville Shale.

Total Haynesville Shale production estimates for the period 2009-2020 were obtained by multiplying the number of active wells by the appropriate annual production rate determined from the decline curve and the year that each well was brought on-line, and summing over all active wells. Annual gas production for each scenario is shown in Figure 17 and also summarized below in Table 6. Cumulative gas production is shown in Figure 18 and summarized in Table 6.



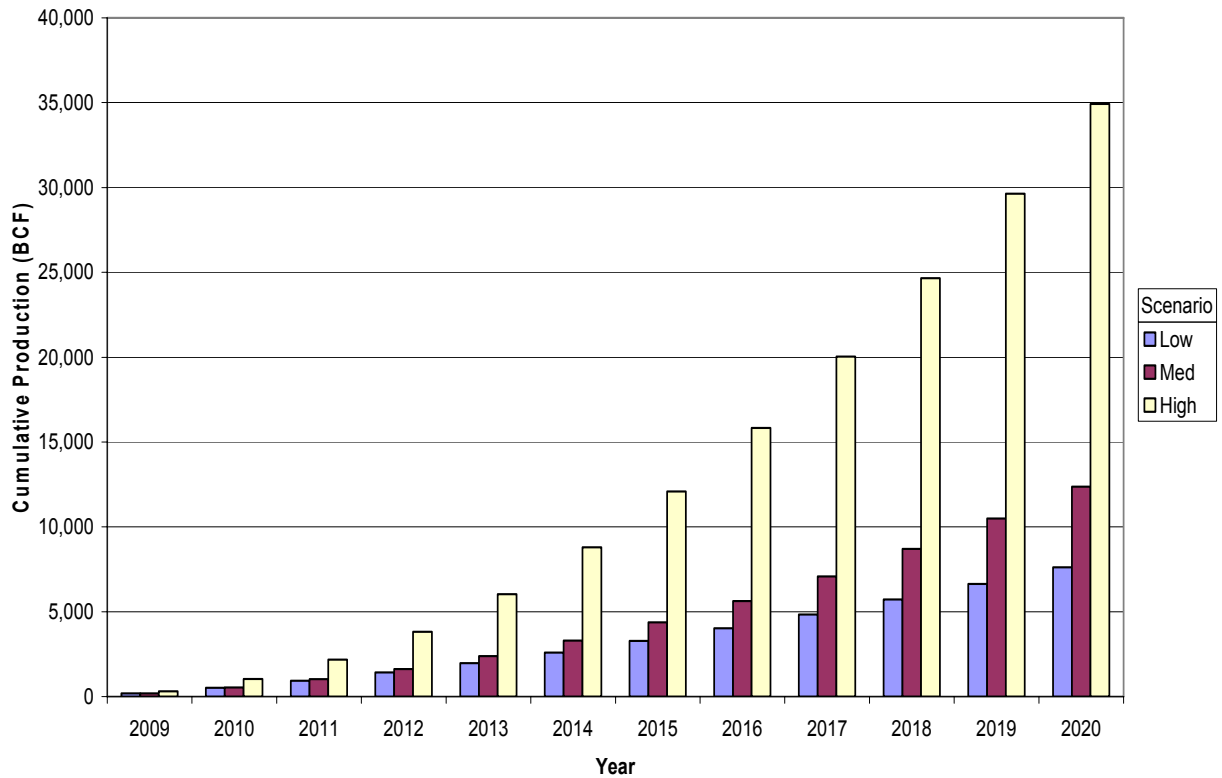


Figure 18. Total cumulative projected gas production in the Haynesville Shale for all three scenarios considered in this analysis.

Table 6. Summary of production projections for the three scenarios.

Calendar Year	Annual Gas Production (BCF/yr)			Cumulative Gas Production (BCF)		
	Low	Moderate	Aggressive	Low	Moderate	Aggressive
2009	185	185	323	185	185	323
2010	335	354	716	519	538	1,039
2011	417	481	1,146	936	1,020	2,185
2012	488	614	1,641	1,424	1,634	3,826
2013	555	756	2,204	1,979	2,390	6,030
2014	620	910	2,771	2,600	3,299	8,801
2015	684	1,076	3,282	3,284	4,375	12,083
2016	748	1,255	3,753	4,032	5,630	15,836
2017	811	1,448	4,197	4,843	7,077	20,033
2018	874	1,637	4,617	5,717	8,714	24,650
2019	928	1,782	4,986	6,645	10,496	29,636
2020	969	1,886	5,286	7,613	12,382	34,922

The 2020 cumulative production figures in Table 6 show a large difference between the low (7.6 TCF) and aggressive (35 TCF) scenarios, however both are within the range of published estimates of the technically recoverable reserves in the Haynesville Shale. For example, the analysis presented in the Tristone Venture Capital report on the Haynesville Shale estimated recoverable reserves to be 60 TCF, which is larger than even the aggressive scenario. Note that

the timeline in Table 6 only extends out to 2020, and the Haynesville Shale would presumably still be under development after 2020. Other published estimates of recoverable reserves in the Haynesville range from 7 TCF (Shreveport Times, 2009) to 250 TCF (Navigant Consulting, 2008). By comparison, the Barnett Shale has been estimated to have recoverable reserves of 25-50 TCF (e.g. Navigant Consulting, 2008).

Estimates of recoverable resources are highly uncertain, and tend to improve in accuracy as a formation is developed and mapped. The future year production figures provided in Table 6 represent a best estimate based on limited existing information on well production characteristics and producer plans for development. These estimates can be refined in the future through integration of additional well decline curve data that will become available with the passage of time and input from producers. Future production will depend sensitively on economic factors that will determine how profitable it is for energy companies to develop the Haynesville Shale. The production scenarios listed above are consistent with other estimates of the Haynesville Shale reserves and forecast production and will serve to provide a range of emissions estimates that may be used to assess future year impacts of the Haynesville Shale on air quality in Northeast Texas.

4.0 EMISSIONS INVENTORY DEVELOPMENT

This section describes the development of the emissions inventory for the Haynesville Shale for the three scenarios considered in this analysis: (1) the low development; (2) moderate development; and (3) aggressive development scenarios. The emissions inventory considers a number of gas production source categories which are described below, and provides a detailed description of the methodology used to estimate emissions on a unit level for each source category, the scale-up of these emissions to the entire Haynesville Shale region, and lists the sources of the data used in the inventory calculations.

4.1 Source Categories

The purpose of the Haynesville Shale emissions inventory is to quantify emissions of ozone precursors from the most significant source categories resulting from the development of the Haynesville Shale formation. In determining which source categories to include in the emissions inventory, ENVIRON consulted other studies, the most relevant of which are a study assessing CENRAP state oil and gas emission inventories (Bar-Ilan, et al. 2008) and a recent study documenting the development of an emissions inventory for the Barnett Shale (Armendariz, 2009). Source categories were grouped as either “exploration and production” or “midstream/gas processing” sources. The exploration and production grouping generally refers to source categories that would be located at the well site and would be owned and operated by production companies. The midstream/gas processing grouping refers primarily to compressor stations and major gas processing facilities that would be located downstream of the well sites and are typically owned and operated by midstream companies (but in the case of gas processing plants sometimes owned by production companies as well). Table 7 shows emission source categories included in the Haynesville Shale emission inventory.

Table 7. Haynesville Shale emission inventory source categories.

Phase	Source Category
Exploration and Production	Drill Rigs
	Fracing
	Completion Venting
	Blowdown Venting
	Fugitives
	Pneumatic device
	Heaters
	Dehydrators
	Flaring
	Wellhead Compressors
	Midstream/Gas Processing

ENVIRON generated emission estimates on a per unit of activity basis and then scaled the per unit of activity emissions to the area-wide level based on scaling parameters as listed in Table 8. In an effort to develop emission estimates based on the most accurate data possible, ENVIRON queried many of the major Haynesville Shale operators for data that could be used to estimate emissions for all source categories. As noted above, a survey questionnaire was distributed to

major producers asking for representative information on configurations of equipment, equipment specifications and usage, and process data on venting, dehydration and other processes (Appendix A). However, no operator was able to provide ENVIRON with information that could be used to refine emissions estimation inputs.

In the absence of Haynesville-specific data from operators, ENVIRON consulted other oil and gas emission inventory studies and adapted a methodology that could be used to estimate Haynesville Shale emissions. For exploration and production sources, emission rates were estimated based on data gathered primarily from Bar-Ilan, et al. 2008 and Armendariz, 2009. For midstream sources, emission rate estimates were based on 2004 emissions obtained from the LADEQ and 2005 emissions obtained from TCEQ scaled to future year Haynesville Shale formation production. 2004 emissions were used for Louisiana rather than 2005 to avoid using emissions data that are atypical due to the impact of Hurricane Katrina. The sources used to develop emissions estimation methodologies are summarized by source in Table 8.

Table 8. By source category scaling parameters and methodology.

Category	Scaling Parameter	Emissions Estimation Methodology
Drill Rigs	Spuds	CENRAP East Texas Basin (Bar-Ilan et al., 2008)
Fracing	Spuds	Barnett Shale Emission Inventory (Armendariz, 2009)
Completion Venting	Spuds	CENRAP East Texas Basin (Bar-Ilan et al., 2008)
Blowdown Venting	Active Well Count	CENRAP East Texas Basin (Bar-Ilan et al., 2008)
Fugitives	Active Well Count	CENRAP East Texas Basin (Bar-Ilan et al., 2008)
Pneumatic device	Active Well Count	CENRAP East Texas Basin (Bar-Ilan et al., 2008)
Heaters	Active Well Count	CENRAP East Texas Basin (Bar-Ilan et al., 2008)
Dehydrators	Gas Production	CENRAP East Texas Basin (Bar-Ilan et al., 2008)
Flaring	Gas Production	CENRAP East Texas Basin (Bar-Ilan et al., 2008)
Wellhead Compressors	Active Well Count	CENRAP East Texas Basin (Bar-Ilan et al., 2008)
Midstream Sources (Compressor Stations and Gas Plants)	Gas Production	2004-5 TCEQ and LADEQ Point Source Data

4.2 Base Year Methodologies

Methodologies are presented separately below for the exploration and production and midstream/gas processing source categories for base year (2009) emission calculations. The methodologies for developing unit-level emissions factors are described as well as the scale-up to the region-wide emissions for the entire Haynesville Shale region. For venting source categories, the emissions estimation methodology depends on knowledge of the gas composition to determine the VOC content of the gas.

ENVIRON attempted to obtain from Haynesville Shale operators, LDNR, and the Texas RRC natural gas composition analyses specific to the Haynesville Shale formation. Haynesville Shale operators were not able to provide natural gas composition data to ENVIRON, while LDNR and the Texas RRC did not have access to Haynesville Shale natural gas composition analyses. In the absence of a Haynesville Shale-specific natural gas composition, ENVIRON estimated gas composition based on data for a group of natural gas fields with gas characteristics similar to the Haynesville.

The production data for the 8 Louisiana wells used to derive the average Haynesville well decline curve showed that no condensate was produced at any of these wells. Discussions with producers (Alan Gradet, El Paso Corporation, personal communication, 2009; Nina Hutton, XTO, personal communication, 2009) as well as state regulatory agency personnel (Turner Williamson, RRC, personal communication, 2009) indicated that only dry gas and no condensate was expected to be produced from Haynesville Shale wells. Data for 10 gas fields in District 6, Northern California (California Department of Oil, Gas, and Geothermal Resources, personal communication, 2009) was used to approximate the Haynesville Shale gas composition. The Northern California gas composition data was chosen because, like the Haynesville Shale formation, these fields in Northern California produce dry natural gas exclusively, i.e. no significant quantities of condensate are extracted from these Northern California wells. Other Texas and Louisiana formations were considered for use as proxies for Haynesville Shale natural gas composition, but all formations for which ENVIRON was able to find natural gas compositions produced significant amounts of condensate.

The average of the natural gas compositions available for Northern California natural gas composition data for the following fields was used as an approximation of Haynesville natural gas composition: Afton, Beehive Bend, Bounde Creek, Butte Sink, Compton, Landing, Corning, Crossroads, Denverton, Dixon East and Dufour. The average derived natural gas composition and selected natural gas properties are shown in Table 9.

Table 9. Dry gas natural gas composition analysis and select properties.

Natural Gas Properties	
Heating Value of Gas (BTU/SCF)	950
Gas Molecular Weight	17.2
VOC Fraction (molar)	0.43%
VOC Molecular Weight	58.9
Component	Weight Fractions
CO ₂	0.3%
N ₂	11.8%
Methane C ₁	85.4%
Ethane C ₂	1.1%
Propane C ₃	0.5%
i-Butane i-C ₄	0.2%
n-Butane n-C ₄	0.2%
i-Pentane iC ₅	0.2%
n-Pentane nC ₅	0.1%
Hexanes C ₆	0.4%

4.2.1 Drill Rigs – Drilling Operations

Methodology

Drill rigs are most commonly powered by one or more diesel-fired compression-ignition engines. There are three primary functions of these engines:

- (1) Draw works – the draw works engine(s) provides power to the rotating drill bit and is responsible for the actual cutting operation of the rig
- (2) Mud pumps – the mud pump engine(s) provides pumping of the working fluid (often referred to as “mud”) into the bore hole for lubrication and cooling as well as pumping the spent fluid and debris material out of the bore hole
- (3) Generators – the generator engine(s) provides power to the drilling crew and incidental power for the entire site operation (lighting, HVAC, crew quarters, etc.), or provides power to drive the draw works and pump motors in a diesel-electric configuration

Although there are three primary functions of the rig engines, there may be more than one of each engine type with the additional engines either required for additional horsepower or used as back-up engines. Each of these three engine types is used for differing durations throughout a drilling process and is likely to have different load factors. In addition, each of the three engine types is likely to be of differing model years and hence Tier levels, since individual engines on rigs may be replaced on independent turnover schedules.

Emissions from a single drilling event are determined according to Equation 1:

$$\text{Equation (1) } E_{drilling} = \frac{EF_i \times HP_{total} \times LF_{average} \times t_{drilling}}{907,185}$$

where:

- $E_{drilling,engine}$ is the emissions from a drilling rig for drilling one well [ton/spud]
- EF_i is the emissions factor for all drilling rig engines for pollutant i [g/hp-hr]
- HP_{total} is the total horsepower of all engines on the drilling rig [hp]
- $LF_{average}$ is the average load factor for all engines on the drilling rig
- $t_{drilling}$ is the actual on-time of all engines on the drilling rig for a typical drilling event [hr/spud]

Extrapolation to Region-Wide Emissions

Drilling emissions from a single drilling event are scaled to formation-wide emissions according to Equation 2:

$$\text{Equation (2) } E_{drilling,TOTAL} = E_{drilling} \times S_{TOTAL}$$

where:

- $E_{drilling,TOTAL}$ is the total emissions in the formation from drilling activity [tons/yr]
- $E_{drilling}$ is the total emissions in the formation from single drilling event [tons/drilling event]
- S_{TOTAL} is the total number of spuds that occurred in the formation for a given calendar year

Input Data

In the absence of Haynesville Shale-specific data, drill rig properties and emission factors were taken from the East Texas Basin drill rig configuration identified in Bar-Ilan, et al. 2008. Haynesville Shale drilling duration was estimated based on LDNR online wells data (http://sonris-www.dnr.state.la.us/www_root/sonris_portal_1.htm) and was approximately 63 days, consistent with the drilling time used in the activity/production estimates described above. Table 10 shows the data used to estimate drill rig emissions.

Table 10. Drill rig emissions estimation inputs.

Property		Value	Source
Fuel Type		diesel	Bar-Ilan, et al. 2008 - East Texas Basin
Rated horsepower		3605	Bar-Ilan, et al. 2008 - East Texas Basin
Time used per spud (hrs)		1500	LDNR online oil and gas records
Load Factor		0.67	Bar-Ilan, et al. 2008 - East Texas Basin
Emission Factors (g/bhp-hr)	NOx	8.0	Bar-Ilan, et al. 2008 - East Texas Basin
	VOC	1.0	Bar-Ilan, et al. 2008 - East Texas Basin
	CO	5.0	Bar-Ilan, et al. 2008 - East Texas Basin

4.2.2 Fracing

Methodology

Fracing, short for hydraulic fracturing, is performed after a well bore has been drilled in order to stimulate natural gas production from the well bore. The process of fracing requires the use of pump engines to push large quantities of fluid and sand/glass into the well bore to hydraulically fracture the formation to increase surface area and release natural gas. Generators and other equipment may also be used in this process on an as needed basis.

Emissions from a single fracing event are determined according to Equation 3:

$$\text{Equation (3) } E_{fracing} = \frac{EF_i \times HP_{total} \times LF_{average} \times t_{fracing}}{907,185}$$

where:

$E_{fracing}$ is the emissions from fracing engines for one fracing event [ton/fracing event]

EF_i is the emissions factor for all fracing engines for pollutant i [g/hp-hr]

HP_{total} is the total horsepower of all engines on the fracing rig [hp]

$LF_{average}$ is the average load factor for all engines on the fracing rig

$t_{drilling}$ is the actual on-time of all engines on the fracing rig for a typical fracing event [hr/spud]

Extrapolation to Region-Wide Emissions

Fracing emissions from a single fracing event are scaled to formation-wide emissions according to Equation 4:

$$\text{Equation (4) } E_{fracing,TOTAL} = E_{fracing} \times S_{TOTAL}$$

where:

$E_{fracing,TOTAL}$ is the total emissions in the formation from fracing activity [tons/yr]

$E_{fracing}$ is the total emissions in the formation from single fracing event [tons/fracing event]

S_{TOTAL} is the total number of spuds that occurred in the formation for a given calendar year

Input Data

In the absence of Haynesville Shale specific data, fracing engine power and activity were taken from a study in which emissions were estimated for the Barnett Shale formation (Armendariz, 2009) and emission factors were taken from the EPA NONROAD model (EPA, 2008).

Table 11. Fracing emissions estimation inputs.

Property		Value	Source
Fuel Type		diesel	Armendariz, 2009 (Barnett Shale EI)
Rated horsepower		1000	Armendariz, 2009 (Barnett Shale EI)
Time used (hrs)		54	Armendariz, 2009 (Barnett Shale EI)
Load Factor		0.5	Armendariz, 2009 (Barnett Shale EI)
Emission Factors (g/bhp-hr)	NO _x	8.0	EPA NONROAD Base Engine
	VOC	1.3	EPA NONROAD Base Engine
	CO	5.0	EPA NONROAD Base Engine

4.2.3 Completion Venting

Methodology

Once drilling and other well construction activities are finished, a gas well must be completed in order to begin producing gas. 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 CO₂ and/or N₂) and to bring the gas composition to pipeline grade. During this process, significant amounts of gas may be vented, and this gas can be a VOC emissions source. This analysis assumes that the composition of the completion venting gas is identical to production gas, because no detailed information is available on the completion venting gas specifically.

Emissions from well completions are estimated on the basis of the volume of gas vented during completion and the average VOC content of that gas, obtained from gas composition analyses. Flaring and/or green completion practices may be used to control emissions from the completion process. Flaring typically has a control efficiency greater than 95% for VOC emissions, and green completion practices have a range of control efficiencies depending on the amount of vented gas that is captured during the process.

The calculation methodology for estimating emissions from a single completion event is shown below in Equation 5:

$$\text{Equation (5)} \quad E_{\text{completion},i} = \left(\frac{P \times (V_{\text{vented}})}{\left(\frac{R}{MW_{\text{gas}}} \right) \times T \times 3.5 \times 10^{-5}} \right) \times \frac{f_i}{907200}$$

where:

$E_{\text{completion},i}$ is the emissions of pollutant i from a single completion event [ton/event]

P is atmospheric pressure [1 atm]

V_{vented} is the volume of vented gas per completion [MCF/event]

R is the universal gas constant [0.082 L-atm/mol-K]

MW_{gas} is the molecular weight of the gas [g/mol]

T is the atmospheric temperature [298 K]

f_i is the mass fraction of pollutant i in the completion venting gas

Extrapolation to Region-Wide Emissions

The total emissions from all completions occurring in a formation are evaluated following Equation 6:

$$\text{Equation (6)} \quad E_{\text{completion},\text{TOTAL}} = E_{\text{completion},i} \times S_{\text{formation}} \times (1 - 0.95c_{\text{flare}} - c_{\text{green}})$$

where:

$E_{\text{completion},\text{TOTAL}}$ are the total emissions formation-wide from completions [tons/year]

$E_{\text{completion},i}$ are the completion emissions from a single completion event [tons/event]

c_{flare} is the fraction of completions in the formation that were controlled by flares

c_{green} is the fraction of completions in the formation that were controlled by green completion techniques

$S_{formation}$ is the formation-wide spud count in the formation for a given calendar year

Input Data

In the absence of Haynesville Shale specific data, completion venting data were taken from the East Texas Basin data as identified in Bar-Ilan, et al. 2008. Table 12 shows the data used to estimate completion venting emissions. Note that the data used in Bar-Ilan et al. (2008) were for the year 2002, and the fraction of green completions in 2009 is likely to be higher. The emission estimate for completion venting emissions is therefore conservative as the venting emissions will be lower if a higher percentage of completions are carried out using green techniques.

Table 12. Completion venting emissions estimation inputs.

Property	Value	Source
Volume of Gas Vented Per Initial Completion (MCF) uncontrolled	2417	Bar-Ilan et al. 2008 - East Texas Basin
Fraction of completions in the formation controlled by flares	0%	Bar-Ilan et al. 2008 - East Texas Basin
Fraction of completions in the formation controlled by green completion techniques	0%	Bar-Ilan et al. 2008 - East Texas Basin

4.2.4 Blowdown Venting

Methodology

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. Sometimes 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 causing a pressure drop across the well orifice that restricts gas flow. Because gas is directly vented from the blowdown event, blowdowns can be a source of VOC emissions.

Emissions from blowdowns are estimated on the basis of the volume of gas vented during a blowdown and the average pollutant content of that gas obtained from gas composition analyses. This methodology is very similar to that of completion venting. Flaring and/or green practices may be used to control emissions from the blowdown process. Flaring typically has a 98% control efficiency for VOC emissions, and green practices have a range of control efficiencies depending on the amount of vented gas that is captured during the process.

The calculation methodology for estimating emissions from a single blowdown event is shown below in Equation 7:

$$\text{Equation (7)} \quad E_{\text{blowdown},i} = \left(\frac{P \times (V_{\text{vented}})}{\left(\frac{R}{MW_{\text{gas}}} \right) \times T \times 3.5 \times 10^{-5}} \right) \times \frac{f_i}{907200}$$

where:

- $E_{\text{blowdown},i}$ is the emissions of pollutant i from a single blowdown event [ton/event]
- P is atmospheric pressure [1 atm]
- V_{vented} is the volume of vented gas per blowdown [MCF/event]
- R is the universal gas constant [0.082 L-atm/mol-K]
- MW_{gas} is the molecular weight of the gas [g/mol]
- T is the atmospheric temperature [298 K]
- f_i is the mass fraction of pollutant i in the vented gas

Extrapolation to Region-Wide Emissions

The total emissions from all blowdowns occurring in a formation are evaluated following Equation 8:

$$\text{Equation (8)} \quad E_{\text{blowdown},\text{TOTAL}} = E_{\text{blowdown},i} \times N_{\text{blowdown}} \times N_{\text{wells}} \times (1 - 0.95c_{\text{flare}} - c_{\text{green}})$$

where:

- $E_{\text{blowdown},\text{TOTAL}}$ are the total emissions formation-wide from blowdowns [tons/year]
- $E_{\text{blowdown},i}$ are the blowdown emissions from a single blowdown event [tons/event]
- c_{flare} is the fraction of blowdowns in the formation that were controlled by flares

c_{green} is the fraction of blowdowns in the formation that were controlled by green techniques

$N_{blowdown}$ is the number of blowdowns per well in the formation

N_{wells} is the total number of active wells in the formation for a given calendar year

Input Data

In the absence of Haynesville Shale specific data, blowdown venting data were taken from the East Texas Basin data as identified in Bar-Ilan, et al. 2008. Table 13 shows the data used to estimate blowdown venting emissions.

Table 13. Blowdown venting emissions estimation inputs.

Property	Value	Source
Blowdown Frequency (events/well/year)	1	Bar-Ilan et al. 2008 - East Texas Basin
Volume of Gas Vented Per Blowdown (MCF)	32	Bar-Ilan et al. 2008 - East Texas Basin
Fraction of completions in the formation controlled by flares	0%	Bar-Ilan et al. 2008 - East Texas Basin
Fraction of completions in the formation controlled by green completion techniques	0%	Bar-Ilan et al. 2008 - East Texas Basin

4.2.5 Fugitives (Leaks)

Methodology

Fugitive emissions refer to emissions of produced gas through connectors, flanges, valves and other pipeline hardware at the wellhead. These emissions are essentially leaks that result from high-pressure gas moving through the various hardware components of a wellhead assembly. It should be noted that this source category is distinct from fugitive emissions from pipelines, which are not considered here, and refers only to components located at wellheads. Because the fugitive emissions are produced gas, this source category can be a source of VOC emissions.

Fugitive emissions from wellheads are estimated using AP-42 emissions factors (EPA, 1995) and component counts for typical well setups. The well setup is typically characterized by the type of equipment installed and by the type of service to which the equipment applies – gas, light liquid, heavy liquid, or water. Typical well setup information for the East Texas Basin was developed by Bar-Ilan et al. (2008) and was adapted for this study in order to take into account the lack of condensate produced to date by Haynesville Shale wells. The count of components in heavy and light oil service in Bar-Ilan et al. (2008) were set to zero in this study. This assumption may need to be revised in the future if Haynesville Shale wells are shown to produce condensate.

Fugitive emissions for an individual typical well are estimated according to Equation 9:

$$\text{Equation (9)} \quad E_{fugitive,j} = \sum_i EF_i \times N_i \times t_{annual} \times Y_j \times 0.0011$$

where:

$E_{fugitive}$ is the fugitive emissions for a single typical well for pollutant j [ton/yr/well]

EF_i is the emission factor of TOC for a single component i [kg/hr/component]

N_i is the total number of components of type i

t_{annual} is the annual number of hours the well is in operation [8760 hr/yr]

Y_j is the mass fraction of pollutant j to TOC in the vented gas

Extrapolation to Region-Wide Emissions

Formation-wide fugitive emissions are estimated according to Equation 10:

$$\text{Equation (10)} \quad E_{fugitive,TOTAL} = E_{fugitive,j} \times N_{well}$$

where:

$E_{fugitive,TOTAL}$ is the total fugitive emissions in the formation [ton/yr]

$E_{fugitive,j}$ is the fugitive emissions for a single well of pollutant j [ton/yr]

N_{well} is the total number of active wells in the formation for calendar year 2002

Input Data

In the absence of Haynesville Shale specific data, fugitives data were taken from the East Texas Basin data as identified in Bar-Ilan, et al. 2008. Table 14 shows the data used to estimate fugitive emissions.

Table 14. Fugitives emissions estimation inputs.

Device Type	Service	No. of Devices Per Typical Well*
valves	Gas	12
valves	Heavy Oil	0
valves	Light Oil	0
valves	Water/Oil	0
pump seals	Gas	0
pump seals	Heavy Oil	0
pump seals	Light Oil	0
pump seals	Water/Oil	0
others	Gas	0
others	Heavy Oil	0
others	Light Oil	0
others	Water/Oil	0
connectors	Gas	35
connectors	Heavy Oil	0
connectors	Light Oil	0
connectors	Water/Oil	0
flanges	Gas	18
flanges	Heavy Oil	0
flanges	Light Oil	0
flanges	Water/Oil	0
open-ended lines	Gas	6
open-ended lines	Heavy Oil	0
open-ended lines	Light Oil	0
open-ended lines	Water/Oil	0

* source: Bar-Ilan et al. 2008 - East Texas Basin

4.2.6 Pneumatic Devices

Methodology

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. All of these devices vent the working fluid, which is produced gas, and are therefore a source of VOC emissions. Like fugitive emissions, the emissions from these devices are typically estimated by obtaining a configuration of a typical well, including the count of devices by type at the typical well. Emissions rates of gas from these pneumatic devices have been studied extensively by the EPA as part of the Natural Gas Star program (EPA, 2004), which are the source of quantitative emissions factors for pneumatic devices in this analysis.

The methodology for estimating the emissions from pneumatic devices for a single typical well is shown in Equation 11:

$$\text{Equation (11)} \quad E_{pneumatic,j} = \frac{f_j}{907200} \left(\sum_i \dot{V}_i \times N_i \times t_{annual} \right) \times \frac{P}{\left(\left(\frac{R}{MW_{gas}} \right) \times T \times 3.5 \times 10^{-5} \right)}$$

where:

$E_{pneumatic,j}$ is the total emissions of pollutant j from all pneumatic devices for a typical well [ton/year/well]

\dot{V}_i is the volumetric bleed rate from device i [MCF/hr/device]

N_i is the total number of device i owned by the participating companies

t_{annual} is the number of hours per year that devices were operating [8760 hr/yr]

P is the atmospheric pressure [1 atm]

R is the universal gas constant [0.082 L-atm/mol-K]

MW_{gas} is the molecular weight of the gas [g/mol]

T is the atmospheric temperature [298 K]

f_j is the mass fraction of pollutant j in the vented gas

Extrapolation to Region-Wide Emissions

Formation-wide pneumatic device emissions were estimated according to Equation 12:

$$\text{Equation (12)} \quad E_{pneumatic,TOTAL} = E_{pneumatic,j} \times N_{well}$$

where:

$E_{pneumatic,TOTAL}$ is the total pneumatic device emissions of pollutant j in the formation [ton/yr]

$E_{pneumatic,j}$ is the pneumatic device emissions of pollutant j for a single typical well [ton/yr/well]

N_{well} is the total number of active wells in the formation for a given calendar year

Input Data

In the absence of Haynesville Shale specific data, pneumatic devices data were taken from the East Texas Basin data as identified in Bar-Ilan, et al. 2008. Table 15 shows the data used to estimate pneumatic devices emissions.

Table 15. Pneumatic devices emissions estimation inputs.

Device Type	No. of Devices*	Bleed Rate (SCF/hr)*
Liquid level controller	2	31
Positioner	-	15
Pressure controller	1	17
Transducer	-	14
Other	-	-
Totals	3	

* source: Bar-Ilan et al. 2008 - East Texas Basin

4.2.7 Heaters

Methodology

Heaters and boilers in use at natural gas production facilities are generally natural gas-fired external combustors. 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. This latter usage is covered under the dehydrator source category methodology description below. It should also be noted that this category does not consider heaters in use at large central facilities such as gas processing plants.

Heaters are primarily considered a NO_x emissions source category, although they are also a minor source of CO, VOC and PM emissions. Heater emissions are calculated on the basis of the emissions factor of the heater, and the annual flow rate of gas to the heater. The annual gas flow rate is calculated from the BTU rating of the heater and the local BTU content of the gas.

The basic methodology for estimating emissions for a single heater is shown in Equation 13:

$$\text{Equation (13)} \quad E_{heater} = \frac{EF_{heater} \times Q_{heater} \times t_{annual} \times hc}{(HV_{local} \times 10^6 \times 2000)}$$

where:

E_{heater} is the emissions from a given heater [ton/yr]

EF_{heater} is the emission factor for a heater for a given pollutant [lb/million scf]

Q_{heater} is the heater MMBTU/hr rating [MMBTU_{rated}/hr]

HV_{local} is the local natural gas heating value [MMBTU_{local}/scf]

t_{annual} is the annual hours of operation [hr/yr]

hc is a heater cycling fraction to account for the fraction of operating hours that the heater is firing (if available)

Extrapolation to Region-Wide Emissions

Formation-wide heater emissions are estimated by determining the typical number of heaters per well and scaling up by well count. This is shown in Equation 14:

$$\text{Equation (14)} \quad E_{heater,TOTAL} = (E_{heater}) \times N_{heater} \times W_{TOTAL} / 2000$$

where:

$E_{heater,TOTAL}$ is the total heater emissions in the formation [ton/yr]

E_{heater} is the total emissions from a single heater [lb/yr]

W_{TOTAL} is the total number of wells in the formation

N_{heater} is the typical number of heaters per well in the formation

Input Data

In the absence of Haynesville Shale-specific data, heater data were taken from the East Texas Basin data as identified in Bar-Ilan, et al. 2008. Table 16 shows the data used to estimate heater emissions.

Table 16. Heater emissions estimation inputs.

Property		Value	Source
Type		separator/tank	Bar-Ilan et al. 2008 - East Texas Basin
Typical Fuel		Natural Gas	Bar-Ilan et al. 2008 - East Texas Basin
No. per Typical Well Setup		0.95	Bar-Ilan et al. 2008 - East Texas Basin
Heater MMBtu Rating (MMBTU/hr)		0.64	Bar-Ilan et al. 2008 - East Texas Basin
Annual Activity (hours)		2,982	Bar-Ilan et al. 2008 - East Texas Basin
Heater Cycling		1.00	Bar-Ilan et al. 2008 - East Texas Basin
Emission Factors (lb/MMscf)	NO _x	100	Bar-Ilan et al. 2008 - East Texas Basin
	VOC	5.50	Bar-Ilan et al. 2008 - East Texas Basin
	CO	84	Bar-Ilan et al. 2008 - East Texas Basin

4.2.8 Dehydrators

Methodology

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. There are both liquid dessicant and solid dessicant dehydrators, but in practice liquid dessicant dehydrators are overwhelmingly used. The liquid dessicant is typically either glycol, diethylene glycol (DEG) or triethylene glycol (TEG). Glycol dehydrators have two emissions sources: the still vent from which some fugitive gas is emitted; and the reboiler which is essentially a heater and has similar emissions characteristics to a heater. For both still vent and heater emissions from dehydrators, emissions factors are typically developed using the process simulation software GLYCalc, developed by the Gas Research Institute. The producer survey effort did not yield usable information to generate per-dehydrator or per-unit production emissions factors for dehydrator still vents and reboilers, and therefore broad regional emissions factors per unit production from Bar-Ilan et al. 2008 for the East Texas Basin are used in this analysis. These per-unit production emissions factors are used to directly estimate regional dehydrator emissions.

The basic methodology for estimating formation-wide emissions from dehydrator still vents is shown in Equation 15:

$$\text{Equation (15)} \quad E_{dehydrator} = \frac{EF_{dehydrator} \times P_{formation}}{2 \times 10^6}$$

where:

$E_{dehydrator}$ is the formation-wide emissions from dehydrators [ton-VOC/year]

$EF_{dehydrator}$ is the emission factor per unit production [lb/MMSCF]

$P_{formation}$ is the formation-wide gas production [MCF/year]

Input Data

In the absence of Haynesville Shale specific data, dehydrators per unit of production emissions data were taken from the East Texas Basin data as identified in Bar-Ilan, et .al. 2008. Table 17 shows the data used to estimate dehydrator emissions.

Table 17. Dehydrator emissions estimation inputs.

Property		Value	Source
Emission Factors (lb/MMSCF produced gas)	NO _x	0.05	Bar-Ilan et al. 2008 - East Texas Basin
	VOC	0.11	Bar-Ilan et al. 2008 - East Texas Basin
	CO	2.62	Bar-Ilan et al. 2008 - East Texas Basin

4.2.9 Flaring

Methodology

Flaring is used for a number of processes to control VOC and other emissions. Based on emissions estimation guidance for the East Texas Basin in Bar-Ilan, et al. 2008, the only flaring process considered for this analysis is gas dehydration. For dehydrators the still vent emissions may be controlled by flaring. The vented gas is routed to a combustor which then burns the gas to remove upwards of 95% of VOC emissions. However, these flares are themselves a source of NOx and CO emissions.

The methodology for estimating formation-wide emissions from dehydration processes is described in Equation 16:

$$\text{Equation (16) } E_{\text{flare,dehydration}} = \left(\frac{EF_i \times Q_{\text{flare,dehydrator}} \times HV}{1000} \times \frac{P_{\text{basin,gas}}}{10^6} \right) / 2000$$

where:

$E_{\text{flare,dehydration}}$ is the basin-wide flaring emissions from flaring of dehydrator vent gas [ton/yr]

EF_i is the emissions factor for pollutant i [lb/MMBtu]

$Q_{\text{flare,dehydrator}}$ is the volume of dehydrator still vent gas flared per unit of gas produced in the basin [MCF/million MCF produced]

HV is the local heating value of the gas [BTU/scf]

$P_{\text{basin,gas}}$ is the basin-wide gas production [MCF]

Input Data

In the absence of Haynesville Shale-specific data, flaring data were taken from the East Texas Basin data as identified in Bar-Ilan, et al. 2008. Table 18 shows the data used to estimate flaring emissions.

Table 18. Flaring emissions estimation inputs.

Property		Value	Source
Flared Process		Dehydrator	Bar-Ilan et al. 2008 - East Texas Basin
Gas Flared per Unit of Activity Surrogate (MCF flared / million MCF produced)		8.84	Bar-Ilan et al. 2008 - East Texas Basin
Emission Factors (lb/MMbtu)	NOx	0.068	Bar-Ilan et al. 2008 - East Texas Basin
	CO	0.370	Bar-Ilan et al. 2008 - East Texas Basin

4.2.10 Wellhead Compressors

Methodology

Wellhead compressor engines can represent a significant NO_x area emissions source category. These engines are used to boost produced gas pressure from downhole pressure to the required pressure for delivery to a transmission pipeline. Generally these engines are natural-gas powered, using the produced gas (after some separation and dehydration) as fuel for a spark-ignited internal combustion engine. They generally operate 8760 hours per year with a minimum of down-time. Any down-time is typically associated with repairs or routine maintenance, but gas production companies attempt to minimize this down-time to the extent possible.

The most common makes of wellhead compressor engines are Caterpillar, Waukesha, and Ajax. Generally wellhead compressor engines are uncontrolled, but two distinct types are utilized: “rich-burn” engines that are characterized by NO_x emissions factors in the range of approximately 10 – 20 g/bhp-hr; and “lean-burn” engines that are characterized by NO_x emissions factors in the range of approximately 1.0 – 5.0 g/bhp-hr. The exact NO_x emissions factors depend on the horsepower of the engine, the make and model, the model year of the engine, and whether the engine has been converted from a rich-burn to a lean-burn engine.

The basic methodology for estimating emissions from wellhead compressor engines is shown in Equation (17):

$$\text{Equation (17)} \quad E_{engine} = \frac{EF_i \times HP \times LF \times t_{annual}}{907,185}$$

where:

- E_{engine} are emissions from a rich-burn or lean-burn compressor engine [ton/year/engine]
- EF_i is the emissions factor of pollutant i [g/hp-hr] (note that this may be different for NO_x emissions from rich-burn vs. lean-burn engines)
- HP is the horsepower of the engine [hp]
- LF is the load factor of the engine
- t_{annual} is the annual number of hours the engine is used [hr/yr]

Extrapolation to Region-Wide Emissions

The emissions are scaled to the formation level using the ratios of rich-burn engines to total engines, lean-burn engines to total engines, the fraction of wells with wellhead compressor engines, and the total well count in the formation, according to Equation (18):

$$\text{Equation (18)} \quad E_{engine,TOTAL} = (C_{Rich} E_{engine,Rich} + C_{Lean} E_{engine,Lean}) \times W_{TOTAL} \times f_{wellhead}$$

where:

- $E_{engine,TOTAL}$ is the total emissions from compressor engines in the formation [ton/yr]
- $E_{engine,Rich}$ is the total emissions from a single representative rich-burn compressor engine per Equation (1) [ton/yr]
- $E_{engine,Lean}$ is the total emissions from a single representative lean-burn compressor engine per Equation (1) [ton/yr]

C_{Rich} is the fraction of wellhead compressors in the formation that are rich-burn
 C_{Lean} is the fraction of wellhead compressors in the formation that are lean-burn
 W_{TOTAL} is the total well count in the formation
 $f_{wellhead}$ is the fraction of all wells in the formation with wellhead compressor engines

Input Data

In the absence of Haynesville Shale specific data, wellhead compressor data were taken from the East Texas Basin data as identified in Bar-Ilan, et al. 2008. Table 19 shows the data used to estimate wellhead compressor emissions. A key uncertainty in this calculation is the fraction of wells served by wellhead compressors. The amount of wellhead compression required by a gas well changes over the life of the well. Newly-drilled wells tend to require little compression, but as the gas reservoir is drained, more compression is needed to produce and transport the gas. The timing of the need for additional compressions depends on the well and the characteristics of the formation (e.g. field pressures, production, etc.). The Haynesville Shale is just beginning development, so it is reasonable to assume that little compression is required at present. It has been noted (Alan Gradet, El Paso Corporation, personal communication, 2009) that some Haynesville Shale wells have relatively steep decline curves and may require wellhead compression sooner than might typically be expected for a gas well in this region. If this is the case, the emissions estimates provided below will likely underestimate emissions from wellhead compression with the underestimate increasing in magnitude from 2010 to 2020. Updates to the wellhead compression calculation based on actual well head compressor usage data provided by producers are an important area for refinement of this emission inventory.

Table 19. Wellhead compressor emissions estimation inputs.

Description		Value	Source
Typical Engine Operational Characteristics	Fraction of wells serviced by wellhead compressors	2%	Bar-Ilan et al. 2008 - East Texas Basin
	Fuel Type	Natural Gas	Bar-Ilan et al. 2008 - East Texas Basin
	Rated Horsepower	242	Bar-Ilan et al. 2008 - East Texas Basin
	Annual Activity	8760	Bar-Ilan et al. 2008 - East Texas Basin
	Load Factor	85%	Bar-Ilan et al. 2008 - East Texas Basin
	Emission Controls	None	Bar-Ilan et al. 2008 - East Texas Basin
	Fraction Rich Burn	97%	Bar-Ilan et al. 2008 - East Texas Basin
	Fraction Lean Burn	3%	Bar-Ilan et al. 2008 - East Texas Basin
Typical Emission Factors for Rich Burn (g/bhp-hr)	NOx	2.00	EPA, 2008 - New Source Performance Standards (NSPS)
	VOC	1.00	EPA, 2008 - NSPS
	CO	4.00	EPA, 2008 - NSPS
Typical Emission Factors for Lean Burn (g/bhp-hr)	NOx	2.00	EPA, 2008 - NSPS
	VOC	1.00	EPA, 2008 - NSPS
	CO	4.00	EPA, 2008 - NSPS

4.2.11 Midstream/Gas Processing Sources

Another source category of emissions due to development of the Haynesville Shale is the emissions from midstream sources due to the transportation and processing of produced natural gas from the Haynesville Shale formation. Two major source categories are compressor stations and natural gas processing plants. New pipelines are in the process of being constructed for the purpose of transporting the Haynesville Shale natural gas to markets but it is beyond the scope of this study to determine emissions due to their construction. As discussed above, it does not appear that any new processing plants are permitted, and sufficient processing infrastructure for the quantities of natural gas that the Haynesville Shale formation may produce in the near term appears to be in place. 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. The validity of this method as a reasonable estimation is based on assumptions that 2004 Haynesville Shale region natural gas was processed relatively locally and that Haynesville Shale region natural gas was not shipped elsewhere for processing. It is also assumed that natural gas losses in the 2004 Haynesville region are fractionally equivalent to predicted Haynesville Shale formation losses. The major midstream point sources in Haynesville Shale region and surrounding areas are shown in Figure 4, and the Haynesville Shale region considered for purposes of the midstream sources is shown in Figure 5.

Total 2004 natural gas production from the counties highlighted in Figure 5 was 1,144 billion cubic feet, as summarized in Table 20 below.

Table 20. 2004 gas production in all Texas counties and Louisiana parishes considered part of the Haynesville Shale midstream/gas processing region.

Texas County	Gas Production (MCF)	Louisiana Parish	Gas Production (MCF)
Anderson	7,193,009	Bienville	55,493,797
Camp	896,592	Bossier	97,277,797
Cass	3,643,819	Caddo	24,506,628
Cherokee	14,491,485	Claiborne	24,182,308
Franklin	3,708,653	De Soto	70,450,043
Gregg	60,917,256	Jackson	101,998,043
Harrison	62,928,011	Lincoln	17,483,031
Henderson	1,499,151	Natchitoches	1,818,444
Hopkins	1,234,282	Red River	2,016,840
Marion	4,796,210	Sabine	3,364,247
Morris	0	Webster	51,192,075
Nacogdoches	48,136,114	Winn	593,558
Panola	251,748,856		
Rains	1,864,400		
Rusk	78,501,560		
Sabine	0		
San Augustine	36,401		
Shelby	40,035,140		
Smith	39,905,362		
Titus	0		
Upshur	54,270,183		
Van Zandt	8,020,363		
Wood	9,788,171		
TOTAL	693,615,018		450,376,811

For each scenario, and each year, emissions from the each point source are estimated according to Equation 19

$$\text{Equation (19) } E_i = E_{i,2004} \frac{P_{\text{formation}}}{P_{\text{region},2004}}$$

where:

E_i are emissions from a midstream source due to Haynesville Shale formation production [ton/year]

$E_{i,2004}$ are emissions from a midstream source in 2004 [ton/year]

$P_{\text{formation}}$ is the production from the Haynesville Shale formation [MCF/year]

$P_{\text{region},2004}$ is the production from the Haynesville Shale region in 2004 [MCF/year]

4.3 Future Year Control Methodology

This methodology considered any “on-the-books” federal or state regulations that would affect the emissions projections.

Table 21 below lists the “on-the-books” federal and state regulations that affect emissions source categories in the oil and gas industry, and the action taken to adjust the 2012 emissions inventory appropriately. A more detailed description follows of the methodology used to address each of these regulations as they affected the uncontrolled future year Haynesville Shale formation emissions projections.

The uncontrolled future year emissions were adjusted based on the proposed actions or control factors developed for each regulation described in Table 21 to account for how these regulations may affect any oil and gas source category considered in this inventory.

Table 21. Summary of federal and state “on-the-books” regulations affecting the oil and gas source categories considered in this inventory.

Source Category	Regulation	Enforcing Agency	Effective Date	Implementation in the Haynesville Shale formation Emissions Projections
Federal				
Drill Rigs, Fracing	Nonroad engine Tier standards (1-4) (EPA, 2005)	US EPA	Phase in from 1996 - 2014	EPA NONROAD model used to create county-level control factors for the drill rig SCC to account for fleet turnover.
All New Spark-Ignited Stationary Engines	New Source Performance Stds. (NSPS) (EPA, 2008)	US EPA	Phase in from 2008 - 2011	Control factors developed for wellhead engines considering the specific composition of engines in the inventory.
State				
Engines	East Texas Combustion Rule	TCEQ	Effective from 2010	Control factors developed for wellhead engines considering the specific composition of engines in the inventory.

Nonroad Diesel Engine Standards and Fuel Sulfur Standards

The EPA NONROAD2008 model was run with diesel fuel inputs of 500 ppm for 2009 to 2010 and 15 ppm for 2010 to 2020. The model outputs were used to develop emissions per unit population for “other oil field equipment” (SCC 2270010010) for the calendar years 2009 to 2020. These emissions per unit population reflect the predicted fleet mix of engines – for various tier standards from baseline uncontrolled engines through Tier IV engines – and are used as a representation of fleet turnover for drilling rigs and fracing engines. The ratios of the per unit emissions in a future year to those in 2009 for each were taken to be the control factors accounting for federal non-road tier standards.

Spark Ignition Engines

New Source Performance Standards for Stationary Spark-Ignited Engines

The EPA has promulgated a new regulation covering new stationary, spark-ignited engines of various horsepower classes. The regulation is assumed to apply to central compressor engines, wellhead and lateral compressor engines, and other engines that are stationary, spark-ignited

natural gas engines. The regulation requires new engines of various horsepower classes to meet increasingly stringent NO_x and VOC emission standards over the phase-in period of the regulation.

For engines less than 25 horsepower, Table 22 shows the requirements of the NSPS regulation.

Table 22. Federal NSPS emissions standards for engines less than 25 horsepower.

HP Range ^a	Emissions Standards Requirement in (g/hp-hr) ^b		
	HC + NO _x	NMHC + NO _x ^c	CO
≤ 25 Hp			
Class I	16.1 (12.0)	14.8 (11.0)	610 (455)
Class I -A	50-37	-	-
Class I -B	40 (30)	37 (27.6)	
Class II	12.1 (9.0)	11.3 (8.4)	

^a. Class I-A: Engines with displacement less than 66 cubic centimeters (cc); Class 1-B: Engines with displacement greater than or equal to 66cc and less than 100cc; Class I: Engines with displacement greater than or equal to 100 cc and less than 225 cc

^b. Modified and reconstructed engines manufactured prior to July 1, 2008, must meet the standards applicable to engines manufactured after July 1, 2008

^c. NMHC+NO_x standards are applicable only to natural gas fueled engines at the option of the manufacturer, in lieu of HC+NO_x standards

For engines in the horsepower range 25 – 100 horsepower, Table 23 shows the requirements of the NSPS regulation.

Table 23. Federal NSPS emissions standards for engines greater than 25 horsepower but less than 100 horsepower.

HP Range	Manufacture Date	Emissions Standards Requirement (g/hp-hr)	
		HC + NO _x	CO
25<HP<100	1-Jul-08	3.8	6.5
	1-Jul-08 (severe duty)	3.8	200

For engines in the horsepower range 100 – 1,350 horsepower, Table 24 shows the requirements of the NSPS regulation.

Table 24. Federal NSPS emissions standards for engines greater than 25 horsepower but less than 100 horsepower.

Engine Type and Fuel	HP Range	Manufacture Date	Emissions Standards Requirement (g/hp-hr)		
			NO _x	CO	VOC
Non-Emergency SI Natural Gas and Non-Emergency SI Lean Burn LPG	100≤HP<500	1-Jul-08	2	4	1
		1-Jan-11	1	2	1
Non-Emergency SI Lean Burn Natural Gas and LPG	500≥HP<1350	1-Jan-08	2	4	1
		1-Jul-10	1	2	1
Non-Emergency SI Natural Gas and Non-Emergency SI Lean Burn LPG (except lean burn 500≥HP<1350)	HP≥500	1-Jul-07	2	4	1

East Texas Combustion Rule

TCEQ promulgated rule §117.3310 in June 2007. Section 117.3310(a) specifies the NO_x emission specifications for stationary gas-fired reciprocating internal combustion engines. Beginning in 2010, stationary gas-fired rich-burn engines with a maximum rated capacity less than 500 hp in all Texas Counties within the Haynesville Shale area are subject to the East Texas Combustion Rule. The East Texas Combustion Rule limits NO_x emissions from these engines to 1.00 g/hp-hr.

Implementation

ENVIRON estimated the effect of this rule on wellhead compressor engine by assuming that for each applicable year all rich burn wellhead compressor engines would meet the TCEQ NO_x standards and that added lean natural gas compressors would meet the applicable NSPS standards.

Midstream source emissions also would be expected to be affected by NSPS and East Texas Combustion Rule requirements, however, given the lack of engine specific emissions, horsepower rating, and activity data for midstream sources, estimating expected decreases to emissions as a result of this requirement would be highly speculative and thus has not been performed. At this time, midstream emissions which were not controlled from the base year can be considered to be conservative.

4.4 Emission Inventory Summary

Summary results of the Haynesville Shale regional emissions inventory are presented below for NO_x, VOC and CO emissions. The results are presented in detail for the calendar year 2012 only as this is the future year for which regional photochemical ozone modeling will be conducted by NETAC. However the inventory has been generated for each calendar year in the period 2009-2020 and the summary inventory results are presented for these additional calendar years, including the base year of 2009.

4.4.1 Detailed Emissions Inventory for 2012

Results of the Haynesville Shale regional emissions inventory for 2012 are presented below in tabular (Table 21) and graphical formats. Table 21 indicates that 2012 NO_x emissions in Northeast Texas and Northwest Louisiana due to development in the Haynesville Shale range from 61 tons/day in the low development scenario to 82 tons/day in the moderate scenario to 140 tons/day in the high (aggressive) scenario. VOC emissions from the Haynesville range from 12 tons/day in the low scenario to 16 tons/day in the moderate scenario to 29 tons/day in the aggressive scenario. CO emissions range from 40 tons/day to 96 tons/day.

Figures 19-22 illustrate the breakdown of emissions by source category. Figure 19 shows that, for the moderate scenario, drill rigs and midstream compressor station and natural gas plant emissions are projected to account for 98% of NO_x emissions from the development of the Haynesville Shale formation. Drill rigs contribute the largest amount of NO_x, making up 67% of total NO_x emissions. Drill rig NO_x emissions total 40 tons/day, 55 tons/day, and 71 tons/day for the low, medium, and high development scenarios, respectively (Table 21). The 2005 emission

inventory used in NETAC's 2005 ozone model (Kemball-Cook et al., 2008) contains 24 tons/day of NO_x from drill rigs within the Haynesville Shale counties shown in Figure 4. Development in the Haynesville Shale is therefore projected to significantly increase the amount of NO_x emitted for this source category under all three scenarios.

Figure 20 shows that, for the moderate scenario, drill rigs and midstream compressor station and natural gas plant emissions are projected to account for 79% of VOC emissions while pneumatic devices and completion venting are projected to account for 19% of VOC emissions. Figure 21 shows that, for the moderate scenario, drill rigs and midstream compressor station and natural gas plant emissions are projected to account for 94% of CO emissions from the Haynesville Shale formation.

2012 emissions for the low, moderate, and aggressive (high) development scenarios are compared in Figure 22. Figure 22 shows that relative to the moderate scenario, NO_x emissions are 26% lower for the low scenario and 71% higher for the high scenario, VOC emissions are 24% lower for the low scenario and 78% higher for the high scenario, and CO emissions are 25% lower for the low scenario and 78% higher for the high scenario. For the low and moderate scenarios, drill rig emissions are the largest NO_x emissions category, and for the high scenario, drill rigs and midstream compressor stations and natural gas plants contribute about equally to the total NO_x emissions. As expected, the high scenario shows a larger contribution of emissions from midstream compressor station and natural gas plants for all pollutants due to the use of a decline curve that predicted greater per well production and hence midstream activity for the high scenario relative to the moderate and low scenarios.

Table 22. 2012 emissions (TPD) of NO_x, VOC, and CO by scenario for the Haynesville Shale formation.

Pollutant	Category	Low	Moderate	High
NO _x	Blowdowns	0.00	0.00	0.00
	Completion Venting	0.00	0.00	0.00
	Dehydrator	0.03	0.04	0.12
	Drill Rigs	39.75	55.44	71.13
	Flaring	0.00	0.00	0.00
	Fracing	0.30	0.41	0.53
	Fugitives	0.00	0.00	0.00
	Heaters	0.41	0.49	0.57
	Pneumatic Devices	0.00	0.00	0.00
	Wellhead Compressors	0.13	0.15	0.18
	Midstream CS and NGP	20.02	25.18	67.31
	NO_x Total		60.64	81.72
VOC	Blowdowns	0.05	0.06	0.07
	Completion Venting	1.30	1.82	2.33
	Dehydrator	0.07	0.09	0.24
	Drill Rigs	4.83	6.73	8.64
	Flaring	0.00	0.00	0.00
	Fracing	0.05	0.06	0.08
	Fugitives	0.06	0.07	0.08
	Heaters	0.02	0.03	0.03
	Pneumatic Devices	1.05	1.26	1.46
	Wellhead Compressors	0.13	0.15	0.18
	Midstream CS and NGP	4.59	5.78	15.44
	VOC Total		12.15	16.04
CO	Blowdowns	0.00	0.00	0.00
	Completion Venting	0.00	0.00	0.00
	Dehydrator	1.75	2.21	5.89
	Drill Rigs	24.35	33.96	43.58
	Flaring	0.00	0.00	0.01
	Fracing	0.18	0.25	0.32
	Fugitives	0.00	0.00	0.00
	Heaters	0.35	0.41	0.48
	Pneumatic Devices	0.00	0.00	0.00
	Wellhead Compressors	0.33	0.39	0.45
	Midstream CS and NGP	13.57	17.07	45.63
	CO Total		40.54	54.30

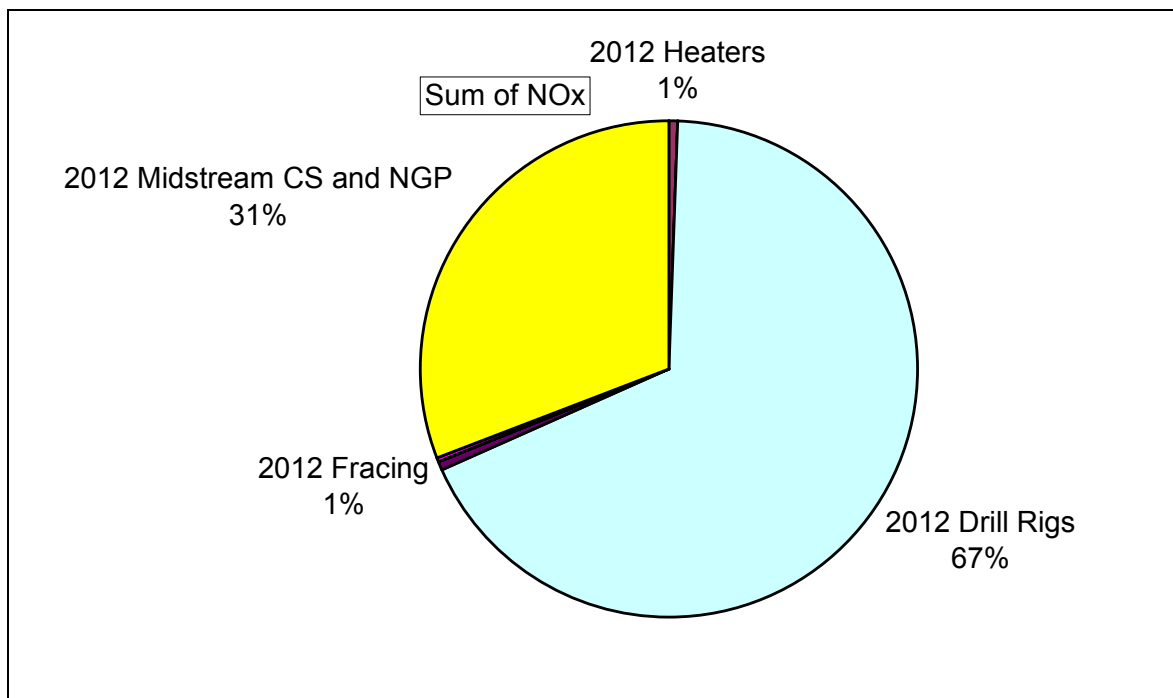


Figure 19. 2012 moderate development scenario Haynesville Shale formation NOx proportional contributions by source category.

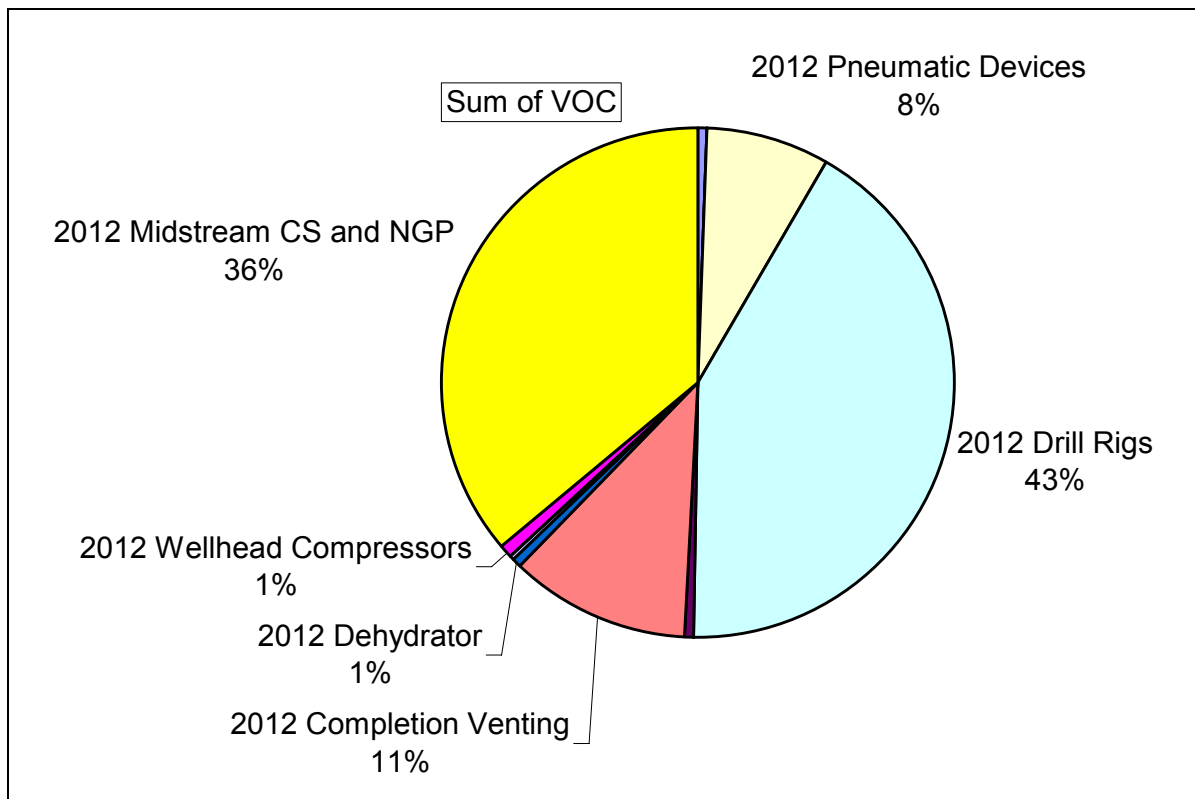


Figure 20. 2012 moderate development scenario Haynesville Shale formation VOC proportional contributions by source category.

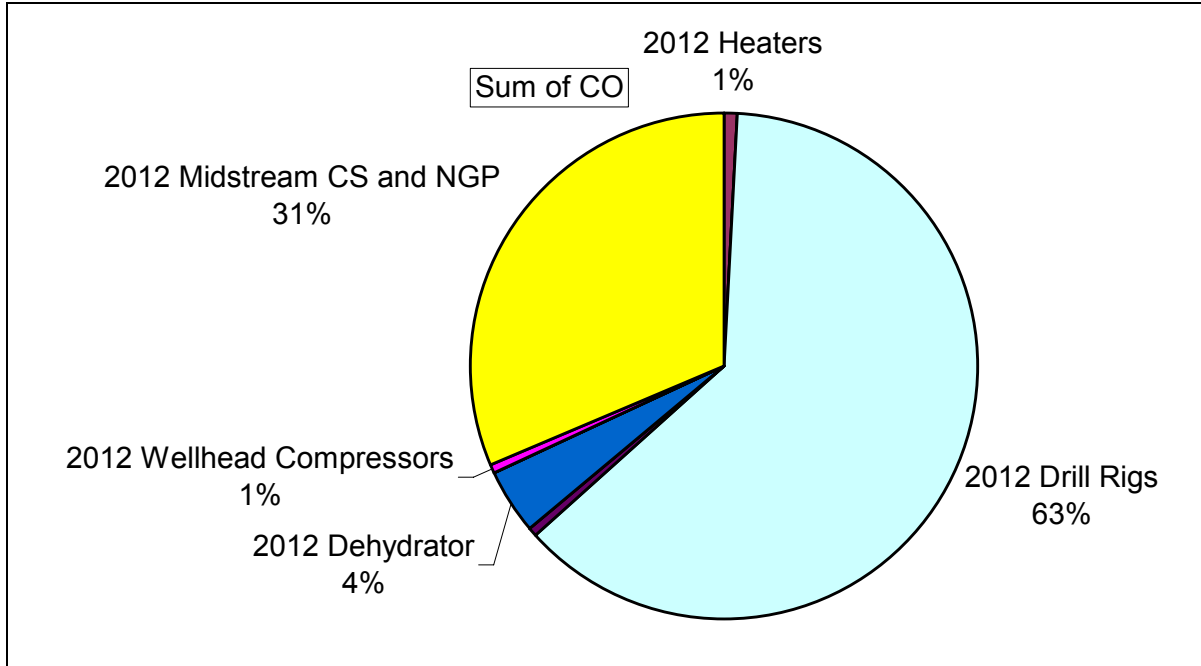


Figure 21. 2012 moderate scenario Haynesville Shale formation CO proportional contributions by source category.

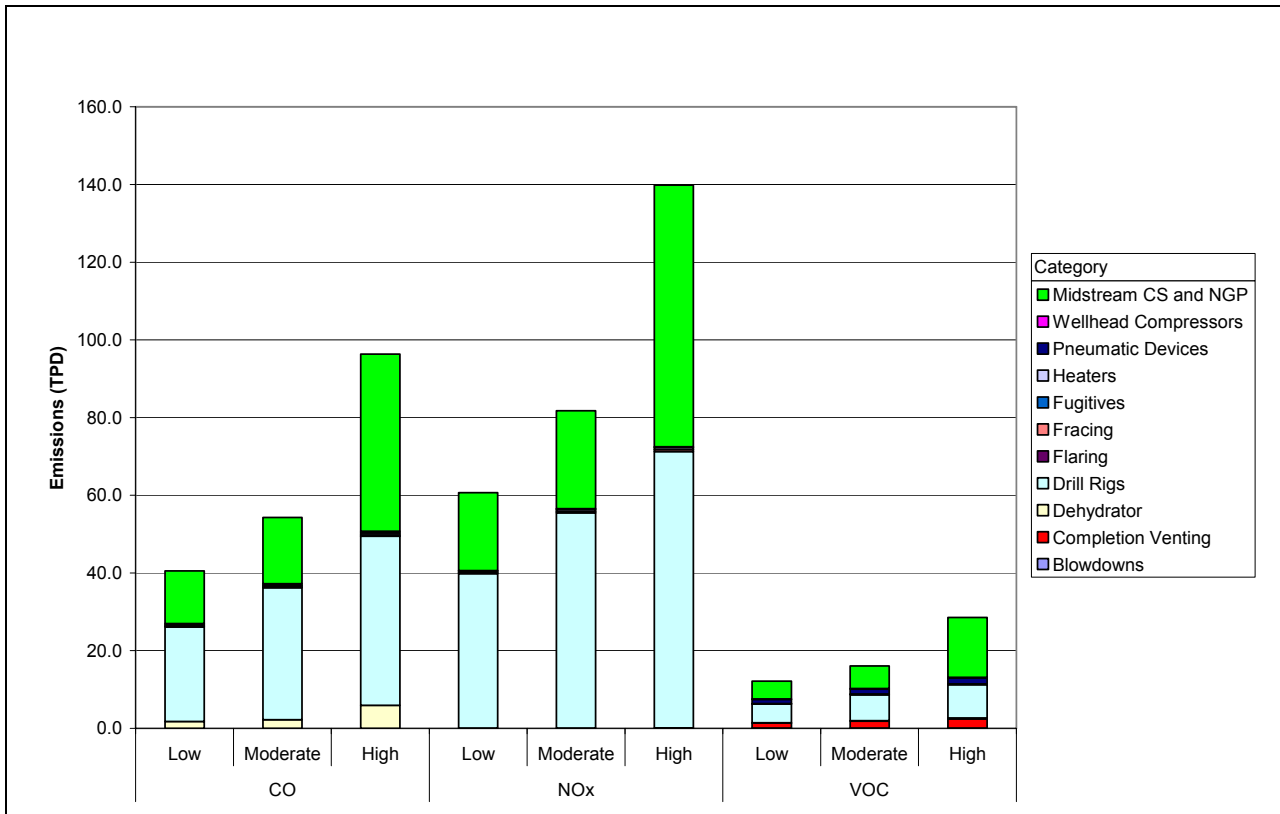


Figure 22. 2012 Haynesville Shale formation emissions of NOx, VOC, and CO by scenario and source category.

4.4.2 Emissions Inventories for Calendar Years 2009-2020

Results of the Haynesville Shale regional emissions inventory for the period 2009-2020 are presented below as a series of bar graphs for the moderate scenario. A quantitative emissions summary is presented in Table 23 with results for all scenarios and percent changes from the moderate scenario for the low and high (aggressive) scenarios.

Figure 23 shows that moderate scenario NO_x emissions are projected to increase by 124% from 2009 to 2020. By 2020, development in the Haynesville Shale results in more than 120 tons/day of NO_x emitted in northeast Texas and northwest Louisiana. Notably, drill rig NO_x emissions remain relatively constant while midstream compressor station and natural gas plant NO_x emissions account for most of the increase. For the moderate scenario, the number of rigs in the Haynesville Shale region increases from 2009-2017 in the moderate scenario (Figure 9), and the drill rig emissions flatten out and eventually decrease because of turnover in the drill rig engine fleet that results in replacement of older engines with higher tier, cleaner-burning engines. Figure 24 shows that moderate scenario VOC emissions are projected to increase by 271% from 2009 to 2020. VOC emissions increases are primarily due to increases in midstream compressor station and natural gas plant VOC emissions, though pneumatic devices, drill rigs, and completion venting among other categories also contribute significantly to VOC emission increases. Figure 25 shows that moderate scenario CO emissions are projected to increase by 131% from 2009 to 2020. Midstream compressor station and natural gas plants together with drill rigs account for most of the increases in CO emissions.

Table 23. 2009 to 2020 emissions of NOx, VOC, and CO by scenario for the Haynesville Shale region and percent difference from the moderate scenario.

Pollutant	Year	Emissions (TPD)			Percent Difference from Moderate	
		Low	Moderate	High	Low	High
NOx	2009	56.69	56.69	62.39	0%	10%
	2010	60.44	67.34	88.35	-10%	31%
	2011	60.69	74.77	113.49	-19%	52%
	2012	60.64	81.72	139.84	-26%	71%
	2013	60.59	88.54	167.73	-32%	89%
	2014	60.49	95.14	187.12	-36%	97%
	2015	60.63	102.00	202.92	-41%	99%
	2016	61.00	109.21	217.57	-44%	99%
	2017	61.60	116.85	231.55	-47%	98%
	2018	62.43	122.31	245.13	-49%	100%
	2019	63.12	125.11	257.08	-50%	105%
2020	63.70	127.06	267.08	-50%	110%	
VOC	2009	9.55	9.55	10.88	0%	14%
	2010	10.80	11.93	16.34	-10%	37%
	2011	11.50	13.96	22.16	-18%	59%
	2012	12.15	16.04	28.55	-24%	78%
	2013	12.83	18.27	35.62	-30%	95%
	2014	13.61	20.78	41.70	-34%	101%
	2015	14.36	23.34	46.86	-39%	101%
	2016	15.14	26.11	51.74	-42%	98%
	2017	15.98	29.09	56.45	-45%	94%
	2018	16.85	31.73	61.05	-47%	92%
	2019	17.66	33.74	65.19	-48%	93%
2020	18.38	35.43	68.74	-48%	94%	
CO	2009	36.61	36.61	40.96	0%	12%
	2010	39.81	44.23	59.43	-10%	34%
	2011	40.29	49.40	77.35	-18%	57%
	2012	40.54	54.30	96.36	-25%	77%
	2013	40.52	58.75	116.13	-31%	98%
	2014	40.92	63.78	131.64	-36%	106%
	2015	41.15	68.51	143.98	-40%	110%
	2016	41.48	73.37	155.27	-43%	112%
	2017	41.91	78.43	165.92	-47%	112%
	2018	42.47	82.15	176.13	-48%	114%
	2019	42.82	83.91	184.89	-49%	120%
2020	42.84	84.53	191.66	-49%	127%	

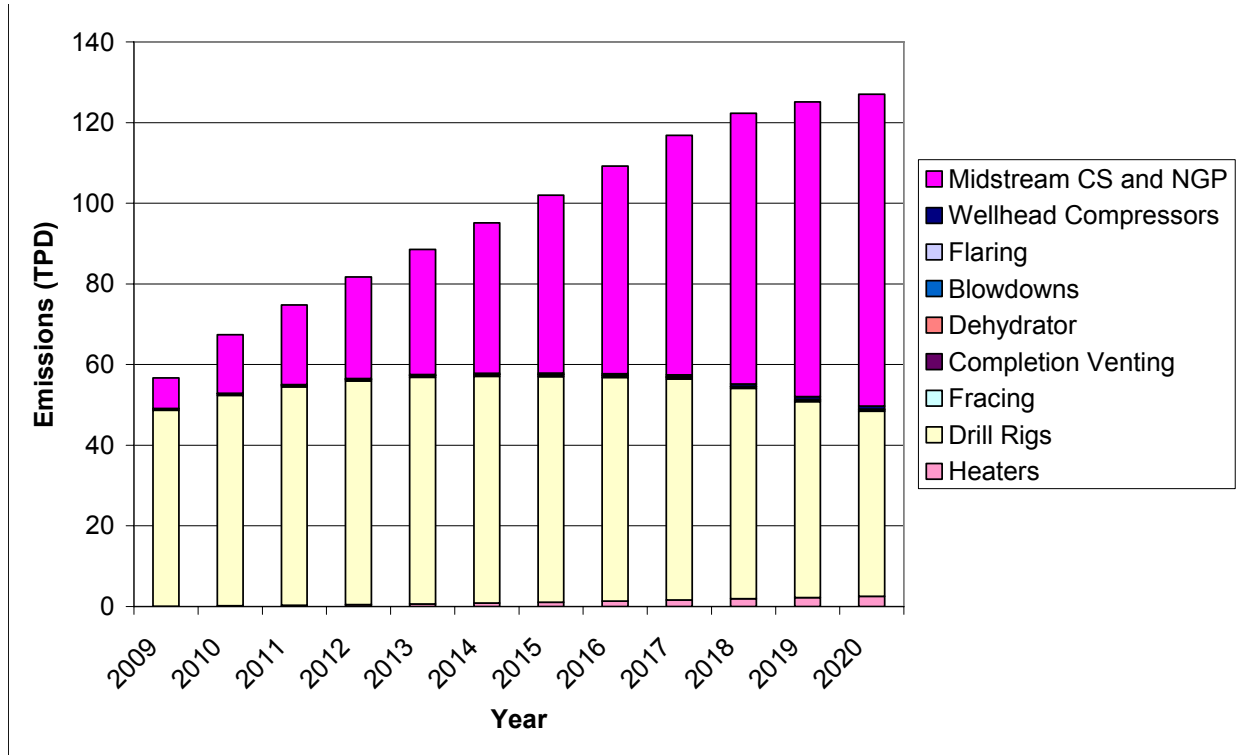


Figure 23. 2009 to 2020 moderate scenario Haynesville Shale regional NOx emissions by source category.

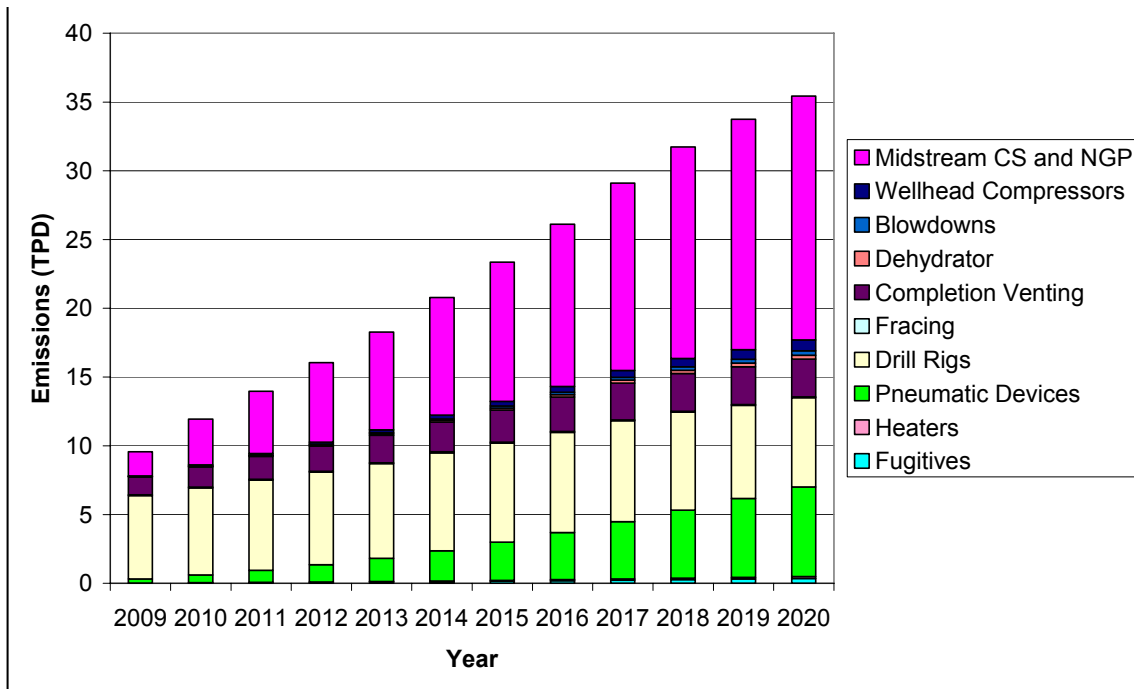


Figure 24. 2009 to 2020 moderate scenario Haynesville Shale formation VOC emissions by source category.

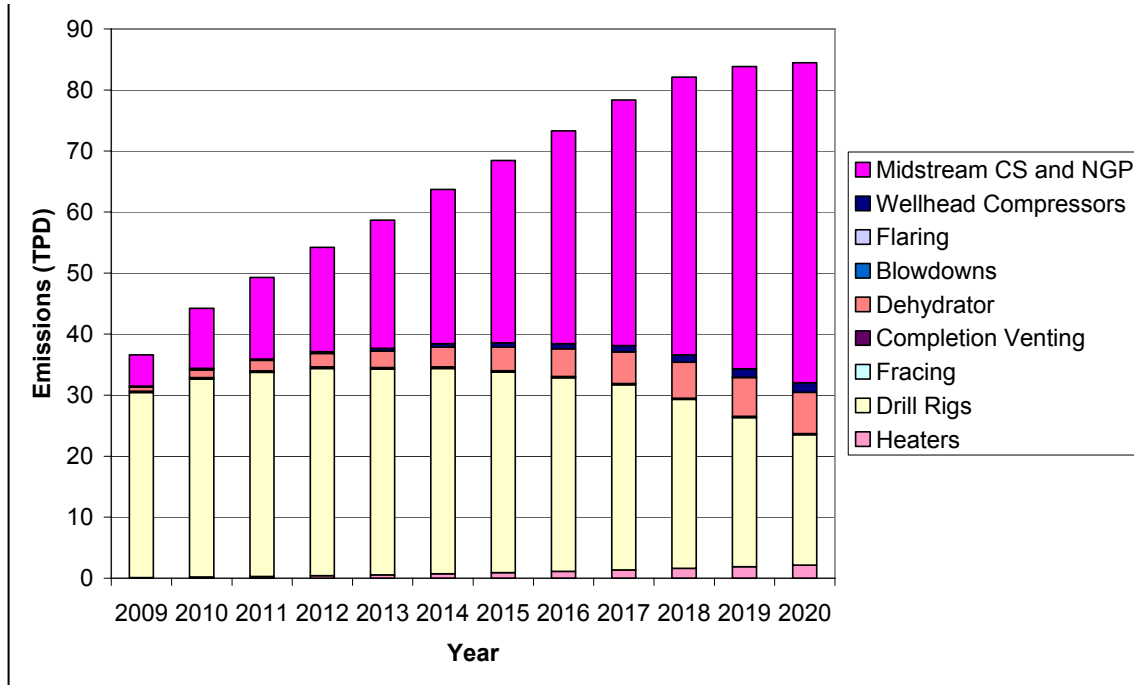


Figure 25. 2009 to 2020 moderate scenario Haynesville Shale formation CO emissions by source category.

5.0 DISCUSSION

This study provides an initial estimate of potential emissions from future development of natural gas resources in the Haynesville Shale. The emission inventory compiled in this study suggests that if the development of the Haynesville proceeds at even a relatively slow pace, emissions of ozone precursors from exploration and production will increase. Because Northeast Texas and Northwest Louisiana are regions of abundant biogenic VOC emissions, ozone formation is limited by the amount of available NO_x; therefore, in the following discussion, we focus on potential NO_x emissions from the Haynesville Shale.

Estimates of 2012 NO_x emissions in Northeast Texas and Northwest Louisiana due to development in the Haynesville Shale range from 61 tons/day in the low development scenario to 82 tons/day in the moderate scenario to 140 tons/day in the high (aggressive) scenario. Results for the moderate scenario indicate that by 2020, development in the Haynesville Shale results in more than 120 tons/day of additional NO_x emitted in northeast Texas and northwest Louisiana. In order to put these figures in perspective, we consider the NO_x emissions from oil and gas sources in the emission inventory used in the 2005 NETAC ozone model. For the five Texas counties that comprise the Haynesville Shale, total NO_x emissions from all oil and gas sources (including drill rigs) are 80 tons/day. Total 2005 NO_x emissions *for all source categories* in the 5-County Tyler-Longview-Marshall (TLM) area were 246 tons/day. The moderate development scenario projection of additional 82 tons/day emitted in the Texas Haynesville counties and the adjacent Haynesville parishes in Louisiana in 2012 is equal to the total 2005 NO_x emissions from all of the Haynesville counties in Texas and is approximately 30% of the total NO_x emissions from all source categories for the 5-County TLM area. For the low development scenario, the Haynesville Shale 2012 NO_x emissions of 61 tons/day amounts to ~75% of the total 2005 NO_x emissions from all of the Haynesville counties in Texas and is approximately 25% of the total NO_x emissions from all source categories for the 5-County area. This suggests that the Haynesville Shale will contribute significant amounts of NO_x to the regional inventory under the low and moderate scenarios, and will have an even larger impact under the aggressive development scenario. As discussed in Section 4.2.10, the wellhead compression emission calculations likely underestimate emissions from this source category, with the underestimate increasing in magnitude from 2010 to 2020. This means that the NO_x emissions estimates provided above are likely to represent a lower bound, especially for the later years of the inventory.

High ozone days in Northeast Texas are often marked by stagnant winds (Kemball-Cook and Yarwood, 2008; Stoeckenius and Yarwood, 2004) which would tend to keep the Haynesville ozone precursor emissions in the region and available for ozone formation. It is therefore important to evaluate the effect of the Haynesville Shale emissions on ozone levels in Northeast Texas with careful attention to their effect on the area's ozone attainment status. NETAC is developing an ozone model for the year 2012 for the purposes of control strategy evaluation, and this model will be used to quantify the impacts of development of the Haynesville Shale. The emission inventory developed in the present study will be incorporated into the ozone model and the contribution of the Haynesville Shale emissions to Northeast Texas ozone will be determined.

Because development of the Haynesville Shale began very recently, there is considerable uncertainty in a number of factors that affect this study's projections of future year activity and emissions. Among these are uncertainties in: the geographic extent of the formation; the shape of well decline curves; quantity of recoverable natural gas reserves; type and quantity of equipment to be used for exploration and production (the amount of wellhead compression used is of critical importance here); and limits on development imposed by the available infrastructure (i.e. limits imposed by pipeline or gas processing capacity or drill rig availability). As exploration of the Haynesville Shale proceeds, many of these quantities will become better defined, and we may expect that future emission inventories will be better constrained by a greater quantity of available data. Input from producers regarding projected future activity and equipment used would be invaluable in informing future emissions estimates.

ACKNOWLEDGEMENT

We thank Anne Inman of the TCEQ for providing data on permitted sources in Texas.

6.0 REFERENCES

- Armendariz, A., 2009. "Emissions from Natural Gas Production in the Barnett Shale Area and Opportunities for Cost-Effective Improvements". Report prepared for Ramon Alvarez, Ph.D., Environmental Defense Fund, 44 East Avenue, Suite 304, Austin, Texas 78701. January. http://www.edf.org/documents/9235_Barnett_Shale_Report.pdf.
- Bar-Ilan, A., J. Grant, R. Friesen, A. Pollack, D. Henderer, D. Pring, K. Sgamma, 2008. "Development of Baseline 2006 Emissions from Oil and Gas Activity in the Denver-Julesburg Basin" Prepared for Western Governor's Association. Prepared by ENVIRON International Corporation, Novato, CA.
[http://www.wrapair.org/forums/ogwg/documents/2008-04_%2706_Baseline_Emissions_DJ_Basin_Technical_Memo_\(04-30\).pdf](http://www.wrapair.org/forums/ogwg/documents/2008-04_%2706_Baseline_Emissions_DJ_Basin_Technical_Memo_(04-30).pdf)
- Bar-Ilan, A. R. Parikh, J. Grant, T. Shah, A. Pollack, 2008. Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories". Prepared for Central States Regional Air Partnership 10005 S. Pennsylvania, Ste. C, Oklahoma City.
- Bar-Ilan, A., Grant, J., R. Parikh, Pollack, A., Henderer, D., Pring, D., Sgamma, K., 2009. "Development of 2012 Oil and Gas Emissions Projections for the Piceance Basin"; Prepared for Western Governor's Association by ENVIRON International Corp., Novato CA. <http://www.wrapair.org/forums/ssjf/documents/eiccts/oilgas.html>.
- Barnett Shale News, 2009. "Drilling Statistics by Rig Data".
<http://www.barnettshalenews.com/documents/RigData%20Barnett%20Shale%20Rig%20Count%20Booklet%20Barnett%20Shale%20EXPO%203-11-2009.pdf>.
- Energy Information Administration (EIA) Office of Oil and Gas, 2009. "Natural Gas Market Centers: A 2008 Update". April.
http://www.eia.doe.gov/pub/oil_gas/natural_gas/feature_articles/2009/ngmarketcenter/ngmarketcenter.pdf.
- EPA, 2004. Natural Gas Star Program, "Convert Gas Pneumatic Controls to Instrument Air, Lessons Learned," EPA-430-B-04-003, February.
- EPA, 2005. "User's Guide for the Final NONROAD2005 Model". Assessment and Standards Division Office of Transportation and Air Quality, EPA, Prepared with assistance from Cimulus, Inc. and ENVIRON International Corp. December.
- Groundwater Resources Council and ALL Consulting, 2009. "Modern Shale Gas Development in the United States: A Primer". Prepared for U.S. Department of Energy Office of Fossil Energy and National Energy Technology Laboratory. April.
- Kemball-Cook, S., J. Johnson, E. Tai, M. Jimenez, G. Mansell, and G. Yarwood. 2008. "Modeling Northeast Texas Ozone for May-June 2005". Prepared for the East Texas Council of Governments. 3800 Stone Road, Kilgore, TX, 75662. August 31.

Navigant Consulting. 2008. "North American Natural Gas Supply Assessment". Prepared for American Clean Skies Foundation. July.

New York Times, 2009. "Dramatic Natural Gas Growth Seen in Unconventional Plays". <http://www.nytimes.com/gwire/2009/04/13/13greenwire-dramatic-growth-seen-in-unconventional-plays-10513.html?scp=5&sq=Haynesville%20shale&st=cse>.

Nossiter, A., 2008. "Gas Rush Is On and Louisianans Cash In," New York Times, August 2008. Internet address: http://www.nytimes.com/2008/07/29/us/29boom.html?_r=1&oref=slogin

Pickering Energy Partners Inc., 2005. "The Barnett Shale: Visitors Guide to the Hottest Gas Play in the US". (<http://www.tudorpickering.com/pdfs/TheBarnettShaleReport.pdf>).

Scandinavian Oil and Gas Magazine, 2008. <http://www.scandoil.com/moxiebm2/news/chesapeake-and-pxp-declares-haynesville-shale-jv.shtml>.

Shreveport Times, 2008. "Playing the Haynesville Shale". <http://www.shreveporttimes.com/article/99999999/SPECIALPROJECTS02/805040320>

Stoeckenius, T., and G. Yarwood, 2004. "Conceptual Model of Ozone Formation in the Tyler/Longview/Marshall Near Nonattainment Area". Prepared for East Texas Council of Governments. January, 2004.

Tristone Capital Co., 2008. "Welcome to Haynesville, Population, 60 TCF". <https://research.tristonecapital.com/Haynesville%20Report%20-%202006-20-08.pdf>

Wall Street Journal, 2008. "Chesapeake, Plains Set to Tap Gas Field". <http://online.wsj.com/article/SB121501262685723169.html>

Wall Street Journal, 2009. "Chesapeake Continues Gas-Production Increase". <http://online.wsj.com/article/SB124899172528895117.html>.

APPENDIX A

Letter and Questionnaire Sent to Haynesville Shale Producers

April 3, 2009

Producer Address

Dear _____,

We are contacting you seeking general information regarding future development of natural gas resources in the Haynesville Shale in Northwest Louisiana and Northeast Texas. ENVIRON is performing a study of potential emissions from exploration and production activities in the Haynesville Shale for Northeast Texas Air Care (NETAC) and the East Texas Council of Governments (ETCOG).

NETAC is a voluntary association of elected officials and representatives of local industry and public interest groups from Gregg, Harrison, Rusk, Smith, and Upshur counties. Since 1996, NETAC has worked with the Texas Commission on Environmental Quality (TCEQ) and the U.S. Environmental Protection Agency (EPA) to address ozone air quality concerns in Northeast Texas. These efforts have resulted in significant air quality improvements while maintaining the economic vitality of the regional area.

The development of natural gas resources within the Haynesville Shale is an important driver of local economic growth, but also generates emissions of nitrogen oxides and volatile organic compounds that lead to ozone formation. On days with high regional ozone levels, local wind patterns favor transport of pollutants to Northeast Texas from the area encompassed by the Haynesville Shale. A projected increase in emissions of ozone-forming compounds in the Haynesville Shale at a time when the National Ambient Air Quality Standard for ozone has recently been tightened is cause for concern, and requires that potential air quality impacts of proposed development in the Haynesville Shale region be assessed.

ENVIRON is researching how development in the Haynesville Shale may impact air quality in Northeast Texas. We will estimate future emissions from exploration & production and gathering/transmission operations associated with natural gas development of the Haynesville Shale in Northwest Louisiana and Northeast Texas. An outline of this work is given below:

- We will gather current estimates of the potential recoverable gas reserves in the Haynesville Shale.
- Three scenarios will be developed of the annual gas production, annual drilling event count, and annual active well count in the Haynesville Shale for each calendar year between 2009 and 2020. The 3 scenarios would represent a range of production parameters: (1) a limited development scenario; (2) a moderate development scenario; and (3) an aggressive development scenario. For each scenario, estimates of gas production, drilling counts and well counts would be developed by reviewing available documentation and literature.
- Calculate the emissions under each scenario so that they can be incorporated into NETAC ozone modeling studies aimed at assessing whether Northeast Texas will attain the new ozone standard by the year 2012.

We have contacted the Louisiana Department of Natural Resources and the Texas Railroad Commission, but their information on development within the Haynesville Shale is limited, and they recommended that we contact operators who expect to be active in the area for information regarding future production and equipment use. A questionnaire attached to this email contains queries regarding your potential future activities in the Haynesville Shale. We are sending the same questionnaire to all companies that have announced their intention to develop resources in the Haynesville Shale. We would greatly appreciate it if you would complete as many questions as possible and return responses to Section I of the questionnaire to ENVIRON by April 27, 2009 and responses to Section II by May 11, 2009.

We hope to be able to inform our projections of future development in the Haynesville Shale with the most accurate information available, as this will allow comparison of the importance of the Haynesville shale development with other sources of emissions in the region such as motor vehicle traffic, power plants, and oil and gas production unrelated to the Haynesville Shale. NETAC stakeholders will then be able to make decisions using the best possible information. In the absence of detailed information regarding future Haynesville Shale development and equipment use (e.g. drill rig engine tier), ENVIRON will be obliged to make conservative assumptions as we characterize emissions from exploration and production sources.

If you have any questions about the questionnaire or how the information collected will be used, please contact me at (415) 899-0700. If you would like to learn more about NETAC, please see <http://www.netac.org/> or contact Rick McKnight (903-984-8641), who is the environmental manager for the East Texas Council of Governments.

Sincerely,

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CC: Rick McKnight, ETCOG

Haynesville Shale Questionnaire

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April 17, 2009

Overview

Given the developmental stage of the Haynesville Shale formation and the uncertainty in future year projections due to current economic conditions, we have focused this survey on basic activity data as well as information on drilling and fracing operations.

We would like to encourage producers to provide information as soon as possible so that we will have sufficient time to make best use of information provided. Therefore, this questionnaire is organized into two sections:

1. Section 1 contains questions to which we are seeking an earlier answer to by May 4, 2009 in order to be able to use these in the initial project planning and methodology development.
2. Section 2 contains questions to which we are seeking an answer to by a later date, May 25, 2009, for data that we will use to develop future year emission inventories for the Haynesville Shale.

ENVIRON will hold confidential all information provided by producers; we will not share specific producer information in response to the operations. We will use the information provided in aggregate and report emissions by county only. ENVIRON will sign a confidentiality agreement with your company if that will be necessary for you to provide the information requested. All information should be provided in electronic format if possible and preferably in spreadsheet format. All data should be returned to:

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Email: abarilan@environcorp.com

If you have any questions regarding this questionnaire, or any of the questions contained here, please feel free to contact Dr. Bar-Ilan at the phone number or email address above.

SECTION 1: Early response needed by April 27, 2009.

(1) Drilling Information

- a) Average duration of drilling (days)
- b) Average drilling depth and/or typical range of depths (feet)
- c) Fraction of spuds that include directional drilling
- d) Average number of engines used during a spudding event

(2) Fracing Information

- a) Average duration of fracing (days)
- b) Average number of engines used during a fracing event
- c) Average total horsepower used in fracing operations

(3) Gas Composition Analyses:

- a) Representative produced gas composition analysis.
- b) Representative flash gas composition analysis, if available.
- c) Representative sales gas composition analysis, if available.

(4) Well Decline Curve:

- a) Representative well decline curve.

(5) 2008 Activity (spuds, well counts, gas production)

- a) 2008 activity:
 - i. Counties/parishes of operation (names)
 - ii. Number of spuds (total or by county if available)
 - iii. Number of active wells (total or by county if available)
 - iv. Total gas production (total or by county if available)

(6) Future Year Projected Activity

- a) 2009 through 2020 activity estimates
 - i. Counties/parishes of operation (names)
 - ii. Number of spuds per year (total or by county if available)
 - iii. Number of active wells by year (total or by county if available)
 - iv. Total gas production by year (total or by county if available)

SECTION 2: Later response needed by May 11, 2009.**(1) Drilling Information**

- a) For each engine used in drilling operations:
 - i. Engine function
 - ii. Engine fuel type
 - iii. Engine horsepower
 - iv. Engine time-on per drilling event
 - v. Truck mounted or stand alone engine
 - vi. Engine certification standard, tier level, or model year
 - vii. Types of emissions controls used (if any)
 - viii. Fraction of engines subject to emissions controls (if any)
 - ix. Load factor if available

(2) Fracing Information

- a) For each engine used in fracing operations:
 - i. Engine function
 - ii. Engine fuel type
 - iii. Engine horsepower
 - iv. Engine time-on per fracing event
 - v. Truck mounted or stand alone engine
 - vi. Engine certification standard, tier level, or model year
 - vii. Types of emissions controls used (if any)
 - viii. Fraction of engines subject to emissions controls (if any)
 - ix. Load factor if available

(2) Completion Information

- b) Can you provide an estimate of the volume of gas vented during a typical well completion for a Haynesville Shale well?
 - i. Do you use green completion techniques or flaring to control vented gas emissions from completion? If so, what fraction of the gas is controlled by green completions or flaring?

(3) Wellhead Compression

- a) Wellhead compressors:
 - i. What fraction of wells will utilize wellhead compressors?
 - ii. What is a typical make/model of wellhead compressor?
 - iii. What is a typical horsepower of a wellhead compressor?
 - iv. What is the load factor on a typical wellhead compressor?
 - v. Are there controls in place on your wellhead compressors?
 - vi. What types of controls and on what fraction of the compressors
 - vii. What fraction of these compressors is rich-burn, and what fraction is lean-burn?

(4) Other Wellhead Equipment

- a) Dehydrators:
 - i. What fraction of wells would utilize dehydrators?
 - ii. What would be a typical dehydrator emissions factor (lb-VOC/MCF)?
- b) Heaters/boilers:

- i. What would be a typical setup of heaters/boilers for a wellhead (i.e. how many heaters would be used for separation, dehydration, etc., and what would be the firing rates of these heaters in MMBTU/hr)
- c) Acid gas removal
 - i. Is it expected that a field amine unit or other acid gas removal system would be installed at the wellhead?
 - ii. If this equipment is used, could you provide a VOC emissions factor for the units (lb-VOC/MCF)?
 - iii. Note above that if amine units are used at the wellhead, please provide information on the boilers in these units.
- d) Pneumatic devices
 - iv. Could you provide a list of typical pneumatic devices that might be in use at a Haynesville Shale well?
 - v. Please indicate if these devices are high-bleed, low-bleed or run on instrument air

(5) Major Point Sources (gas plants, compressor stations)

(Please note that the following questions refer generally to the Haynesville Shale development area, and not necessarily to the specific operations of your company)

- a) Gas Plants
 - i. How many have been brought online as a result of Haynesville Shale production? Are these owned by your company, jointly owned, or can you provide information on major gas plants brought online as a result of Haynesville that are owned/operated by other companies?
 - ii. Can existing gas plants be used to handle Haynesville Shale production, to your knowledge? If so, can you indicate to which gas plants current Haynesville gas production is sent?
 - iii. How many are expected to be brought online as a result of future Haynesville Shale production.
 - 1. When would these be brought online?
 - iv. Can you provide any information (from permits or other sources) that could point us to typical plant emissions?
 - v. Do you operate Haynesville plants for which you could provide emissions data? (this question is specific to your company's operations)
- b) Compressor Stations
 - i. How many have been brought online as a result of Haynesville Shale production.
 - ii. Can existing compressor stations be used to handle Haynesville Shale production (or with expansion of existing stations), and if so can you provide a list of existing compressor stations?
 - iii. How many are expected to be brought online as a result of Haynesville Shale production.
 - 1. When would these be brought online?
 - iv. Can you provide any information (from permits or other sources) that could point us to typical station emissions?

Do you operate a Haynesville station for which you could provide emissions data? (this question is specific to your company's operations)