Shale Shaker

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Oklahoma 2011 Drilling Highlights,

The Geology and Deep Structure of the Oklahoma Ouachita Mountains – The SOPC 1-22 Weyerhaeuser Well,

And much more.

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Shale Shaker

Shale Shaker Staff

OCGS Executive Committee

OCGS Offices and Geological Library:
120 North Robinson, Suite 900 Center,
Oklahoma City, OK 73102
Phone: (405) 236-8086 | Fax: (405) 236-8085
Website: www.ocgs.org

Michelle Hone,
Accounting Manager/Administrative Assistant
Email: ocgs.mhone@logixonline.com

Pam Yeakley, Library Manager, OCGS
Email: ocgs@logixonline.com

About the Cover

Michael Root creates the covers of the *Shale Shaker*. The cover for this Issue utilizes an image supplied by Michelle Dodd, Coordinator of Photography for Chesapeake Energy Corporation and is one of many contained within Chesapeake's Visual Resource Center.

The cover ties nicely with this Issue's technical subject matter: "Oklahoma 2011 Drilling Highlights," by Dan T. Boyd, of the Oklahoma Geological Survey; and "The Geology and Deep Structure of the Oklahoma Ouachita Mountains – The SOPC 1-22 Weyerhaeuser Well," by Michael D. Allison, North Texas Sample Log Service, William H. Willis II, Manager - Southern Minerals, Weyerhaeuser Company, and Neil H. Suneson, of the Oklahoma Geological Survey.

By: Dan T. Boyd, Oklahoma Geological Survey, (405) 325-8898 | dtboyd@ou.edu

Oklahoma 2011 Drilling Highlights

This article is a summary of Oklahoma drilling activity that became public in 2011. Any activity or key wells that were unavailable before January 1, 2012 will appear in next year's summary. Except where noted, all data were supplied online by Petroleum Information/Dwights LLC dba IHS Energy Group, all rights reserved. A lax State attitude towards completion and production reporting has created extraordinarily long lag times in receiving these data, making analyses of recent activity difficult. Without the Energy Information Administration (E.I.A.) and especially the information provided by the IHS Energy a report of this kind would not be possible. Editing of this article was performed by Neil Suneson and cartography by Russell Standridge, both from the Oklahoma Geological Survey.

General Activity

The number of working drilling rigs is a fundamental barometer of oil and gas activity and Baker Hughes Company tracks monthly rotary drilling rig counts for regions all over the world. After a weekly peak of 219 in September, 2008 Oklahoma's rig count reached a low of 69 working rigs in September, 2009 (Boyd, 2010). Since that time numbers have been steadily climbing, with the last week of 2011 reaching 195 working rigs. This has brought the annual average for the year up to 180 and marks the second year of major increases in drilling activity (Figure 1). Oklahoma's rig count is now on a par with levels seen prior to the collapse of oil and gas prices that occurred at the end of 2008.

In past years as many as 3/4s of all wells drilled in Oklahoma targeted gas, which has made its price the most important factor controlling drilling. This is no longer the case. Although the price for both gas and oil fell at the end of 2008, oil has largely recovered and gas has not (Figure 2). Using the standard 6 MCF per barrel conversion, on a barrel of oil equivalency (BOE), in 2003 gas and oil prices were equal. While 2011 oil prices have risen to near their 2008 peak, gas is now selling for less than it did in 2003. In fact, on a BOE basis oil is now over three times more valuable than gas, and this will likely continue. Oil remains between $90 and $100 per barrel, but gas has again missed the usual winter price increase that occurs during the peak-heating season and has declined steadily since June (Figure 3).

The latest estimate from the Oklahoma Corporation Commission (OCC) places the average 2011 wellhead natural gas price in Oklahoma at approximately $4.67 per MCF (Soltani, 2012) (Figure 2). This is an optimistic forecast as it is based mostly on prices in the first half of the year. Although the sharp fall that occurred in the second half of the year will be eased by hedged contracts and higher Btu gas, the

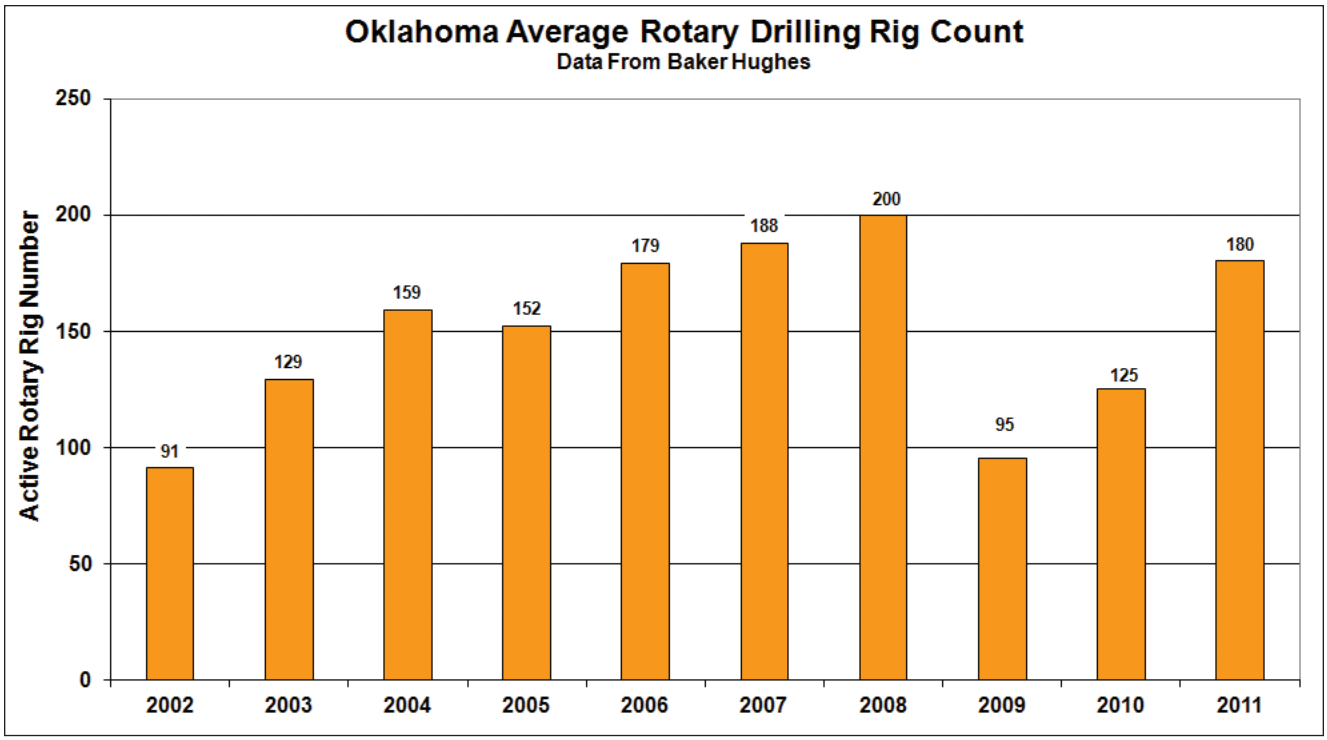


Figure 1. Oklahoma annual rotary rig count from 2002 to 2011. Data from Baker Hughes (2012).

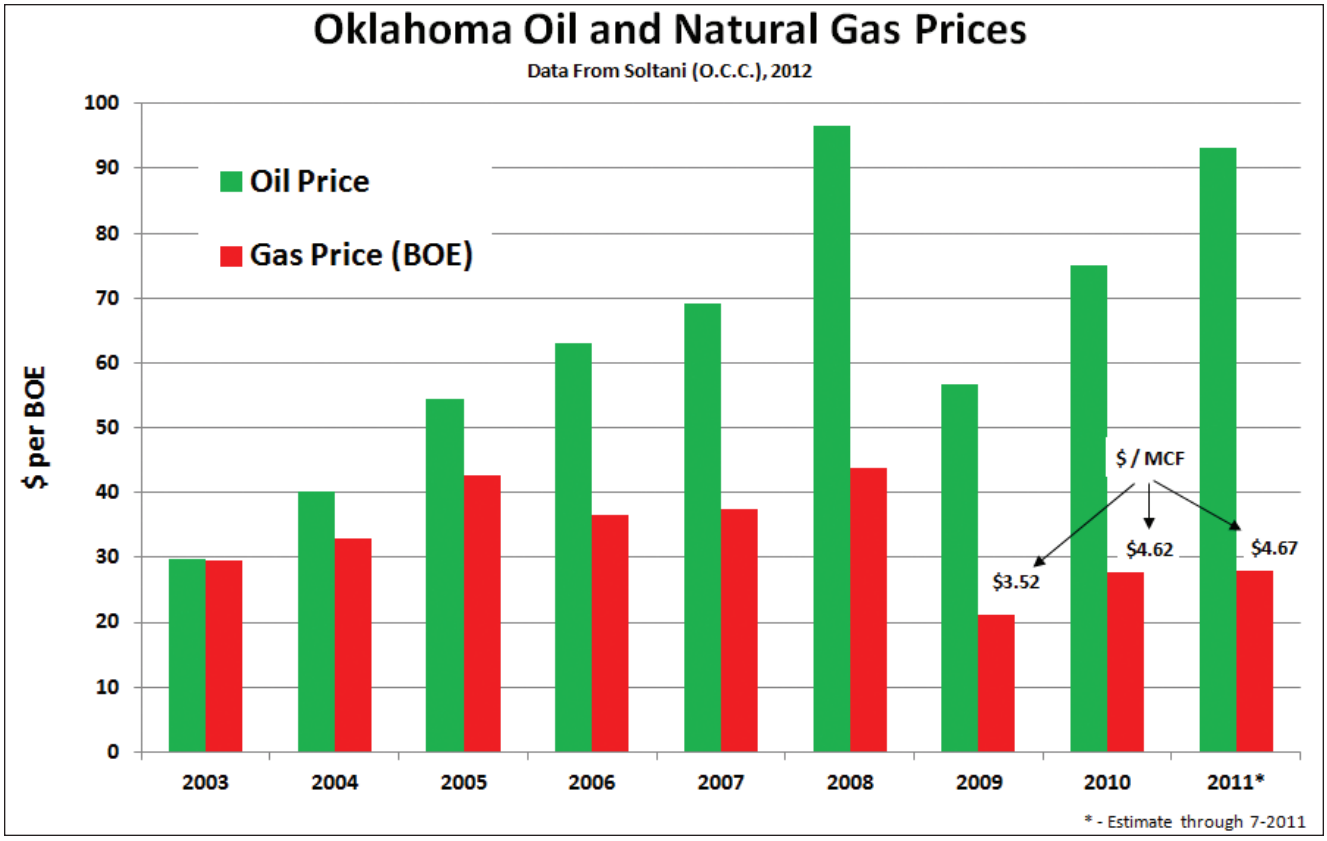


Figure 2. Oklahoma annual average oil and gas price on a barrel of oil equivalency (BOE) from 2003 through 2011. Data from Soltani (2012).

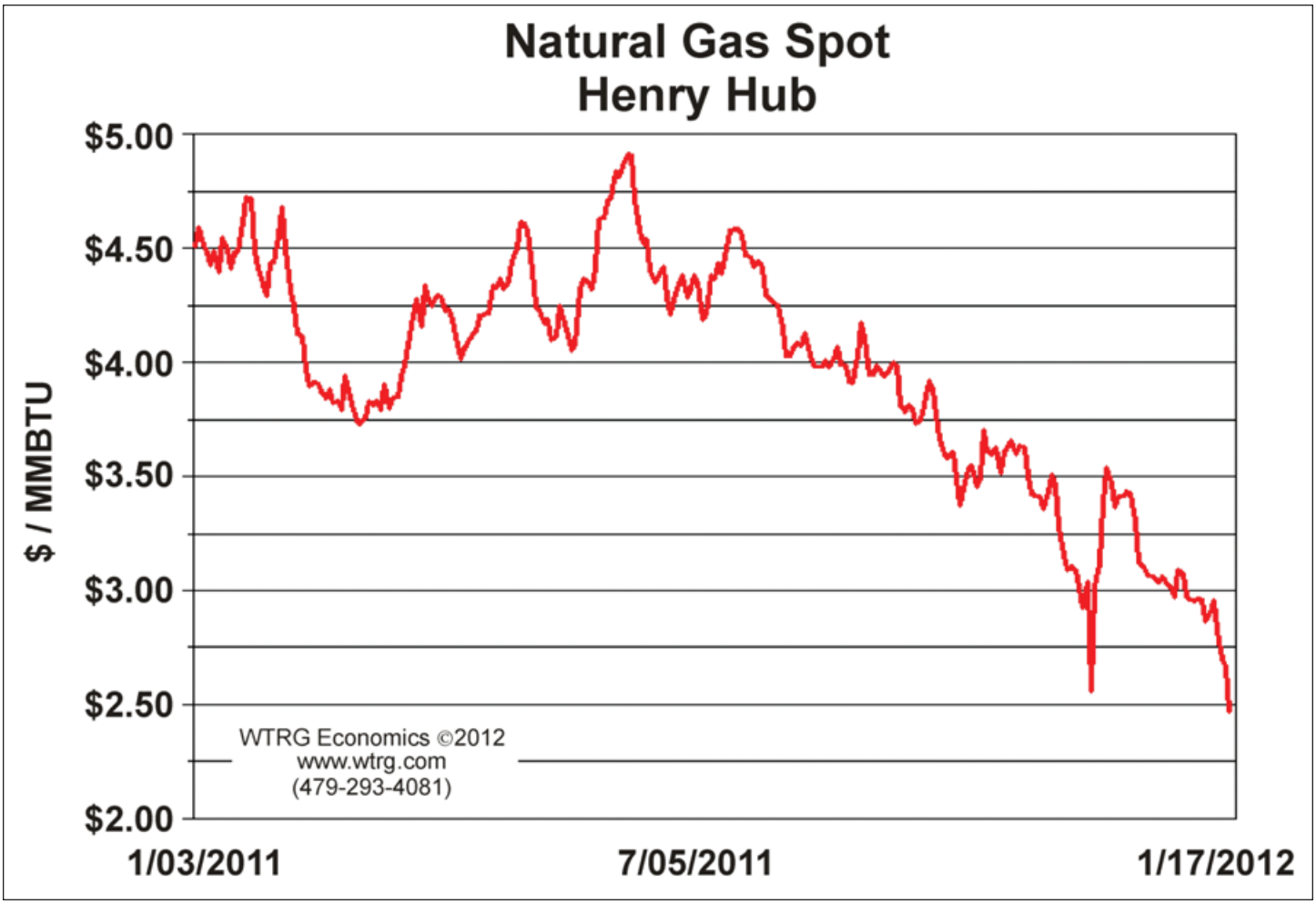


Figure 3. Henry Hub natural gas spot price from January 3, 2011 through January 17, 2012. Adapted from Williams, (2012)

average for 2011 will undoubtedly show a significant fall from 2010. The continued decline of Henry Hub Spot prices below $3/MCF is a disturbing development (Figure 3). These prices result from an oversupply that is being maintained by the active drilling of gas shales and the horizontal development of liquids-rich unconventional plays which produce high volumes of associated gas. This activity continues throughout the country and shows no sign of abating.

Although oil prices are now the main driver in maintaining drilling activity in the State, Oklahoma remains strongly gas-prone with gas representing 81% of our BOE production. Given the dominance of gas in Oklahoma industry earnings, State gross-production tax income can never fully recover until prices reach a level where gas-targeted drilling again becomes economically viable. There are prolific shale-gas plays across the U.S., and like the Woodford in Oklahoma, these continue to be drilled (and produced) in an already glutted market. Price predictions are impossible, but certainly until the bulk of prospective shale-gas acreage is 'held by production,' which will afford operators the luxury of drilling infill wells only when prices are higher, there is little chance that prices will significantly recover.

Languishing gas prices, high oil prices, and the expectation that these will continue has again pushed oil-targeted drilling higher. In 2011 gas drilling fell another 7% with oil rising by the same amount (Boyd, 2011). Technically oil now accounts for over half of all drilling in the State (Figure 4). However, if horizontal gas wells that were drilled to maximize oil/condensate/NGL production are excluded, this disparity would be even more pronounced. As will be discussed, with even the oiliest plays producing mostly gas and many of the 'gas' plays producing substantial volumes of hydrocarbon liquids, well classification becomes problematic. However, acreage expiration issues aside, it appears there are very few wells being drilled in Oklahoma today that are not relying on liquids production for economic viability.

Water-injection and disposal-well drilling represents about 9% of all 2011 drilling (Figure 4) - a slight increase over previous years. High-rate water-disposal wells,

which invariably target the Arbuckle Group, are a prerequisite for production in all of the State's horizontal plays. In fact, future drilling activity can often be gauged based on the number and location of disposal-well drilling permits. Dry and junked holes accounted for an additional 7% of 2011 drilling. Although a large percentage of the wells drilled in Oklahoma were classified as 'New Field Wildcats,' because they are targeting unconventional, blanket reservoirs, this is something of a misnomer. (The term 'unconventional' is used here to denote reservoirs in which the permeability is too low to permit fluid separation.) The overall 93%+ success rate that the industry has enjoyed is comparable to previous years and shows that drilling throughout Oklahoma continues to be overwhelmingly developmental (Figure 4). Even for isolated horizontal wells where economic risk is probably the greatest, the chance of a non-producing dry hole is usually less than the mechanical risk associated with drilling the well.

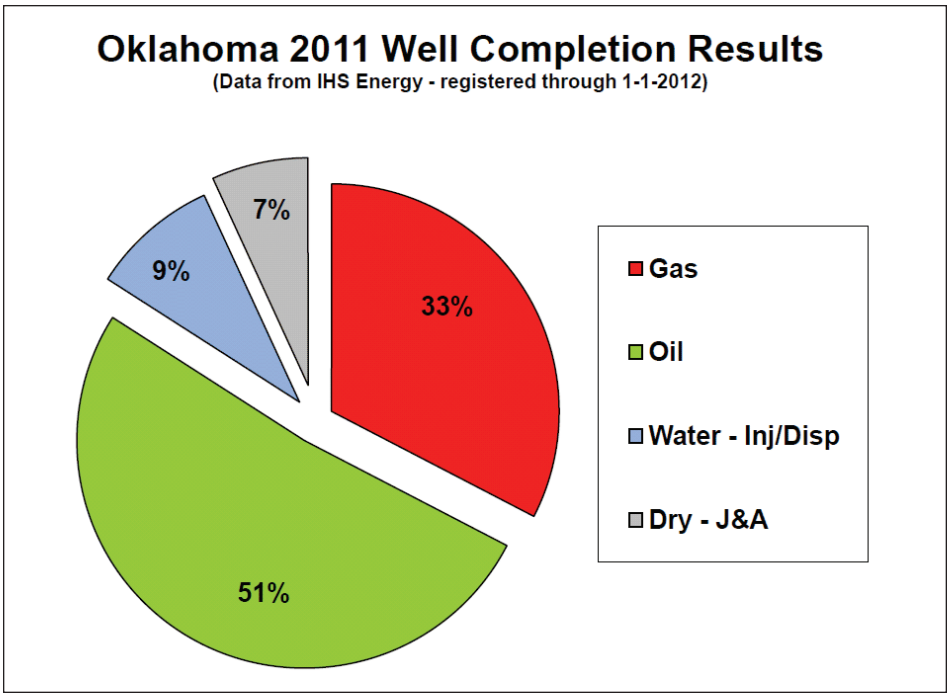


Figure 4. Oklahoma 2011 well completion results (for wells reported through January 1, 2012). Data from IHS Energy (2012).

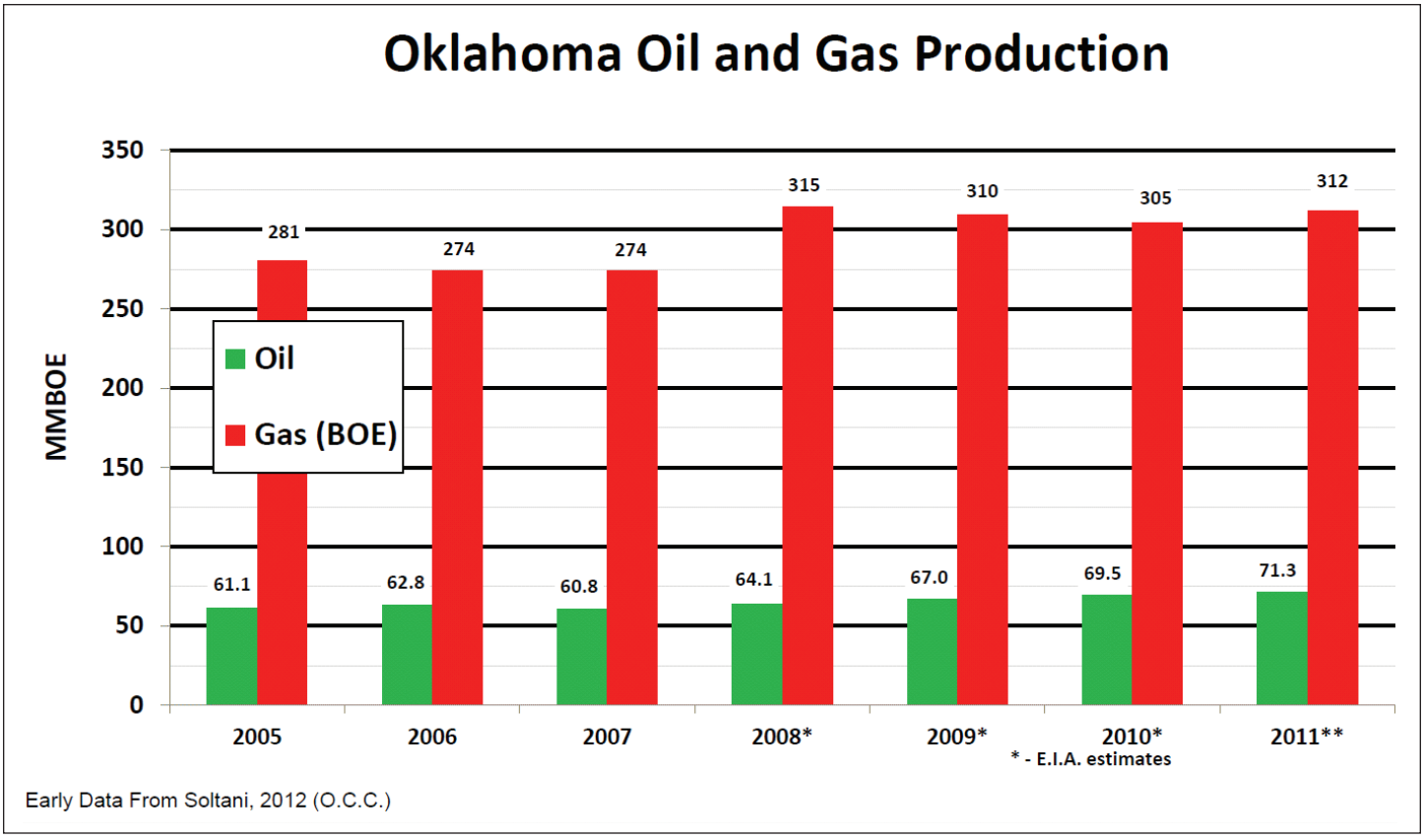


Figure 5. Oklahoma oil and gas production on a barrel of oil equivalency (BOE) from 2005 to 2011. Early data from Soltani, 2012. Later data taken from E.I.A., 2012.

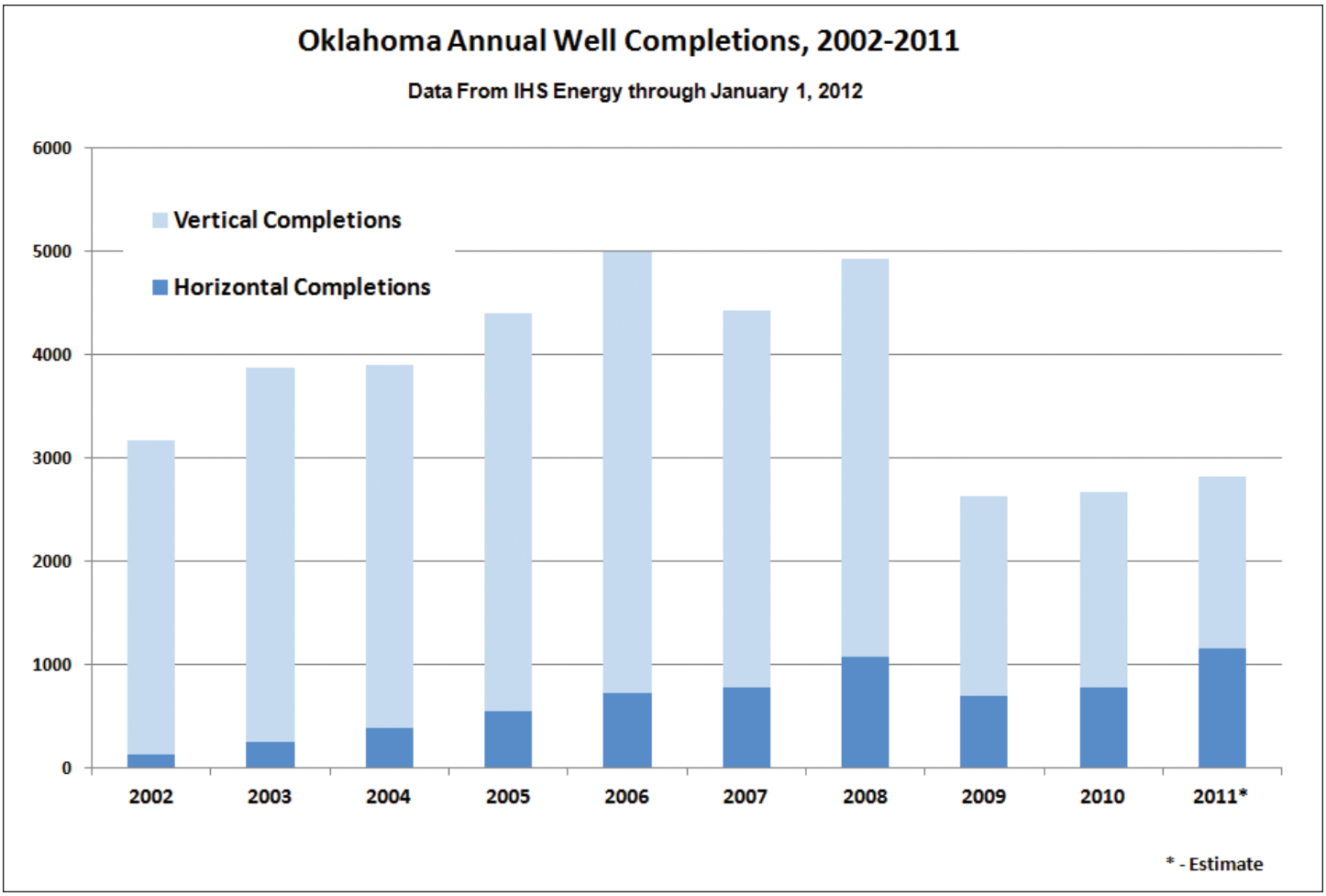


Figure 6. Oklahoma annual well completions comparing vertical and horizontal drilling from 2002 to 2011. Note the resiliency of horizontal drilling despite lower prices over the last three years. Data from IHS Energy (2012) through January 1, 2012.

Active Woodford Shale drilling, with 279 horizontal completions registered so far in 2011, combined with contributions from other high GOR horizontal plays, is projected to increase State gas production in 2011 by 46 BCF (7.7 MMBOE) over 2010 (Figure 5). A continued concentration on oil/condensate-targeted drilling has also increased 'oil' production by almost 2 MMBO and maintained a trend of increasing production that began in 2008. Oil production in Oklahoma declined continuously from the end of the drilling boom in 1984 until 2005. Since then higher prices have fueled increases in both vertical development and horizontal drilling that have increased production by 16%, or over 10 MMB per year.

Reporting delays, which sometimes manifest as gross underreporting of production, have forced the use of the Energy Information Administration (EIA) data for annual State production volumes beginning in 2008 (Figure 5). The EIA develops production statistics from survey forms that are submitted by respondents on a monthly basis. These are combined with data from 'other sources' in order to estimate total State production. Although this is something of a black box, EIA volumes make more sense based on documented drilling and completion activity. They have online data through July, 2011 while the OCC as of this writing has yet to publish 2010 production (E.I.A., 2012). OCC and EIA annual production numbers have diverged from near-agreement in 2007 to a difference of 3% in oil and 11% in gas in 2009. Such discrepancies make year-to-year projections impossible.

Overall, the 876 wells thus far registered as having begun production in 2011 have contributed about 23 thousand barrels (MBO) and 608 million cubic feet (MMCF) per day. This represents about 12% of both State oil and State gas production, but reporting lags ensure that this percentage will be extremely conservative. The vast bulk of this new production is due to horizontal drilling. Despite the industry's success in finding and producing oil and gas in 2011, continued declines in many older wells reduces the annual

rise in overall production to about 3%. This underscores the need for continuous, high levels of drilling activity in order to maintain production levels. On a BOE basis natural gas production is four times that of oil (Figure 5), but the price differential inflates oil's value to 43% of the total. Although this makes the industry and the State less dependent on natural gas, its price remains the key factor in the overall economic health of both.

Reporting delays necessitate a revision of historic State drilling statistics each year. Since January 1, 2011 987 additional completions were registered for 2010 and 163 were added to 2009. In fact, in this year's update it was necessary to add new completions to the totals registered for every year since 2002. Such delays and the fact that the proportion of reported and 'not-yet-reported' wells is inconsistent from year to year make annual comparisons of drilling activity difficult. As in previous years, to reduce the impact of reporting delays all completion numbers for 2011 were increased by one third. Total completions in 2011 registered through January 1, 2012 were slightly above those reported for 2010 at the same time last year. Although both year's well counts will continue to rise, it appears that the number of completions that will ultimately be registered in 2011, despite the higher proportion of (longer to drill) horizontal completions, will be greater than those for 2010 (Figure 6).

From 2002 through 2008 overall drilling activity generally increased, but this trend ended abruptly when prices fell at the end of 2008. The reduction in drilling was especially pronounced for vertical wells, which fell by half in 2009 (Figure 6). The number of horizontal wells drilled also fell that year, but as a proportion of all drilling the rise in horizontal drilling was remarkably consistent until 2011 (Figure 7). The jump in the percentage of horizontal well completions last year was as much due to less vertical activity as more horizontal. Since 2002 horizontal completions in Oklahoma have risen from 4% to 41% of the total number of completions, and these now represent 62% of the total footage drilled in the State.

Hundreds of companies drilled wells in 2011, but Chesapeake Operating continues to be the most active operator (Figure 8). The 184 completions registered through January 1st are comparable to those assigned to them in last year's report, and

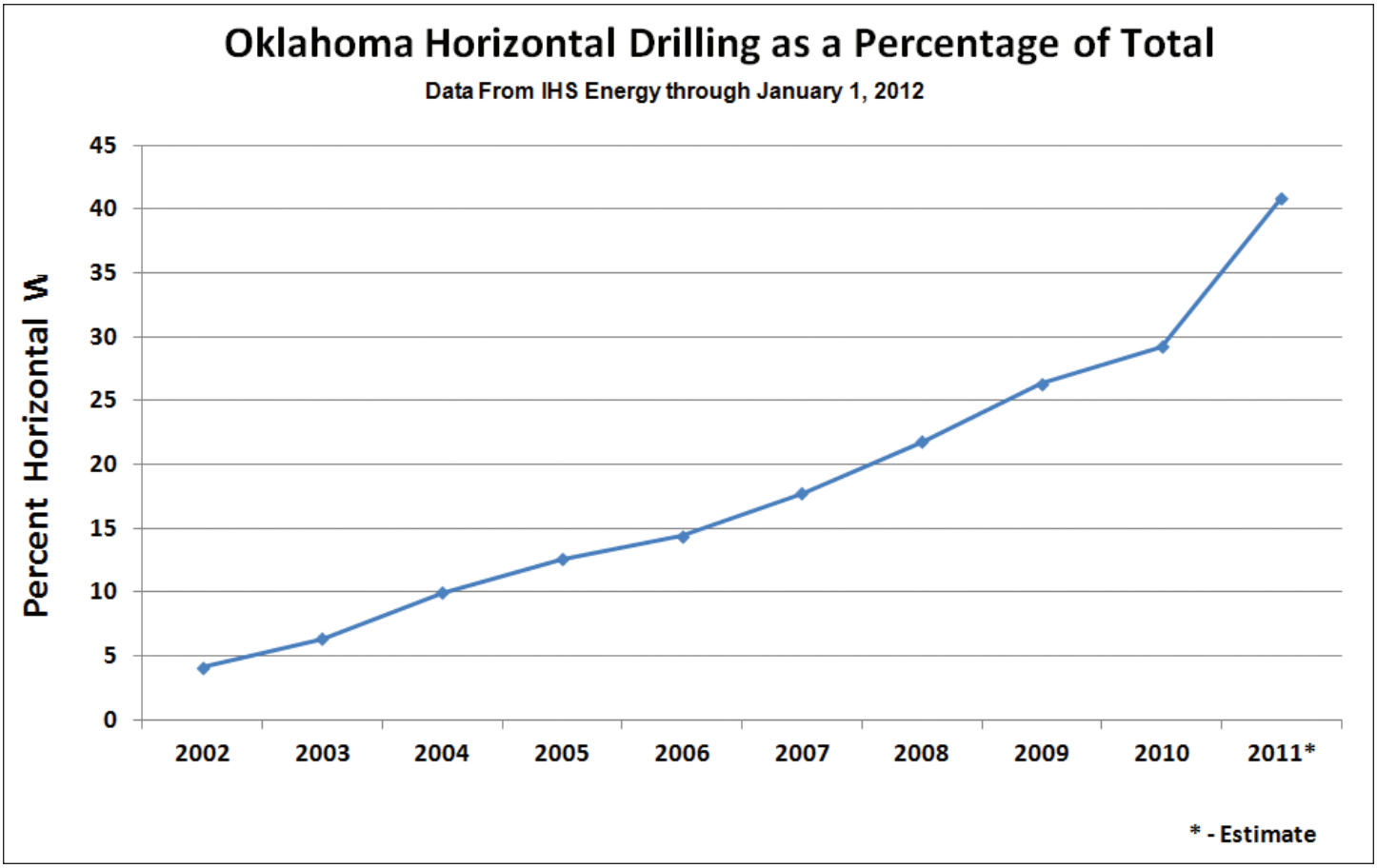


Figure 7. Oklahoma annual horizontal drilling as a percentage of total completions from 2002 to 2011. In terms of footage drilled 2011 horizontal wells accounted for nearly two thirds of State drilling. Data from IHS Energy (2012) through January 1, 2012.

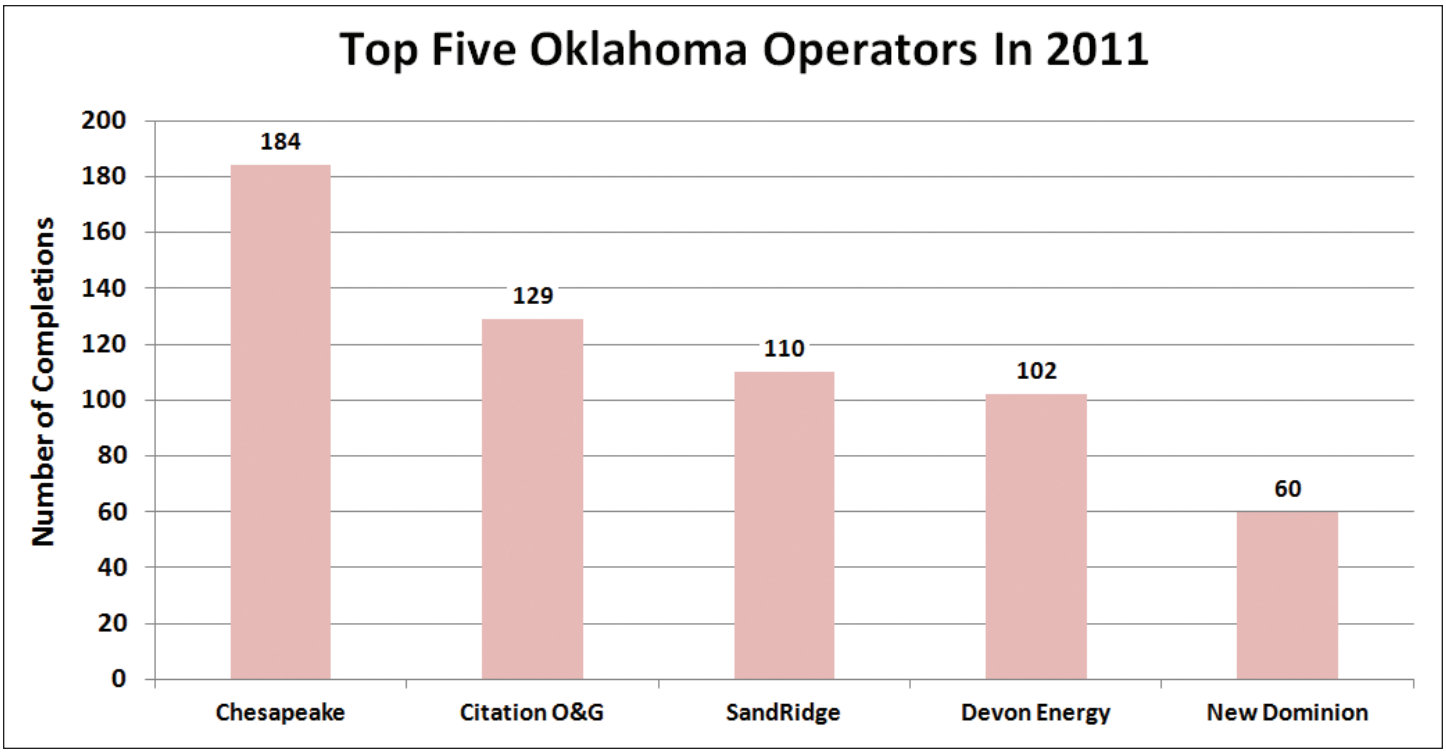


Figure 8. Top five operators in Oklahoma in 2011 based on the number of completions registered through January 1, 2012. Data from IHS Energy (2012).

these represent over 8% of all drilling in the State. Chesapeake is active in almost every part of Oklahoma, but their drilling in 2011 was dominantly horizontal and was concentrated in the Desmoinesian Granite Wash, the Mississippian, and the Cleveland plays in the western part of the State.

The remaining top operators in the State are much more focused in their drilling. Based on completion numbers the second most active operator in 2011 was Citation Oil and Gas who drilled or recompleted 129 vertical, shallow, oil development wells and injectors in southern Oklahoma, mostly in Sho-Vel-Tum, Fitts, and Healdton Fields. SandRidge's drilling activity was restricted exclusively to horizontal wells in the Mississippian play in Woods, Grant and Alfalfa Counties, which included 37 water-disposal wells. Devon Energy was primarily focused on horizontal development of the Woodford Shale, mostly in their 'Cana' play located on the northeastern shelf of the Anadarko Basin. Rounding out the top five operators in 2011, New Dominion, another perennial member of the top-five-operators club, continues to focus exclusively on Misener/Hunton dewatering projects, most of these located in Seminole County (Figure 8).

Horizontal Drilling

The petroleum industry in Oklahoma today is concentrating on low-permeability reservoirs that horizontal drilling and completion technology have made into attractive targets (Figure 9). This activity began in earnest about ten years ago with production from horizontal wells in the Hartshorne coal in the Arkoma Basin. Drilling here accelerated through the early part of the decade and was augmented by the Misener/Hunton dewatering play, which is located mostly in central Oklahoma. These two plays were followed in 2006 by the Woodford Shale, which has seen development in the western Arkoma, Ardmore, and eastern Anadarko Basins. There is now an ever-lengthening list of other reservoirs that lend themselves to horizontal drilling and completion techniques. In addition to dozens of lesser targets, the most active include the Cleveland, Desmoinesian Granite Wash, and now the Mississippian, whose potential prospective area, which extends from northern Oklahoma through central Kansas, could become the largest of them all (IHS Energy, 2012).

Horizontal drilling plays are attractive for many reasons. Because they exist in low-permeability reservoirs in which fluid separation is not possible, the accumulations are continuous and the geological risk of a dry hole is essentially zero. Blanket reservoirs that are often quite thick also contain exceedingly large in-place gas and/or oil volumes, making the potential target large. Relatively small drainage areas, even after extensive fracture stimulation, means that many wells must be drilled in order to adequately develop such reservoirs. Although restricted drainage is not normally

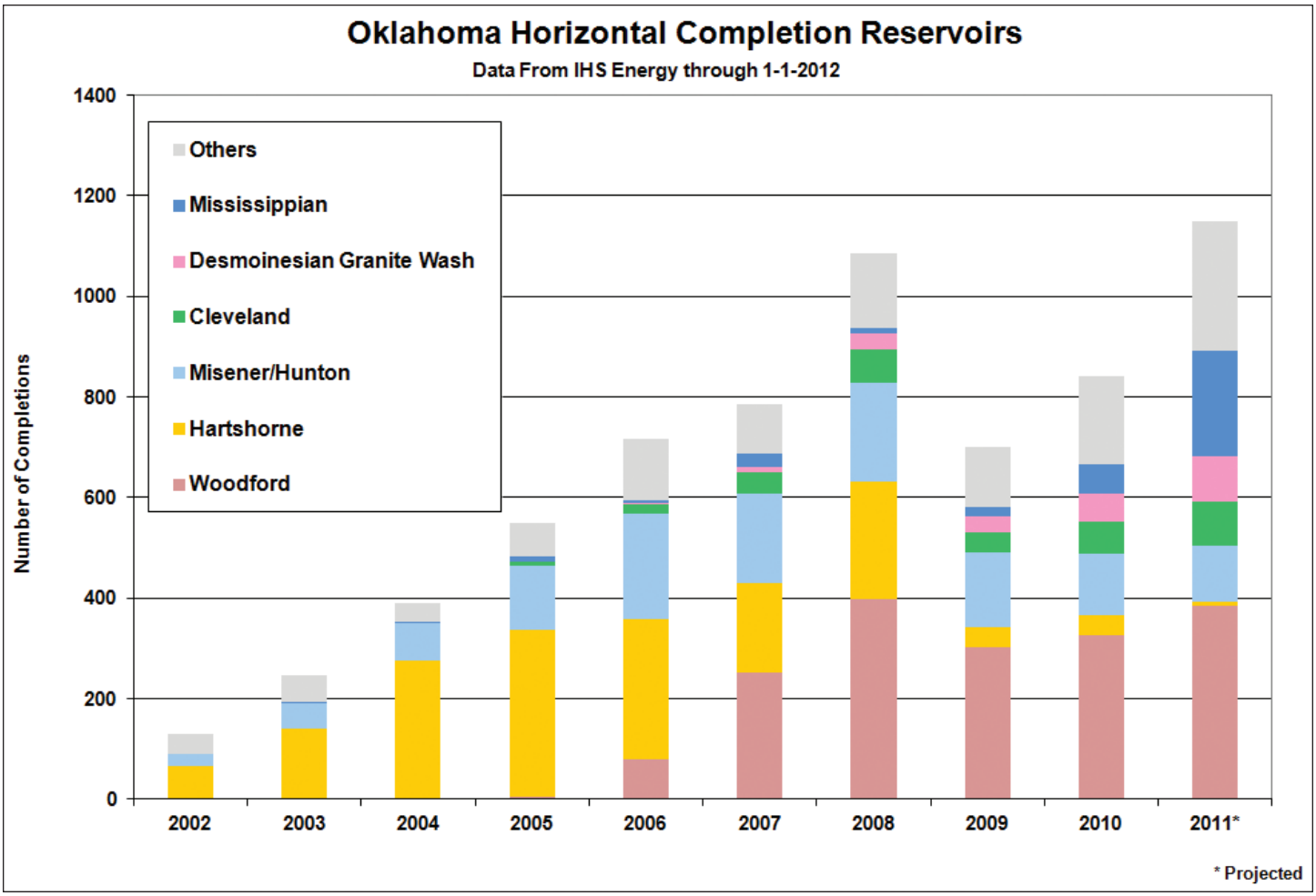


Figure 9. Major Oklahoma horizontal drilling plays (> 100 completions) from 2002 to 2011. Data from IHS Energy (2012) through January 1, 2012. All registered 2011 completion numbers increased by one third to account for reporting delays.

an attractive characteristic, this allows companies to book proved undeveloped reserve volumes that are two to seven times those booked for the first well in the drilling unit. The result is a 'dream scenario' for large operators whose regional leasing programs have captured hundreds of thousands or even millions of net mineral acres. With drainage areas established, locations are permitted and wells drilled based on lease expiration. Large numbers of dedicated drilling rigs are then able to turn reserve bookings into an assembly-line process in which the primary risk is mechanical. The thousands to tens-of-thousands of development locations generated from this 'exploratory' drilling create proved-undeveloped reserve volumes that quickly become astronomical.

However, even horizontal plays are price-sensitive. Early production declines are very steep and drilling, operational (including water disposal) and acreage costs are high. Although most horizontal plays have 'sweet spots' that will remain economic in almost any price environment, based on the data at hand most of the prospective areas appear to be economically marginal in all but higher-price scenarios. With the fall in natural gas prices in late 2008 operators have been forced to focus on horizontal plays that are more liquids-rich, which includes oil, condensate, and natural gas liquids (NGLs). However, because the targeted reservoirs have exceedingly low permeability, even the most liquids-rich horizontal plays produce mostly gas (Figure 10). This preponderance of natural gas, combined with its low price, makes it appear that operators have foregone short-term economics in favor of a strategy of holding acreage by production. Development drilling on this acreage can then wait until prices rise above whatever economic threshold the operator deems necessary to justify future activity.

Almost every significant productive reservoir in the State has been drilled horizontally somewhere, but some have been systematically exploited in well-defined area(s) which can be described as geologic plays. Three of these, while still producing, are largely inactive in terms of drilling.

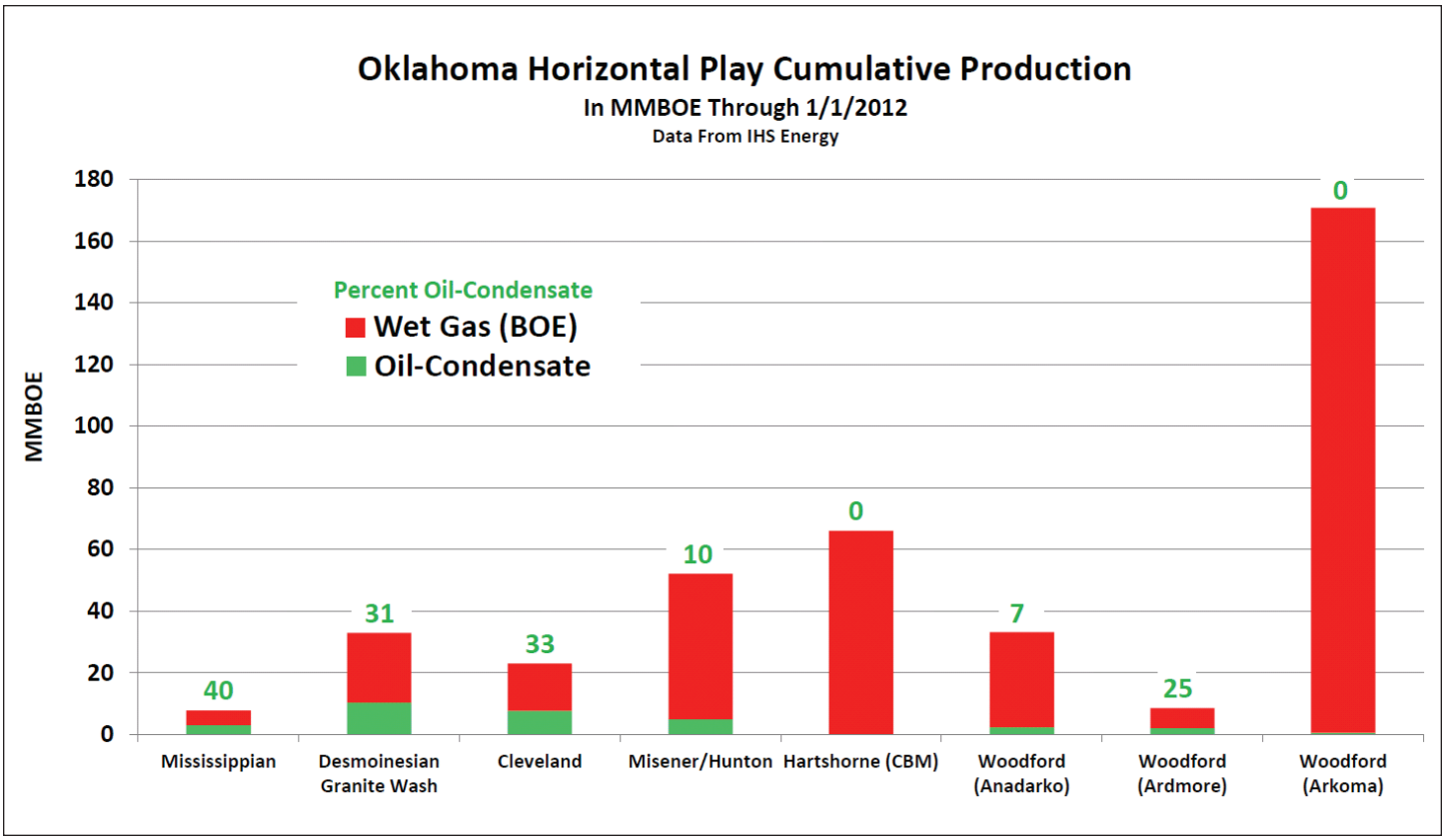


Figure 10. Oklahoma major horizontal play cumulative production in MMBOE. Even the most hydrocarbon liquids-rich horizontal plays produce primarily gas. Natural gas liquid (NGL) production is not taken into account. Data from IHS Energy (2012).

Chesapeake utilized horizontal-drilling technology in the mid- to late-1990's to pursue mostly oil in the Sycamore carbonate in southern Oklahoma. Most of these wells are located in Sho-Vel-Tum Field and the Golden Trend. Another largely inactive horizontal play was made by EOG Resources in the Panhandle in western Texas County. Here they drilled about 70 horizontal gas wells between 2000 and 2003 in the Council Grove, mostly in Unity SW and Guymon-Hugoton Fields. In an aggressive dewatering project that utilizes horizontal drilling, New Dominion has targeted the Arbuckle in the Oklahoma City Field. Here they have drilled 55 horizontal laterals from 17 surface locations and are disposing the water into the Arbuckle on the downthrown side of the field fault (Boyd, 2010).

Using an arbitrary 100-well cutoff, there are six 'major' horizontal plays in Oklahoma with all but one still active. In addition, there are others (Marmaton, Tonkawa and Cherokee) that appear destined to reach this milestone soon. Drilling statistics for the most active horizontal plays over the last ten years are shown in Figure 9. [The 2011 totals for each of those listed have been increased by 33% in an attempt to account for the reporting delays described previously.] Although the 2011 projections are probably still conservative, the graph should be indicative of the direction that activity in these plays is taking. Figure 11 shows the productive areas occupied by the six 'major' horizontal plays at the end of 2010 and the completions that were added to these and all other reservoirs in 2011. In the last month reported, usually between July and September of 2011, Oklahoma's 5,030 producing horizontal wells were making 35 MBO + 1,819 MMCF per day. Even this under-reported volume represents 18% of State oil production and 35% of gas. The six major horizontal plays account for over 90% of this production. (All production cited are from IHS Energy, 2012.)

Hartshorne Coal

Located in the Arkoma Basin, Hartshorne coalbed methane has been exploited with horizontal wells for more than a decade. Low natural gas prices and negligible liquids production have depressed drilling activity in this play since the fall in natural gas prices in 2008. Although still the largest horizontal play with 1,691 wells, with only seven registered completions in 2011 the Hartshorne coal has disappeared as an active play. There appears to be ample room to expand this play eastward (Figure 11), but only a major increase in gas prices will see this area developed. The 1595 actively producing horizontal Hartshorne

coal wells have an average cumulative recovery of 249 MMCF and a current rate of 60 MCF per day.

Woodford Shale

The next largest horizontal drilling play in the State, and the one that is still by far the most active, is the Woodford Shale. In only six years it now boasts 1,639 producing wells of which 279 have been registered thus far for 2011. Although the decline in gas prices has pushed most Woodford drilling into areas with higher liquid yields, activity remains brisk (Figure 9).

Of the three primary producing trends, the western Arkoma Basin accounts for nearly three quarters of all Woodford wells. Here most of the 2011 activity was in and around areas of established production, which has linked several isolated producing areas and appears destined to become contiguous through central Pittsburg County (Figure 11). The most active operators in the Arkoma Basin in 2011 were Newfield Exploration, XTO Energy and Devon Energy. The 1,119 horizontal Woodford producers in this area have average cumulative production of 897 MMCF and a current rate of 751 MCF per day. Oil and condensate production in most of this area is negligible.

The most active 2011 Woodford drilling occurred in the producing area pioneered by Devon Energy in the northeastern Anadarko Basin. This productive area has continued to expand from western Canadian County into southern Blaine and northern Caddo Counties. Previously isolated pods of production in southeastern Dewey County have merged and appear poised to link with the main area. Expansion along strike to the southeast through Grady County is also taking place, but this has not yet become as active. Devon Energy was by far the most active operator in this area in 2011, drilling over half of all wells. There are now 346 horizontal Woodford wells producing in the Anadarko Basin and these have average cumulative production of 662 MMCF and 7 MBO. Average per well production for the last reported month across this part of the play was 960 MCF + 11 BO per day. Although only wet gas production is reported, NGL yields in this play are significant with reported Btu contents as high as 1350 per MCF.

A third major concentration of horizontal Woodford Shale production is located along the northern edge of the Ardmore Basin in Carter, Johnston, and Marshall Counties where there is now a trend about 40 miles long. In 2011 this was the least active part of the play with no major extensions to the previously established producing area (Figure 11). In the Ardmore Basin the most active horizontal Woodford operator is XTO Energy. The 111 producing wells registered in this area have average cumulative production of 662 MMCF and 7 MBO. Average per well production in the last reported month was 960 MCF + 11 BO per day.

Misener/Hunton

Dewatering has found its greatest application in the Hunton (Misener/Hunton) reservoir where over 1,322 horizontal wells have now been drilled. This play has remained consistently strong, with over 100 wells drilled in each of the last seven years (Figure 9). Production through reservoir dewatering has been pursued in this reservoir interval in a number of areas. Aside from a handful of wells in the Edmond West Field area, the bulk of recent activity has again concentrated in central Oklahoma mostly in and around Seminole, Lincoln, and Okfuskee Counties. As was the case last year, New Dominion was the dominant operator in this play, accounting for more than half of all horizontal Misener/Hunton wells drilled in 2011. The second most active operator was OEX-1 LLC, who has 20 wells registered thus far. Activity for both operators was mostly relegated to previously established areas of production. Because this play requires a major drop in reservoir pressure before significant hydrocarbons are produced, a process that can take years, the productivity of new wells or areas cannot be ascertained based on initial potential tests. This is why none of these has ever made the annual list of significant wells. Horizontal Hunton and Misener/Hunton wells have produced about 5 MMBO and 283 BCF, generating an average recovery per completion of 10 MBO + 551 MMCF (Figure 10).

Cleveland

Unlike the first three horizontal plays, the remaining have significant liquids production and so have tended to benefit from the relative strength of oil prices and their continued rise (Figure 2). Horizontal Cleveland Sandstone drilling, which fell by a third in 2009, is at an all-time high with at least 90 completions projected for 2011. Like last year, recent activity has seen a major expansion of the older productive areas and the addition of new areas of production.

The main productive area in Ellis County, which continues into Lipscomb and Ochiltree Counties in the Texas Panhandle, has recently been extended into northern Roger Mills County. The satellite area that began in southwestern Dewey has continued to grow and has now moved well into Custer County. Based on drilling trends it appears that these two productive areas may meet in the future. An isolated pod of horizontal Cleveland production in northern Logan County also saw the addition of two wells in 2011 (Figure 11), but its economic viability remains in doubt. Despite the high oil volumes registered on initial tests and their general classification as oil wells, on a BOE basis horizontal Cleveland production is two-thirds natural gas (Figure 10). To date the play's cumulative production in Oklahoma is 7.7 MMBO + 92 BCF (15.4 MMBOE), giving the average well a cumulative production of 29 MBO + 347 MMCF.

Granite Wash

There are several reservoirs called 'Granite Wash' that are being explored for and

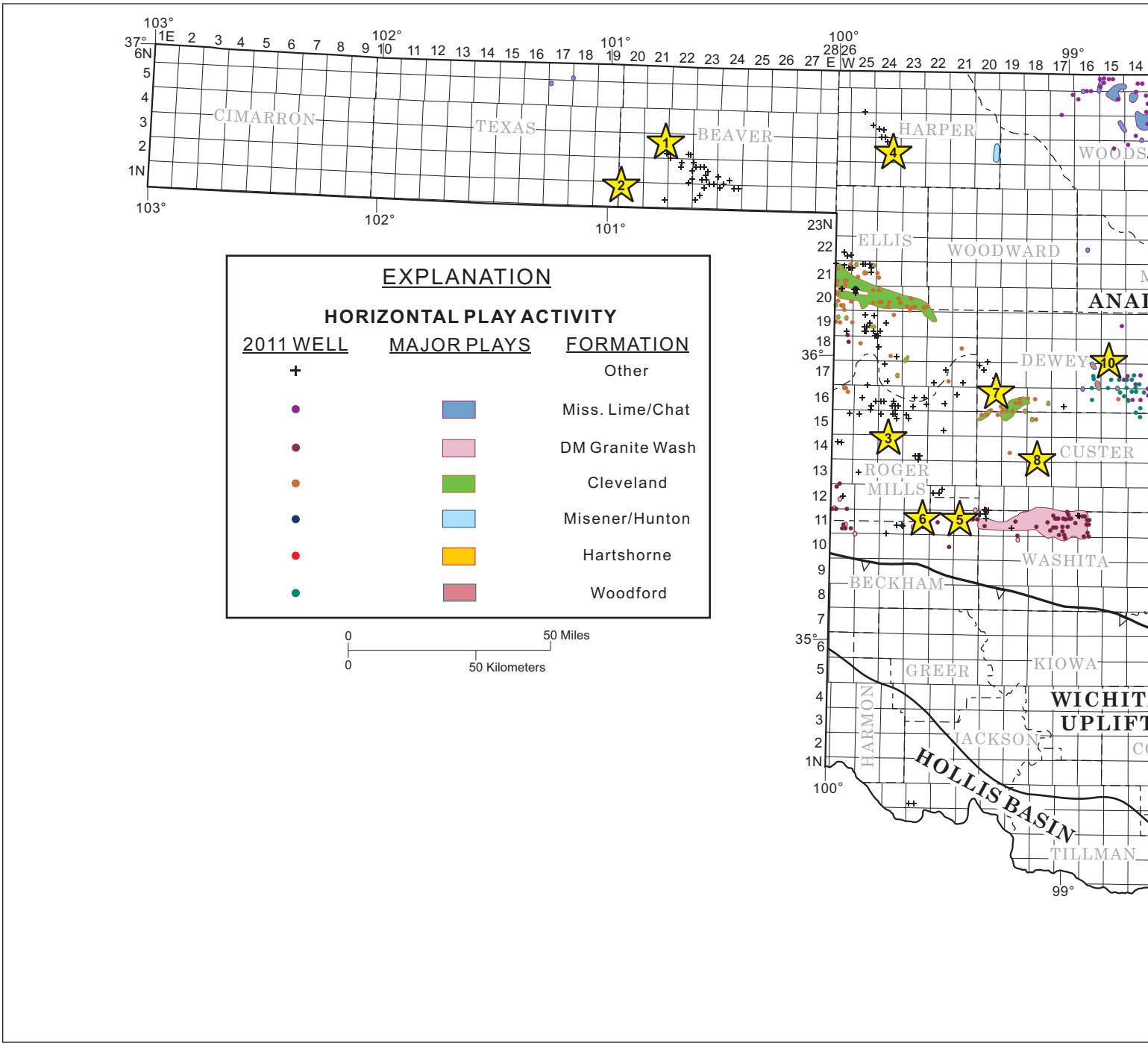
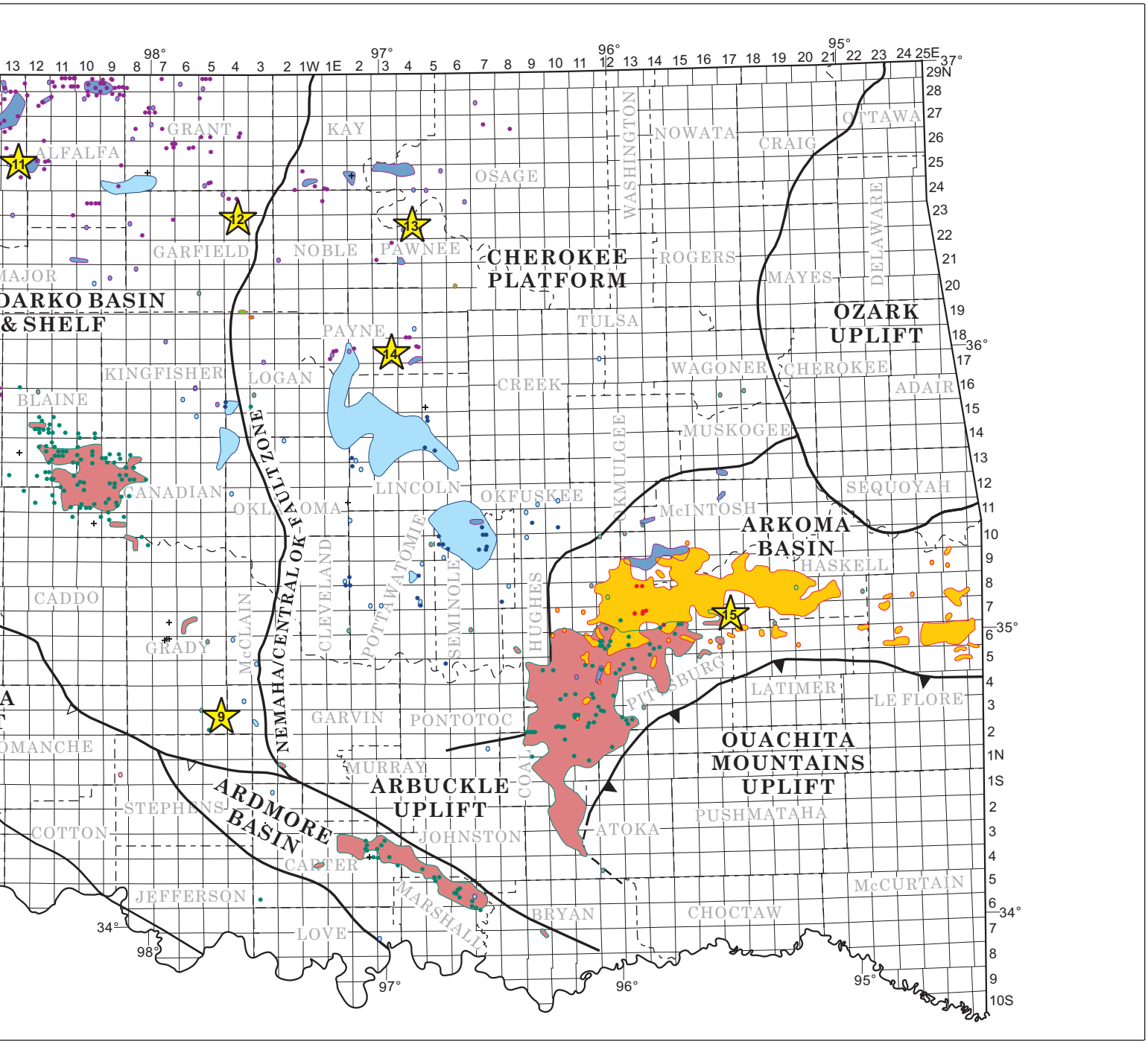


Figure 10. Oklahoma major horizontal play cumulative production in MMBOE. Even the most hydrocarbon liquids-rich horizontal plays produce primarily gas. Natural gas liquid (NGL) production is not taken into account. Data from IHS Energy (2012).

developed in the Anadarko Basin. These reservoirs span nearly the entire Pennsylvanian System through the lower Permian and are comprised of thick, low-permeability sediments shed from the Wichita Uplift located to the south. As such they vary in lithology based on the formation that was exposed on the uplift at the time of deposition. 'Granite Wash' reservoirs have been produced from vertical wells for decades with varying levels of success, but the advent of horizontal drilling and completion techniques has reduced the dry hole risk and made some enormously economic.

The Desmoinesian Granite Wash horizontal play, located in the deepest part of the



Anadarko Basin, is by far the most important of the 'Granite Wash' reservoirs to date. Starting in north-central Washita County, completion numbers grew by a third in the last year. Chesapeake was again the dominant operator in this play, accounting for nearly two thirds of the 2011 completions registered thus far. In addition to development within the main producing area, recent drilling has expanded this core area another township west into Roger Mills County (Figure 11). Activity was also brisk along the Texas border, but efforts to connect these two areas with economic production appear to have failed so far.

Vertical wells have produced Desmoine-

sian Granite Wash since the mid-1980s, but horizontal production only began in April 2007 (Figure 9). Through August of last year the wells in this play registered an average recovery of 727 MMCF and 55 MBC, with most of these on line for less than two years. Having the highest average liquids production for any horizontal play in the State, it is notable for spectacular rates on initial potential tests and wells with payouts often measured in months. Although its high condensate yield makes this horizontal play particularly attractive, like the Cleveland, on a BOE basis it is still about two-thirds gas (Figure 10).

Although the Desmoinesian Granite Wash is the only horizontal wash play with a significant production history, there are several others that appear destined to expand. Naming conventions make these difficult to distinguish from non-wash reservoirs, and some may overlap with reservoirs to the north. However, wells located in Beckham, Washita, Caddo, and southern Roger Mills and Custer Counties likely have a southern source and so could be called 'wash' reservoirs. In addition to those identified as Desmoinesian (Series) and Granite Wash (which is assumed to also be Desmoinesian Granite Wash), this area includes reservoirs identified by operators as Atoka, Skinner, Cherokee, Missouri, Pennsylvanian Missourian, Hoxbar, Marchand, and Hogshooter. Reservoirs using the same names produce in horizontal wells in northern Roger Mills and Ellis Counties, and although their productive characteristics are similar, these are probably sourced from the north and/or east and so are not true 'wash' reservoirs.

Mississippian (Lime / Chat)

A much more scattered horizontal play, but the one that has experienced the greatest drilling surge in the last year, is targeting what is identified as the Mississippian Lime and Chat. These are different reservoirs, but are combined here due to inconsistent naming. The Chat produces horizontally mostly in Osage and Kay Counties and this part of the play appeared to be relatively quiet in 2011. It is a thin, siliceous zone of variable reservoir quality that intermittently develops on top of the Mississippian Lime. Like the Mississippian Lime beneath, it has produced for decades from vertical wells. It can now be identified seismically, and horizontal wells drilled on seismic anomalies have allowed operators to maximize exposure to the Chat. Because it has natural permeability wells are usually untreated.

The Mississippian Lime is a regional carbonate found across most of the State. It has produced from vertical wells for decades, albeit usually marginally. Horizontal wells have the potential to make this reservoir economic over a much wider area. Although it can develop porosity and permeability, reservoir quality tends to be poor. It is often fractured, and horizontal drilling affords the opportunity to enhance natural fractures with multi-stage acid fracture stimulations. The Mississippian Lime is thick and oil-prone across much of the northern half of the State, giving this formation regional prospectivity. Given its wide extent, the play has the potential to become the largest and perhaps the most productive horizontal drilling play in Oklahoma (Figure 11).

A total of 157 horizontal Mississippian wells have so far been registered for 2011, bringing the total number of completions to 285. Recent wells were mostly clustered around the main area of production located in Woods and Alfalfa Counties and this activity has moved across the border into Kansas. The core area is dominated by Chesapeake and SandRidge, each of whom have leaseholds exceeding one million net acres. The core productive area is expanding to the east and south with isolated activity as far east as Payne and Pawnee Counties. Although 241 wells are now on production, the vast majority have been online for less than a year. Average cumulative per well recoveries now stand at 13 MBO + 113 MMCF with production in the last reported month at 25 BO + 306 MCF per day. Although it is the oiliest of the horizontal plays, on a BOE basis Mississippian production is still 60% gas (Figure 10).

The Oklahoma oil and gas industry has applied horizontal-drilling technology to dozens of other reservoirs across the State and will continue to test the limits of where this can be applied. There are sweet spots, but a large proportion of the horizontal wells drilled thus far appear to be marginal to clearly sub-economic. However, low productivity can be as much due to the manner in which the wells are drilled and completed as any inherent geological factors. The learning curve from first (often marginal) production to more consistent, economic development is a process measured in years. There are a number of reservoirs that were not discussed that, based on initial potentials, are showing promise. Wells tapping these reservoirs, which are classified as 'Others' in Figure 9 and are shown as black pluses in Figure 11, may develop into larger horizontal-drilling plays in the future.

Significant Wells in 2011

The following is a list of what are believed to be among the most significant wells registered for Oklahoma in 2011. Although all were registered in the past year, due to reporting delays, some have earlier completion dates. The wells listed were identified from a weekly review of the IHS Energy *EnergyNews on Demand* Midcontinent activity reports released online throughout the year. An initial list of 152 candidates compiled from this publication was distilled to a final total of 15. Such a list is subjective and may miss wells that could eventually become noteworthy. Due to confidentiality issues, wells that may be notable for technical reasons will probably be missed. For instance, those that confirm some new type of trapping style or proved the benefit of a new drilling or completion technique will be difficult to identify until information is disseminated years from now.

Horizontal wells have occupied a progres-

sively larger share of the significant well listings each year. In 2010, and now 2011, they comprise all of the 'all-star' wells in this report. Those listed here have either significantly expanded what appears to be economic production in an established horizontal play or in some way constrained its ultimate extent. To keep this listing to a manageable size, in some cases related nearby wells were added to the discussion. Wells with production histories are given precedence over those with only impressive initial potential tests and, where available, the volumes reported are given. Please refer to Figure 11 for orientation during the following discussion.

1) Sec. 13-3N-21ECM (Beaver County): In one of the State's most active horizontal drilling plays QEP Energy extended Marmaton production two miles to the northwest with the completion of their Bobbitt Trust #3-13H well. As well as expanding the productive area, this well has also established a new highest initial potential with a daily rate of 1,063 BO per day. No gas, water, or stimulation was recorded for this well, which was completed in a 4,508' lateral located at a true vertical depth (TVD) of 6,000'.

2) Sec. 6-1N-20ECM (Beaver County): In a related development, Unit Petroleum made a horizontal Marmaton completion in the State of Oklahoma #1-H that is 15 miles west of the main play. This well is located on the southern limit of a small pod of vertical Marmaton wells assigned to the Camrick District that were drilled in 1970 and 1971. Since that time the five wells in Section 6 have produced about 172 MBO. This new horizontal well had an initial potential on pump of 284 BO (38^{O} API) + 93 MCF + 1,740 BW per day from a 2,218' lateral at a TVD of 5,890'. It was fracture stimulated with 650,000 pounds of sand.

3) Sec. 4-14N-24W (Roger Mills County): Classified for now as part of the same horizontal Marmaton play located to the north, operators drilled about two dozen wells in southern Ellis County and have now pushed production into central Roger Mills County. Although here it may have a southern provenance, making it a Marmaton 'wash', it is still simply identified as Marmaton. The Cordillera Energy Galileo #2-4HA had an initial potential of 367 BO + 5.36 MMCF per day with no water reported. The well has a 2,200' lateral located at a TVD of 11,150'. Cordillera has reported that the NGL yield from the gas at this well is about 93 barrels per MMCF, giving it nearly 500 barrels of NGL production initially. This is comparable to the yield reported for Marmaton wells in Ellis County. The number of horizontal Marmaton wells nearly tripled in 2011 with Unit Petroleum and EOG Resources operating most of them. With a total of 86 completions registered thus far this play will undoubtedly become one of the 'major' horizontal plays in next year's report.

4) Sec. 23-26N-24W (Harper County): In another horizontal play that will probably reach the 100-well hurdle and become 'major' in the next year or two, Cherokee completions also more than tripled in 2011. The 45 completions in 2011 are mostly scattered in three areas in southern Roger Mills, southern Ellis, and western Harper Counties. Apache completed their Zoldoske #4-23H for 525 BO (45 ^{O} API) + 681 MCF + 117 BW per day. This well, which is the southernmost in the Harper County trend, shows that this play is far from defined. The well was completed in a 4,482' lateral at a TVD of 6,750' and acid-fraced in ten stages with about 1.2 million pounds of sand. In six months this well produced about 31 MBO + 77 MMCF with a rate in the last complete month of 117 BO + 3.0 MMCF per day.

5) Sec. 17-11N-21W (Beckham County): In a major westward extension of liquids-rich Desmoinesian Granite Wash production, Apache drilled a pair of excellent wells from the same surface location. Both completed in June 2011, the Smith 1-16H and 1-17H are virtual twins with initial potentials of 1,115 BC + 12,634 MCF + 596 BW and 1,095 BC + 12,582 MCF + 554 BW per day. Both wells have a TVD of about 13,000' and 4,000' laterals that were fracture stimulated with 3.1 to 3.3 million pounds of sand. The heart of the play remains in Washita County, but these wells are the first to establish high liquids production in Beckham County, which until now has been dominantly gas. The two wells have produced 564 and 574 MMCF in less than two months with a combined recovery of 34 MBC. In the last complete month each well was producing about 11.6 MMCF per day with a combined daily rate of 1,082 BC. Although Desmoinesian Granite Wash production extends westward into the Texas Panhandle, the eastern limit of this play seems to be anchored in the center of township 11N-16W. It is not known if this limit is geological or lease related, but high condensate-yield wells have been drilled by Chesapeake right up to this limit.

6) Sec. 14-11N-23W (Roger Mills County): Along the trend of the Desmoinesian, Hogshooter and other horizontal 'Granite Wash' plays operators have been drilling wells targeting what they are calling Missouri Granite Wash or Cottage Grove sand. The most notable of these wells was drilled by Crawley Petroleum. The Moore #5-14H had an initial potential of 1,485 BO + 5,717 MCF + 710 BW per day in a reservoir identified as the Cottage Grove sand. This well has a 5,260' lateral at a TVD of 11,322' that was fraced using about 2.4 million pounds of sand.

7) Sec. 11-16N-20W (Dewey County): Horizontal Tonkawa completions, which doubled in 2011, have historically been situated in Roger Mills and southern Ellis Counties. 2011 saw a major westward development of the play into southwestern Dewey County. Chesapeake drilled what appears to be the best of the nine wells in this area with their Lauder #1-11H. Completed in a 4,260' lateral at a TVD of 8,240' the well had an initial potential on gas lift of 510 BO (46 ^{O} API) + 420 MCF + 1,260 BW per day after a fracture stimulation that used 4.2 million pounds of sand. In four months of production this well, apparently choked back, has cumulative

production of only 76 MMCF with an average rate of about 700 MCF per day with no liquids production noted.

8) Sec. 33-14N-18W (Custer County): There are now over 300 horizontal Cleveland completions with 65 registered thus far for 2011. Most of the activity took place within established producing areas, but the most significant extension seems to be in central Custer County where Chesapeake now has four months of production history on a 2011 discovery. The SGD #1-33H was completed in April from a 4,483' lateral at a TVD of 10,591' with 2.2 million pounds of sand. After an initial flowing potential of 547 barrels of 46 ^{O} API oil + 1,153 MCF + 1,102 BW per day it has produced 23 MBO + 60 MMCF. In the last reported month it was still producing at a rate of 124 BO + 300 MCF per day. Several additional wells have since been permitted in the area.

9) Sec. 11-3N-5W (Grady County): What began as the Woodford Shale 'Cana' play in western Canadian County is spreading over an ever-widening swath of the eastern shelf of the Anadarko Basin. The core area, which now comprises the better part of a dozen townships in Canadian, Blaine and Caddo Counties, appears to have been extended to the extreme southern corner of the basin some 60 miles to the southeast. The Continental Resources Lambakis #1-11H had an initial potential from the Woodford of 5.4 MMCF + 160 BC per day with no water reported. The well was produced after a ten-stage fracture stimulation from a 4,200' lateral at a TVD of 15,128'. Continental has indicated that the gas from the Lambakis has a Btu content of 1,350 (~ 170 barrels NGL per MMCF) and is commanding a price of $6.25/MCF. In three and a half months of production the Lambakis made about 12 MBO + 319 MMCF with a rate in the last complete month of about 100 BC + 4.2 MMCF per day.

10) Sec. 32-18N-15W (Dewey County): The 'Cana' Woodford Shale play has also moved well into Dewey County with Devon drilling the two most northerly wells so far. Their Rauh #1-32H had an initial potential of 147 BO + 3,253 MCF + 908 BW per day. The Btu content of the gas was not reported, but the NGL production will probably be at least double what is reported as the initial 'oil' rate. This well was completed from a 4,292' lateral at a TVD of 11,677' and a fracture treatment using 2.2 million pounds of sand. The best well in this extension of the play is the Continental Resources #1-2H Brown which was drilled about three miles southwest in Section 2-17N-16W. After an initial potential of 3,772 MCFPD this well produced 1.5 BCF in two years and was making about 1 MMCFPD in the last reported month (September, 2011).

11) Sec. 34-26N-13W (Woods County): Eagle Energy recorded the highest initial potential of any horizontal Mississippian well with the completion of their Longhurst #3H-34. This well flowed 2,225 barrels of 32 ^{O} API oil with 4,767 MCF + 2,789 BW per day. Completed in a 3,615' lateral at a TVD of 5,806', it was acid-fraced with 12,500 barrels of fluid and 160,000 pounds of sand. This well is less than a mile west of another Eagle Energy well in section 35. Completed in 2010, the Mary Beth #1-H was completed in a 2,307' lateral (TVD – 5,807') pumping at a rate of 50 BO + 318 MCF + 3,212 BW per day. Oriented north-south like the Longhurst, the Mary Beth is shown as a Chat well completed with a 24,500 barrel 'acid-frac' in which no proppant was reported. There are many examples of wildly different initial potentials in adjacent wells in the Mississippian, as well as other horizontal plays, but this is the largest seen thus far. The underlying cause is not known, and neither well has any recorded production, but this certainly highlights a pitfall in blanket reserve assignments to regional plays.

12) Sec. 3-23N-4W (Garfield County): Establishing the highest horizontal Mississippian initial potential in the county, Plymouth Exploration completed their Sebranek #1-3H flowing at 1,031 BO (44 ^{O} API) + 1,327 MCF + 3,799 BW per day. This well was completed in a 3,302' lateral at a TVD of 5,774' with a nine-stage, 750,000 pound acid-fracture stimulation. The Sebranek seems to confirm at least a step in a bridge that may eventually link the western and eastern Mississippian play areas. However, it is a direct offset to a 2010 well, the Wicklund #1-34H Massie, that had an initial potential on pump of 90 BOPD. This well produced only 6 MBO + 12 MMCF in 17 months, with a rate in the last month of 6 BOPD. It is not known whether the drilling/completion technique or some geologic factor is responsible for this discrepancy.

13) Sec. 22-23N-4E (Pawnee County): Territory Resources pushed horizontal Mississippian production nine miles northeast of Pablo Energy's initial discovery (Ripley #1H-31) in this westernmost part of the play (Boyd, 2011). Their Beast #1-27H had an initial potential on pump of 585 barrels of 40 ^{O} API oil with 1,000 MCF + 2,300 BW per day. In this area the TVD of the 3,689' lateral was only 3,674', which was stimulated with an acid frac treatment using 122,000 pounds of sand. The Beast produced 137 BOPD in its first month, but in its last month was down to 44 BOPD. Cumulative production in four months is about 8 MBO with no reported gas. The Ripley well (Sec. 31-22N-4E), which began Mississippian horizontal activity in this part of the State, in 20 months has produced about 54 MBO with a last reported rate of 24 BOPD. It too has no reported gas production.

14) Sec. 21-18N-3E (Payne County): A horizontal Woodford Shale well that is off the beaten track was drilled by Calyx Energy with their State WFD #16-1H. With a TVD of only 4,379' the 3,700' lateral was acid-fraced with 685,000 pounds of sand and had an initial potential on pump of 310 BO (36 ^{O} API) + 150 MCF + 1,500 BW per day. A true Woodford oil well, this well does not yet have any reported production.

15) Sec. 16-7N-17E (Pittsburg County):

Petroquest Energy pushed the main productive area of the horizontal Woodford Shale in the Arkoma Basin eastward with the drilling of several wells in 2011. The best of these, their Tonya #1-20H, came on for 6,293 MCF + 1,259 BW per day. The well was completed with a fracture stimulation using 2.6 million pounds of sand on a 4,993' lateral located at a TVD of 8,653'. Although there is not yet any recorded production for these wells, they appear to be as good as any in the play and show that there is still ample room to expand horizontal Woodford Shale production in this part of the State.

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Dan T. Boyd

Biographical Sketch

Dan Boyd is a petroleum geologist with the Oklahoma Geological Survey, where he has been employed since 2001. Dan received his Master of Science degree in geology from the University of Arizona in 1978. He spent the first 22 years of his career as an exploration and development geologist in the petroleum industry. From 1978 through 1991 he worked on a variety of areas in the United States from Houston, Dallas, and Oklahoma City for Mobil Oil and Union Texas Petroleum. In 1991 he moved overseas, working in Karachi, Pakistan for four years and Jakarta, Indonesia for the following four. He returned with his family to the U.S. in 1999 with Arco (the successor to Union Texas) where, until Arco's sale to BP, he worked the offshore Philippines from Plano, Texas.

Since joining the OGS staff Dan has presented and published several reports on the history, status, and future outlook of the oil and gas industry in Oklahoma. He chaired the 2002 Symposium on Cherokee Reservoirs in the Southern Midcontinent (OGS Circular 108), and prepared and presented a workshop on the Booch gas play in southeastern Oklahoma (Special Publication 2005-1). His most recent study of oil reservoirs and recovery efficiencies (Shale Shaker May/June, 2008) demonstrates that large volumes of producible oil remain in the ground and that a major barrier to finding and producing this oil is shortcomings in State oil and gas data. Dan serves on the board of Energy Libraries Online (ELO) from a conviction that the long term success of the Oklahoma industry depends on improving both the completeness and accessibility of State oil and gas data.

Shale Shaker

120 North Robinson, Suite 900 Center
Oklahoma City, OK 73102