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Review of Kentucky Oil and Gas Production, 2010

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Abstract

The 2010 oil and natural gas production data by well published by the Kentucky Division of Oil and Gas were analyzed in response to proposed rules for limiting emissions from oil and natural gas facilities. Average daily production was determined for 5,044 oil wells and 12,940 natural gas wells. Of these wells, 955 are combined oil and natural gas producers. The overwhelming majority of Kentucky's wells are marginal (stripper) wells and produce at rates of less than 10 barrels of oil (or barrels of oil equivalent) per day (bo/d) or 60 thousand cubic feet of natural gas per day (Mcf/d) during the months they are operated. The median oil production rate is 0.87 bo/d. The median natural gas production rate is 12 Mcf/d.

The 2010 data used in this assessment include production for both recently completed wells and very old wells, the oldest having been completed in 1912. Although the data describe the production across the state that could contribute to emissions, the findings do not reflect newer wells that are expected to be in the early phase of production. A total of 151 oil wells and 1,468 natural gas wells were selected for study that were completed since January 1, 2005, were operated for 12 months in 2010, and had at least 36 months of production. The median oil well in this category produced 2.2 bo/d over all periods the well was operated. Production data for 2010 consisted of information for only four horizontal oil wells, not sufficient to compare the performance of horizontal and vertical completions. The median natural gas well in this category produced an average of 28 Mcf/d over all periods during which the well was operated. For these gas wells, there were 1,217 vertical and 251 horizontal completions. Horizontal natural gas wells exhibit higher maximum monthly production rates and greater 3-yr cumulative production than was observed in most conventional vertical wells.

Introduction

Kentucky has a long history of oil and gas production. The first documented well was drilled for brine in 1815 near Monticello, Wayne County, and was abandoned when it produced oil, thus contaminating the brine (Jillson, 1952). This well was soon followed in the winter of 1818 with the Beatty well drilled by Marcus Huling and Andrew Zimmerman near the confluence of what is now Oil Well Branch and the Big South Fork of the Cumberland River (Jillson, 1920, 1952). Since those pioneer days, Kentucky severance tax records indicate production in excess of 793 million barrels of oil and 6.9 trillion cubic feet of natural gas. Most recently, Kentucky's oil production and gas production have both increased (Fig. 1).

Kentucky has a vibrant and hardworking oil and natural gas industry that makes a significant contribution to the state's economy. The annual economic benefit of the oil and gas industry to Kentucky is estimated to be $1.1 billion (Kentucky Oil and Gas Association, personal communication, 2013). The industry is dominated by small, often "mom and pop" companies, whose historic

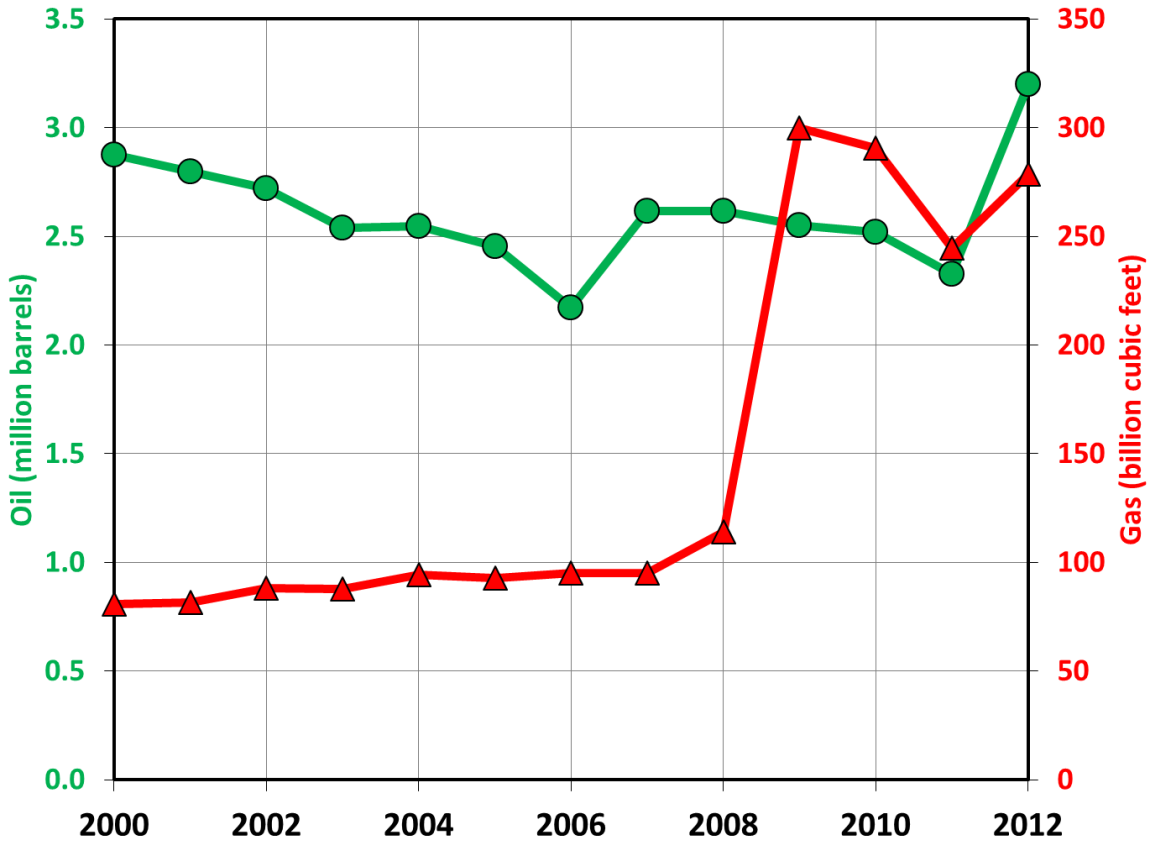

Figure 1. Recent trends in Kentucky oil (green) and natural gas (red) production.

production data are difficult to assess. Therefore, it is easy to misrepresent well performance with production claims based on an insignificantly small number of exceptional wells with limited or no public data. The aggregate assessment of the monthly production data reported for a selected year is not necessarily representative of production that could be expected from a recently drilled and completed well and should not be used as a basis for promotion or investment decisions.

In Kentucky, oil and gas are produced from Paleozoic units ranging in age from Cambrian to Pennsylvanian. In addition to conventional sandstone and carbonate reservoirs developed in a broad spectrum of depositional environments, with and without natural fracturing, nearly two-thirds of Kentucky is underlain by an unconventional, low-permeability, organic-rich, continuous shale gas resource. Horizontal drilling with either nitrogen or hydraulic fracture stimulations in Kentucky's continuous resource play became common beginning in 2007. This variety of conventional and unconventional reservoirs and completion techniques necessarily have differing producing characteristics. The data available for this report, however, are presented without regard for drilling and completion techniques or producing formation in order to maintain sample sizes sufficient for the basic data description needed for this assessment.

Initially, this review of Kentucky production data was prepared in response to the U.S. Environmental Protection Agency's New Source Performance Standards for emissions from oil and natural gas facilities. Information was compiled to address a variety of topics, including:

- The number of oil-producing wells in Kentucky by county
- The number and percentage of Kentucky oil wells that produce less than 5 bo/d; number and percentage of oil wells that produce 5 to 15 bo/d; number and percentage of oil wells that produce more than 15 bo/d; number and percentage of wells that produce more than 20 bo/d

- The number of natural gas wells in Kentucky by county
- The number and percentage of Kentucky gas wells producing more than and less than 60 Mcf/d
- The number of combined oil and gas wells by county.

The number of producing wells in Kentucky is difficult to determine. The Kentucky Division of Oil and Gas maintains a database of wells that have been permitted or transferred, are thought to be active (have a current performance bond), and have not been plugged. The Kentucky Geological Survey oil and gas well records database shows original well completions, but does not reliably indicate whether a well designated as a producer has been shut in, converted to another purpose, or plugged and abandoned. The data used in this review are from 2010 and earlier, obtained from the Kentucky Division of Oil and Gas, and are the most recent publicly available data. The wells listed in this database do not account for all of the production reported on a county basis to the Severance Tax Division of the Kentucky Revenue Cabinet, however. Table 1 shows the difference in production volumes as reported to the Severance Tax and Oil and Gas Divisions.

The 2010 oil and gas production data were downloaded and processed separately. As the gas production data were processed, individual wells were matched with the oil production data file using the permit issued by the Division of Oil and Gas. When both oil and gas production were associated with a permit number, the two production data records were stored and total production was characterized using barrels of oil equivalent on a Btu basis:

$$\text{boeq} = \text{Mcf} \times 0.1724 + \text{barrels}. \quad (1)$$

The constant 0.1724 is a rule of thumb derived from the energy equivalent in Btu of natural gas and crude oil. In general, 1 Mcf of natural gas contains 1 million Btu and one barrel of crude oil contains 5.8 million Btu.

Daily production was calculated from the available data as follows:

$$\text{Daily production} = \frac{\Sigma \text{monthly production}}{\text{months operated} \times 30.4375}. \quad (2)$$

The daily production used in the analysis thus reflects only the number of months in 2010 in which a well was actually operated. The constant 30.4375 is the average days per month considering leap years:

$$30.4375 = \frac{(365 \times 3 + 366)}{48}. \quad (3)$$

Kentucky's oil and natural gas wells are predominantly small producers. A marginal, or stripper, well is defined as a well that produces at a maximum rate of less than 10 bo/d or 60 Mcf/d (Interstate Oil and Gas Compact Commission, 2012). These limits were used to characterize Kentucky production.

Data Vintage

Publicly available data were used to compile this assessment. Production data by well can be accessed and downloaded from the Kentucky Division of Oil and Gas (oilandgas.ky.gov/Pages/ProductionReports.aspx). Oil and gas well location data and completion information can be accessed through the Kentucky Geological Survey oil and gas well records interactive search service (kgs.uky.edu/kgsweb/DataSearching/OilGas/OGSearch.asp).

The oil and gas production data files used in this review contain information for a total of 17,029 wells with nonzero production data reported for 2010. A completion date is available for 15,001 of these wells. Figure 2 shows the distribution of wells in the 2010 production data set by decade of completion. The oldest well in the data set was completed in 1912. The most recent wells in the data set were completed in 2010 and are not likely to include a full 12 months of production at the time the data were reported. Although the production reported includes data for recently completed wells, the data are a snapshot of all active Kentucky producers and are biased toward the lower production rates reported for older wells. The purpose of the analysis was to characterize

Table 1. Oil and gas production as reported to the Severance Tax Division (by county) and Oil and Gas Division (by well).

	Severance Tax Division	*Division of Oil and Gas*	*Difference*
Oil (barrels)	2,519,384	1,801,996	28 percent less
Gas (Mcf)	290,647,924	104,724,831	64 percent less

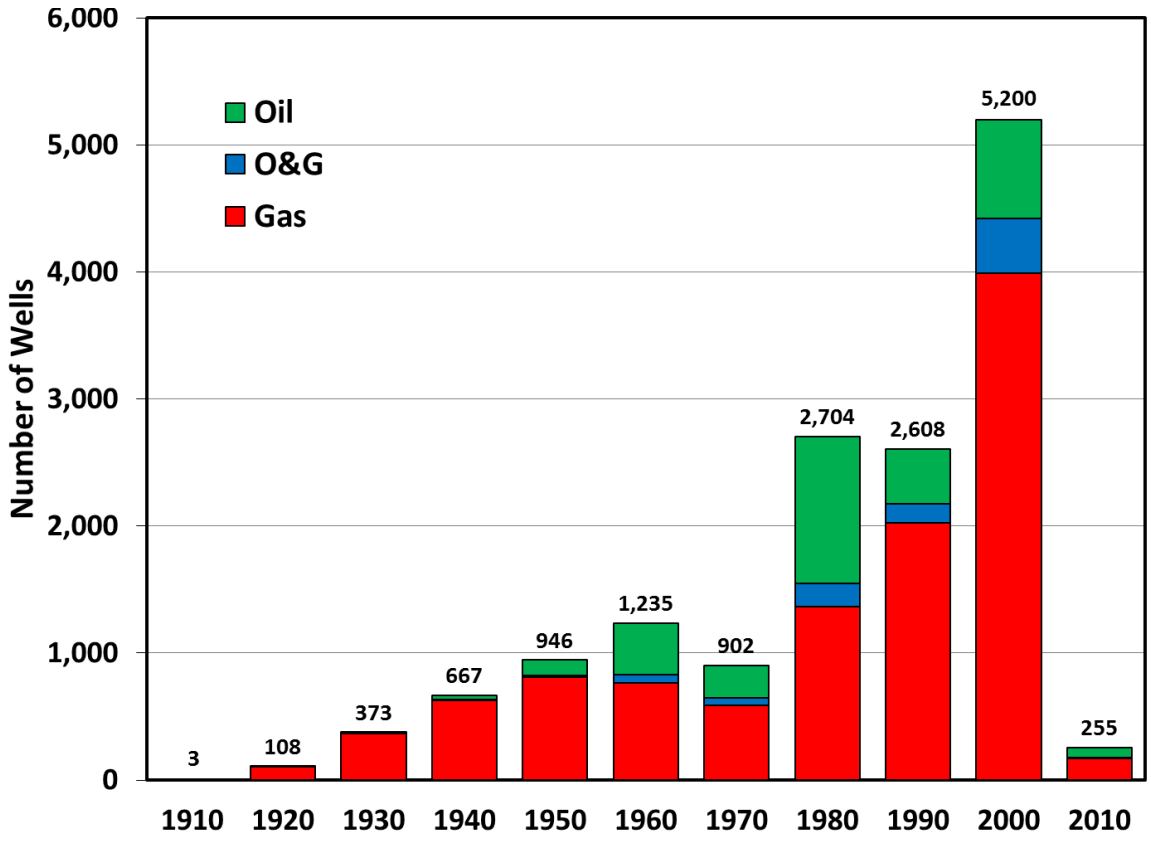

Figure 2. Decade of completion for wells with reported production data in 2010.

the production that could be expected to contribute to emissions that might be subject to regulation.

Oil Production

The oil production data file contains 15,722 records, of which 10,678 (67.9 percent) have 0.0 cumulative barrels of oil reported for the year. Of the 5,044 wells with reported production (greater than 0.0 barrels), only 1,848 (37 percent) were operated for the full 12 months of 2010 (Fig. 3).

Ninety-five percent of Kentucky's reported oil wells produce less than 5 bo/d. Table 2 shows the number of producing oil wells by categories based on production volume.

A minimum production rate of 0.032 bo/d (1 bo/m) was reported for 61 wells. Maximum daily production was 57.05 bo/d. The median production is 0.87 bo/d. Figure 4 illustrates the ranges in reported daily production compared to the number of months each well was actually operated. A stripper oil well is defined as producing less than 10 bo/d. A total of 4,992 (98.9 percent) of Kentucky's wells with reported oil production data were stripper wells at the time of this report (Fig. 5).

Number of Oil Wells by County

The 2010 production data set contains data for 5,044 oil wells in 58 counties across Kentucky (Fig. 6). Severance tax data for 2010 indicate that 51 percent of Kentucky's oil production is from the Appalachian Basin of eastern Kentucky. From Kentucky Severance Tax data, the top oil-producing county in 2010 was Lee County, eastern Kentucky, with 263,797 barrels of oil. Henderson and Union Counties of western Kentucky were the only other counties that produced more than 200,000 barrels. The number of active oil wells in each county based on Division of Oil and Gas production data by well is listed in Table 3.

Gas Production

The gas production data file contains 15,607 records, of which 2,667 (17.1 percent) have 0.0 Mcf reported for the year. Of the 12,940 wells with reported production (more than 0.0 Mcf), 11,053

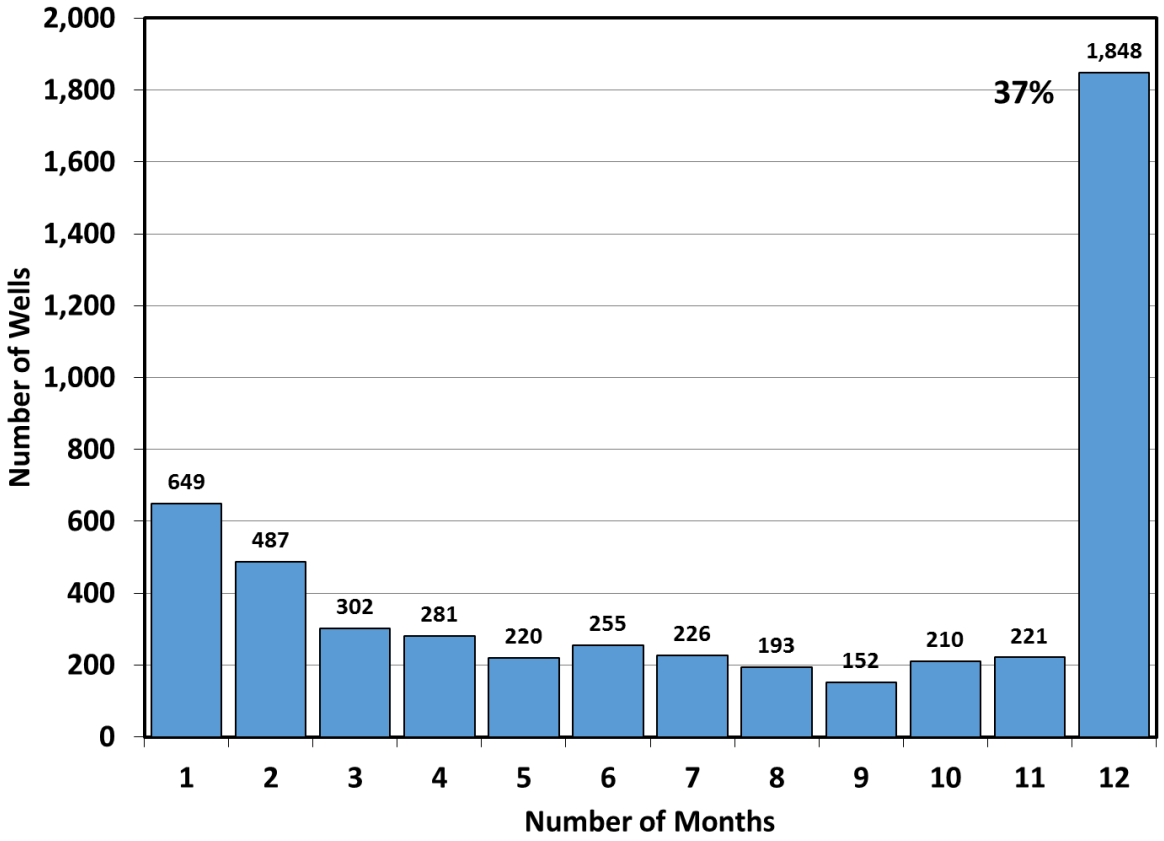

Figure 3. Number of months Kentucky oil wells were operated in 2010.

(85 percent) were operated for the full 12 months of 2010. Table 4 shows the number of producing natural gas wells by category based on production volume.

A minimum production rate of 0.032 Mcf/d (1 Mcf/mo) was reported for seven wells. The maximum daily production rate was 1,009 Mcf/d. Figure 7 illustrates the ranges in reported daily production compared by the number of months each well was actually operated. The median production is 12 Mcf/d. A stripper gas well is defined as producing less than 60 Mcf/d. A total of 12,050 wells (93.1 percent) with reported natural gas production data were stripper wells at the time of this report (Fig. 8).

Table 2. Reported oil well production volumes in barrels per day by category.

At Least (bo/d)	*Less Than (bo/d)*	*Wells*	*Percent*
	5	4,800	95.1
5	15	220	4.4
15	20	9	0.2
20		15	0.3

Number of Gas Wells by County

The 2010 production data set contains data for 12,940 natural gas wells in 41 counties across Kentucky (Fig. 9). Severance tax data for 2010 indicate that 99.2 percent of Kentucky's natural gas production is from the Appalachian Basin of eastern Kentucky. By reported volume from Kentucky Severance Tax data, the top natural gas–producing county in 2010 was Floyd County, eastern Kentucky, with 167 Bcf of natural gas, more than the rest of the state combined. Knott, Letcher, Perry, and Pike Counties of eastern Kentucky were the only other counties that produced more than 12 Bcf of natural gas during 2010. Table 5 shows the number of active natural gas wells in each county based on Division of Oil and Gas production data by well.

The Floyd County production volume reported to the Severance Tax Division is problematic. This volume does not seem to be accounted for by

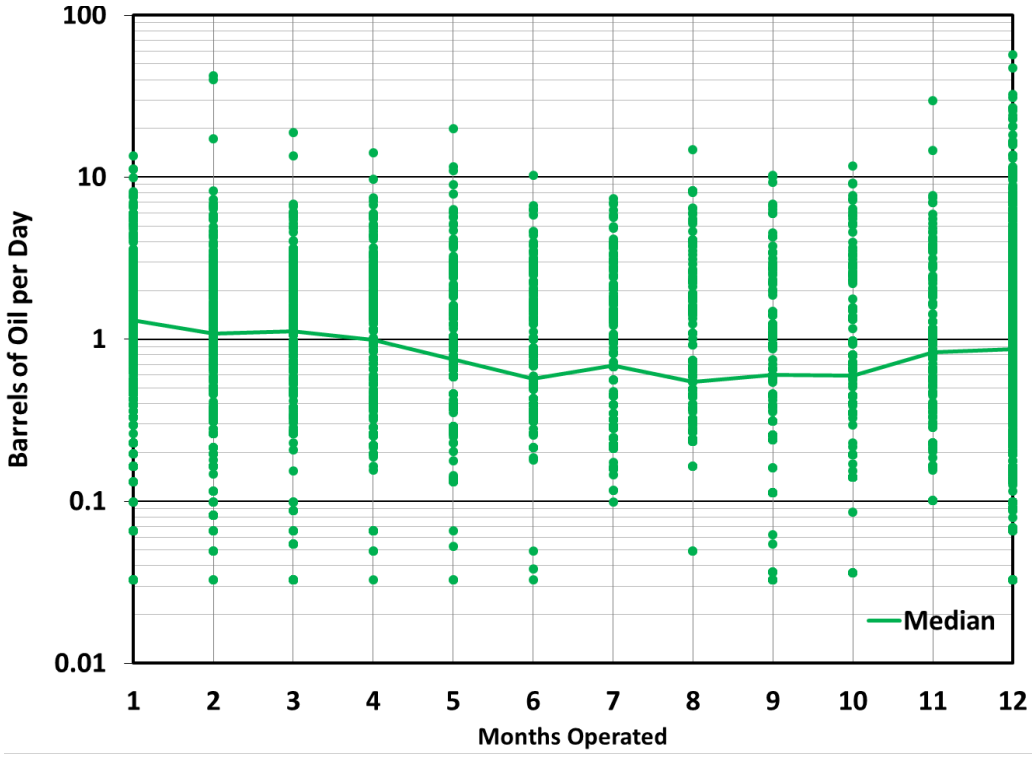

Figure 4. Range of reported production in barrels of oil per day by the number of months oil wells were operated in 2010.

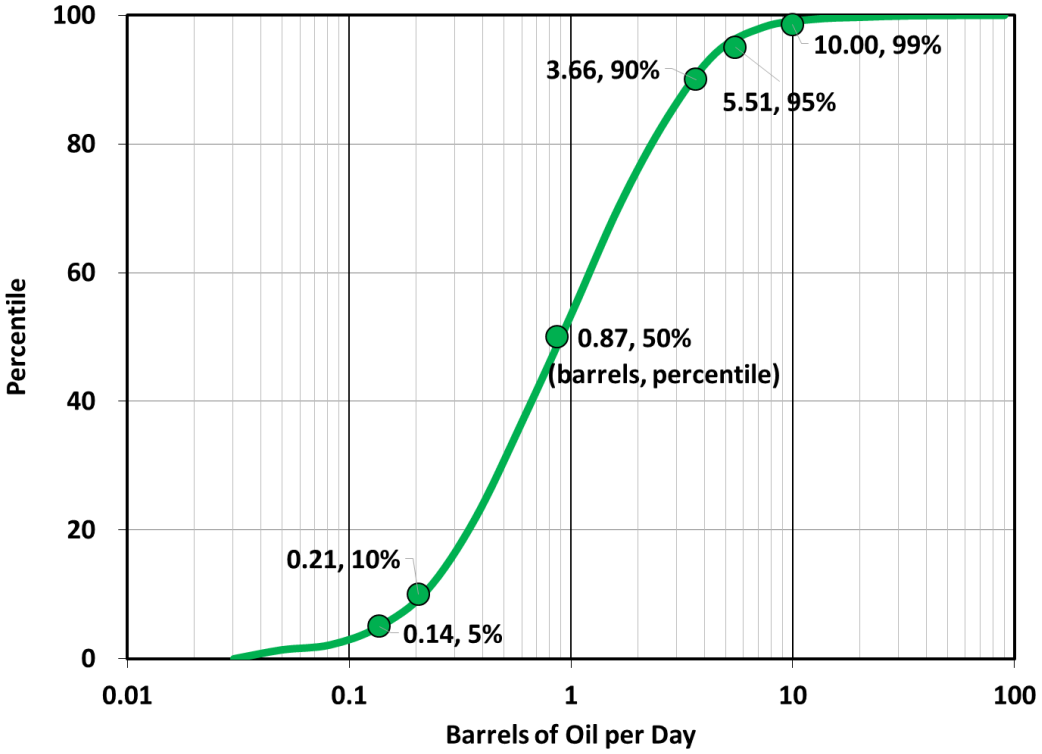

Figure 5. Data distribution and percentiles of estimated daily production for wells with reported oil production data in 2010.

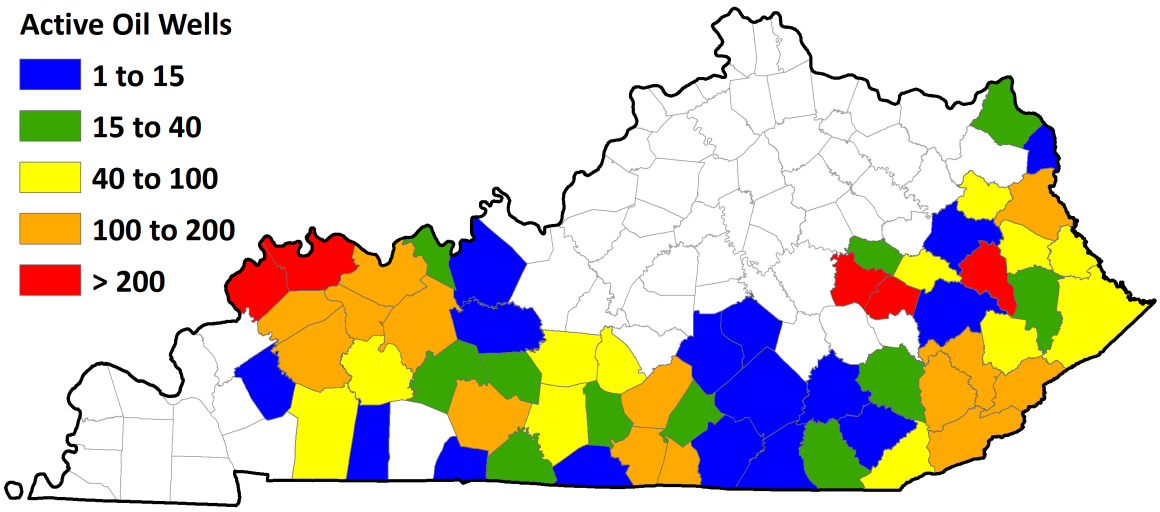

Figure 6. Number of active oil wells by county. In 2010, 5,044 producing wells were reported in 58 counties.

new gas well completions. The Big Sandy Pipeline operated by Spectra Energy (www.spectraenergy.com) originates in Floyd County at the Langley gas-processing facility operated by MarkWest Energy Partners (www.markwest.com). This facility has added cryogenic processing and is delivering natural gas liquids through the Ranger Pipeline to their Siloam fractionation plant near South Shore, Greenup County. Kentucky's public production reporting mechanism is a raw wet gas volume only and does not differentiate between dry gas and natural gas liquids. Therefore, Floyd County is likely the de facto collection and reporting point for liquids extracted from wet gas produced in several other eastern Kentucky counties.

Production from Combined Oil and Natural Gas Wells

Production from combined oil and gas wells is a subset of both of the data sets previously described. Data for these wells were characterized on the basis of the reported total barrels of oil equivalent per day. Oil and natural gas production were not always reported together for every month a well was operated, however. The production data files contain 955 records of wells producing both oil and natural gas combined. Of these wells, 819 (86 percent) were operated for the full 12 months of 2010.

Ninety-one percent (872 wells) of Kentucky's combined oil and gas wells were stripper wells, with reported production of less than 10 boeq/d at the time of this report (Table 6).

A minimum production rate of 0.139 boeq/d (4.2 boeq/mo) was reported for one well. Maximum daily production rate was 83.7 boeq/d (Fig. 10). The median production was 2.8 boeq/d. A stripper well with combined oil and gas production is defined as producing less than 10 boeq/d. A total of 872 wells (91.3 percent) with reported combined oil and natural gas production data were stripper wells at the time of this report (Fig. 11).

Number of Combined Oil and Gas Wells by County

The 2010 production data set contains data for 955 natural gas wells in 27 counties across Kentucky (Fig. 12). The number of active natural gas wells in each county is listed in Table 7.

Performance of Recent Wells

The data so far described include wells initially completed over a wide time span and are not necessarily comparable to production that might be expected from more recently completed wells. The 2010 oil and gas production data files were queried to identify wells permitted since January 1, 2005 (permit 96831 or higher), that were operated for 12 months in 2010, and that have at least 3 yr (36 periods) of reported production data. These newer wells are expected to be representative of rates occurring early in the production history of current

Table 3. Number of active oil wells reported by county. Includes wells with combined oil and gas production.

County	*Wells*	*Percentage of Wells*	*Rank*	*County*	*Wells*	*Percentage of Wells*	*Rank*
Adair	125	2.48	16	Knox	9	0.18	46
Allen	23	0.46	37	Laurel	7	0.14	48
Barren	71	1.41	26	Lawrence	141	2.80	14
Bell	54	1.07	31	Lee	371	7.36	3
Boyd	11	0.22	45	Leslie	169	3.35	10
Breathitt	9	0.18	46	Letcher	190	3.77	6
Breckinridge	5	0.10	51	Lincoln	1	0.02	56
Butler	39	0.77	32	Magoffin	295	5.85	4
Caldwell	5	0.10	51	Martin	62	1.23	29
Casey	1	0.02	56	McCreary	4	0.08	53
Christian	79	1.57	23	McLean	123	2.44	17
Clay	30	0.59	35	Metcalfe	20	0.40	39
Clinton	120	2.38	18	Monroe	6	0.12	50
Cumberland	144	2.85	13	Morgan	7	0.14	48
Daviess	172	3.41	8	Muhlenberg	96	1.90	20
Edmonson	22	0.44	38	Ohio	107	2.12	19
Elliott	81	1.61	22	Perry	171	3.39	9
Estill	202	4.00	5	Pike	91	1.80	21
Floyd	32	0.63	33	Powell	20	0.40	39
Grayson	1	0.02	56	Pulaski	13	0.26	43
Green	70	1.39	28	Russell	17	0.34	42
Greenup	32	0.63	33	Simpson	2	0.04	54
Hancock	20	0.40	39	Todd	2	0.04	54
Harlan	136	2.70	15	Union	396	7.85	2
Hart	71	1.41	26	Warren	179	3.55	7
Henderson	430	8.52	1	Wayne	12	0.24	44
Hopkins	147	2.91	12	Webster	156	3.09	11
Johnson	76	1.51	25	Whitley	28	0.56	36
Knott	62	1.23	29	Wolfe	79	1.57	23

Table 4. Reported natural gas well production volumes in thousand cubic feet of gas per day by category.

At Least (Mcf/d)	*Less Than (Mcf/d)*	*Wells*	*Percent*
	60	12,050	93.1
60		890	6.9

wells drilled in active plays with more modern construction and completion techniques (fracture stimulations and horizontal drilling).

Production trend lines are determined using a Theil-Sen estimator (Wilcox, 2010), a nonparametric statistical model that estimates the equivalent of a least-squares linear best fit of point data. The estimator is calculated by finding the median of the distribution of slopes calculated between all pairs of observed data points. In practice, the linear projection of the Theil-Sen model will pass through a point representing the median value of each of the model variables. The slope and medians of the model variables are then used to calculate an intercept that constrains the model. In particular, the Theil-Sen estimator is an alternative to least-squares regression that is both relatively insensitive to outliers in the data set and not subject to the

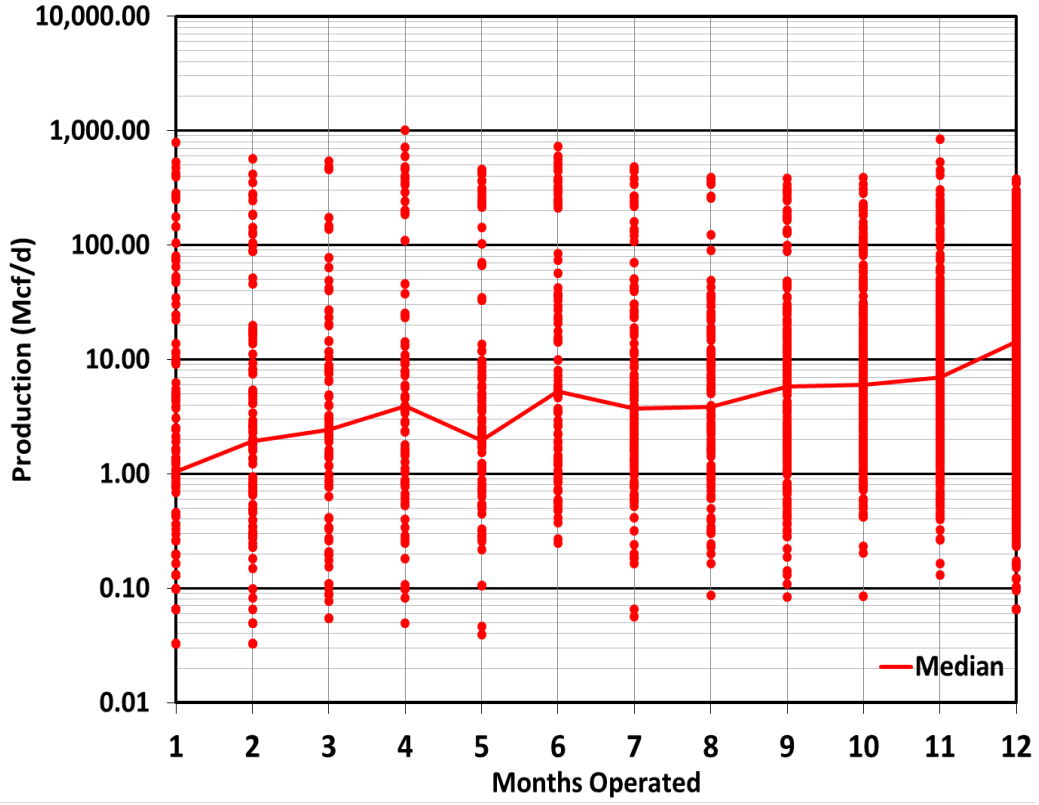

Figure 7. Range of reported production in thousand cubic feet of gas per day by the number of months natural gas wells were operated in 2010.

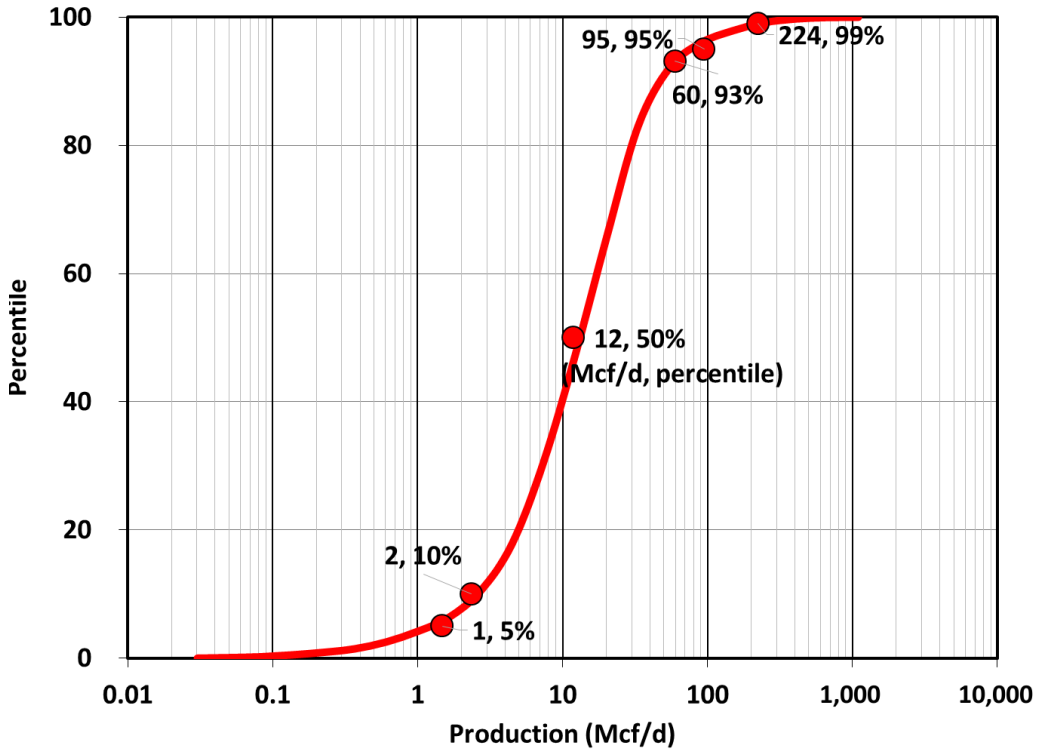

Figure 8. Data distribution and percentiles of estimated daily production for wells with reported gas production data in 2010.

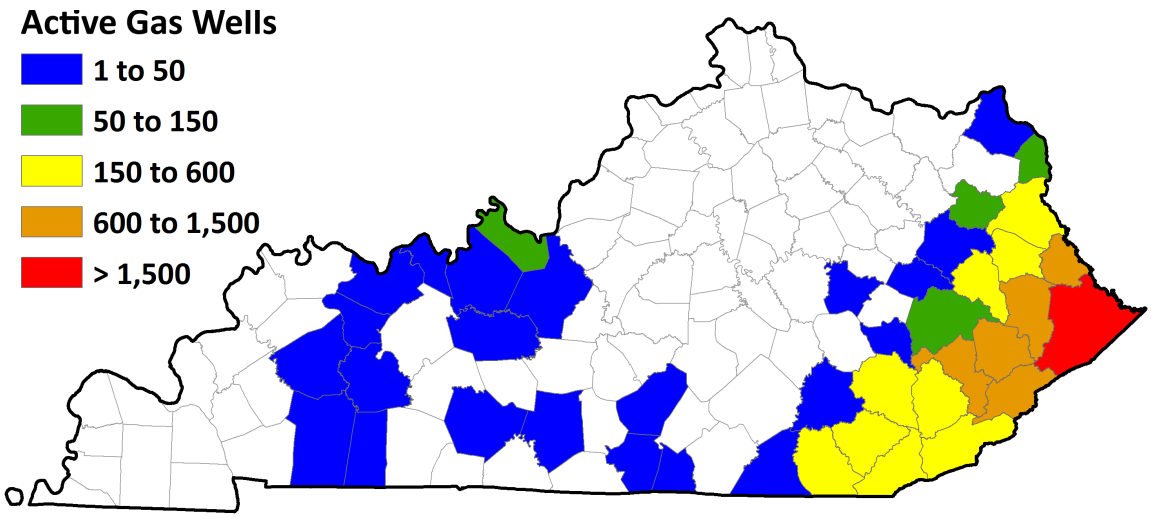

Figure 9. Number of active natural gas wells by county. In 2010, 12,940 producing wells were reported in 41 counties.

limits imposed by assuming the data to be normally distributed. This model is provided here to demonstrate the relationship of the maximum reported monthly production rate to cumulative production over time. No attempt was made to differentiate between single or multiple (commingled) producing zones, or conventional or advanced completions (fracture stimulations).

Table 5. Number of active natural gas wells reported by county. Includes wells with combined oil and gas production.

County	*Wells*	*Percentage of Wells*	*Rank*	*County*	*Wells*	*Percentage of Wells*	*Rank*
Adair	3	0.02	30	Johnson	307	2.37	12
Barren	4	0.03	29	Knott	1,349	10.43	3
Bell	306	2.36	13	Knox	414	3.20	9
Boyd	91	0.70	17	Laurel	29	0.22	24
Breathitt	139	1.07	16	Lawrence	377	2.91	11
Breckinridge	8	0.06	28	Leslie	514	3.97	8
Christian	49	0.38	20	Letcher	986	7.62	4
Clay	583	4.51	7	Magoffin	253	1.96	15
Clinton	2	0.02	32	Martin	859	6.64	6
Cumberland	2	0.02	32	McCreary	43	0.33	22
Daviess	1	0.01	36	McLean	1	0.01	36
Elliott	86	0.66	18	Meade	58	0.45	19
Estill	1	0.01	36	Morgan	49	0.38	20
Floyd	1,407	10.87	2	Muhlenberg	2	0.02	32
Grayson	1	0.01	36	Owsley	14	0.11	26
Greenup	27	0.21	25	Perry	883	6.82	5
Hancock	1	0.01	36	Pike	3,365	26.00	1
Hardin	2	0.02	32	Todd	1	0.01	36
Harlan	275	2.13	14	Warren	38	0.29	23
Hopkins	13	0.10	27	Whitley	394	3.04	10
				Wolfe	3	0.02	30

Table 6. Reported combined oil and natural gas well production volumes in barrels of oil equivalent per day by category.

At Least (boeq/d)	*Less Than (boeq/d)*	*Wells*	*Percent*
	10	872	91.3
10		83	8.7

Recent Oil Producers

The 2010 production data file contains records for 151 oil wells that met criteria for a recent well with production data. The maximum monthly production rate reported during the first year of operation ranged from 16 bo/mo (0.52 bo/d) to 4,200 bo/mo (138 bo/d), with a median of 185 bo/mo (6.1 bo/d) (Fig. 13). The 3-yr cumulative oil production ranged from 294 barrels to 52,272 barrels, with a median of 2,556 barrels. Only four of the 151 oil wells were horizontal completions; this small sample size precludes a statistically valid comparison of the performance of horizontal and vertical wells.

More recently completed oil wells perform better than is indicated by the range of well vintages reported in the 2010 yearly data (Fig. 14). These more recently completed wells are representative of performance during the early part of the expected production decline over the lifetime of a well. Average daily production during 2010 ranged from 0.34 bo/d to 38.7 bo/d, with a median of 2.2 bo/d. Oil wells are most likely to produce between 0.8 bo/d (10th percentile) and 6.0 bo/d (90th percentile). Only seven of the wells exceeded stripper production rates over the span of their reported production.

Recent Natural Gas Producers

The 2010 production data file contains records for 1,468 recent natural gas wells that met the selection criteria for a recent well with production data. The maximum monthly production rate reported during the first year of operation ranged from 31 Mcf/mo (1 Mcf/d) to 53,894 Mcf/mo (1,771 Mcf/d), with a median of 2,271 Mcf/mo

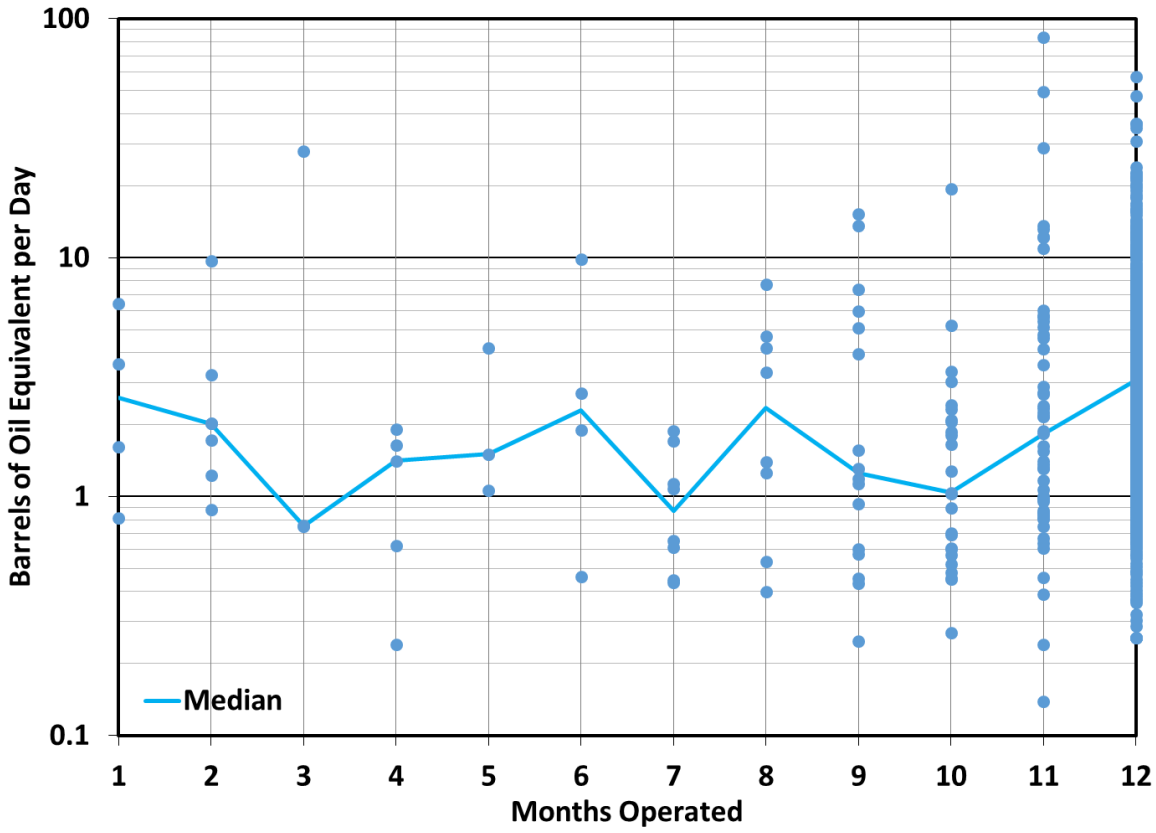

Figure 10. Range of reported production in barrels of oil equivalent per day by the number of months combined oil and natural gas wells were operated in 2010.

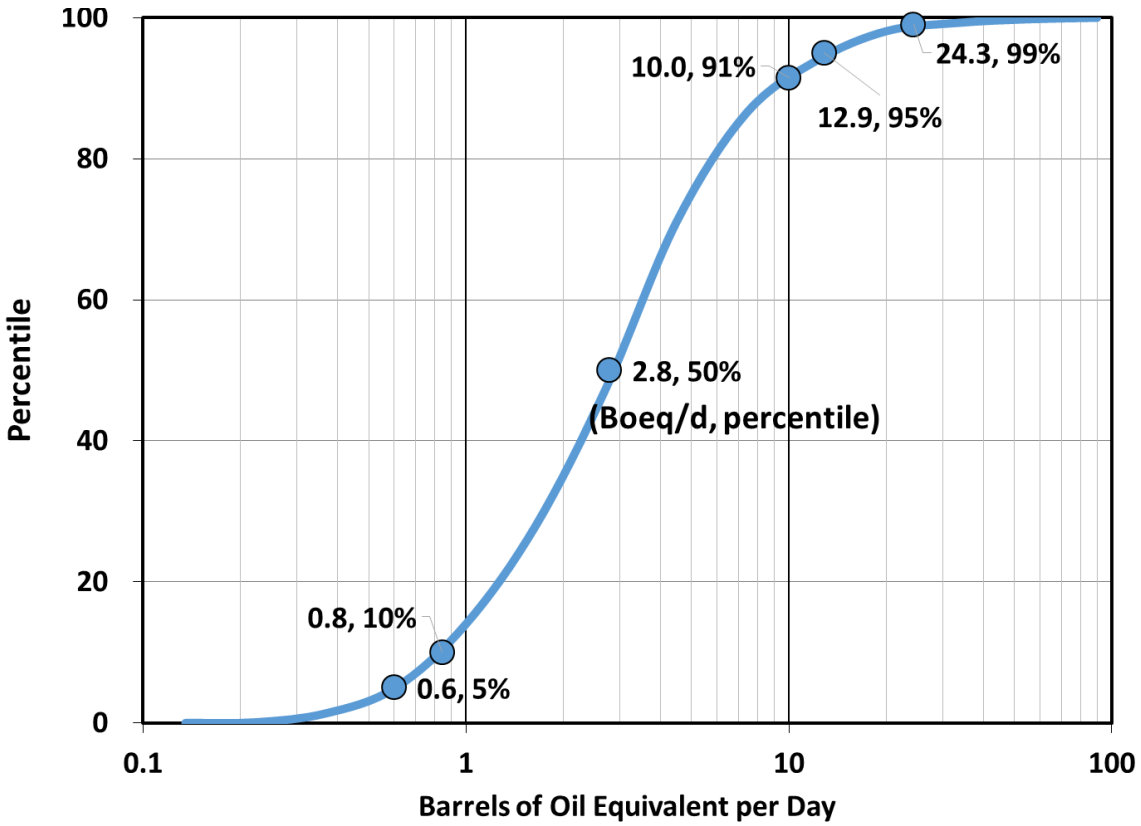

Figure 11. Data distribution and percentiles of estimated daily production for wells with reported combined oil and natural gas production data in 2010.

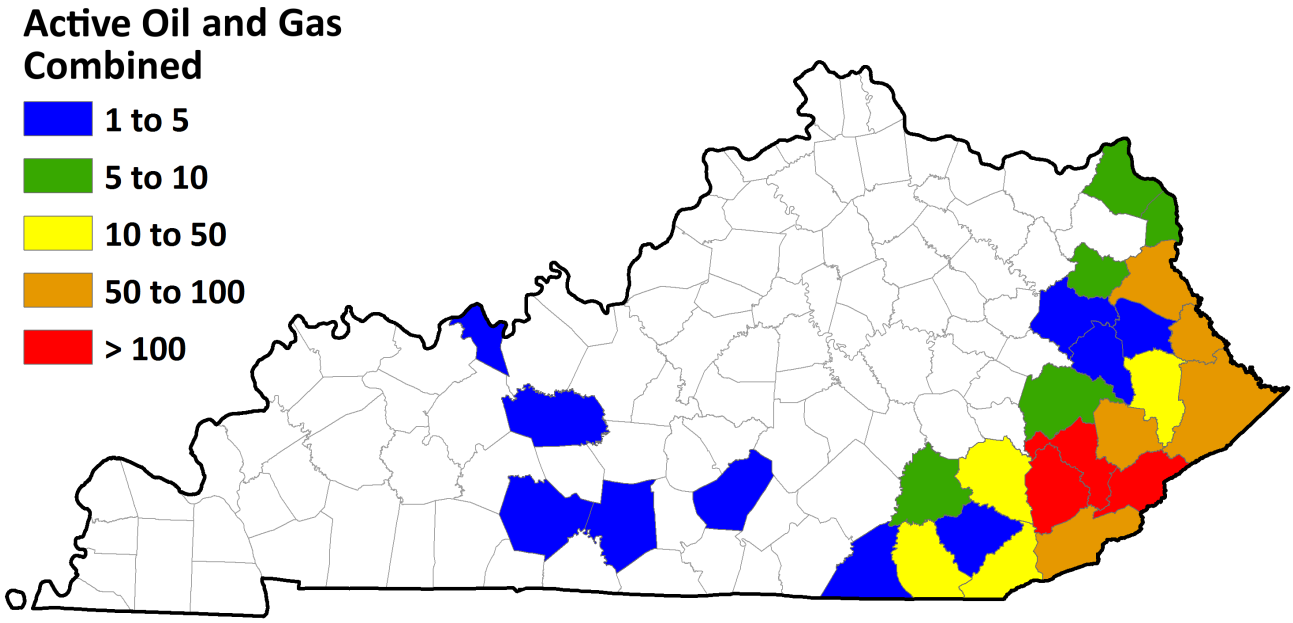

Figure 12. Number of active combined oil and natural gas wells by county. In 2010, 955 producing wells were reported in 27 counties.

Table 7. Number of active wells with combined oil and natural gas production reported by county. Included in the separate counts for oil wells and gas wells.

County	*Wells*	*Percentage of Wells*	*Rank*	*County*	*Wells*	*Percentage of Wells*	*Rank*
Adair	1	0.10	24	Knott	61	6.39	6
Barren	2	0.21	22	Knox	5	0.52	18
Bell	45	4.71	9	Laurel	6	0.63	17
Boyd	10	1.05	13	Lawrence	58	6.07	8
Breathitt	7	0.73	16	Leslie	137	14.35	2
Clay	20	2.09	12	Letcher	136	14.24	3
Elliott	8	0.84	15	Magoffin	3	0.31	19
Floyd	26	2.72	10	Martin	59	6.18	7
Grayson	1	0.10	24	McCreary	3	0.31	19
Greenup	9	0.94	14	Morgan	1	0.10	24
Hancock	1	0.10	24	Perry	149	15.60	1
Harlan	92	9.63	4	Pike	89	9.32	5
Johnson	2	0.21	22	Warren	3	0.31	19
				Whitley	21	2.20	11

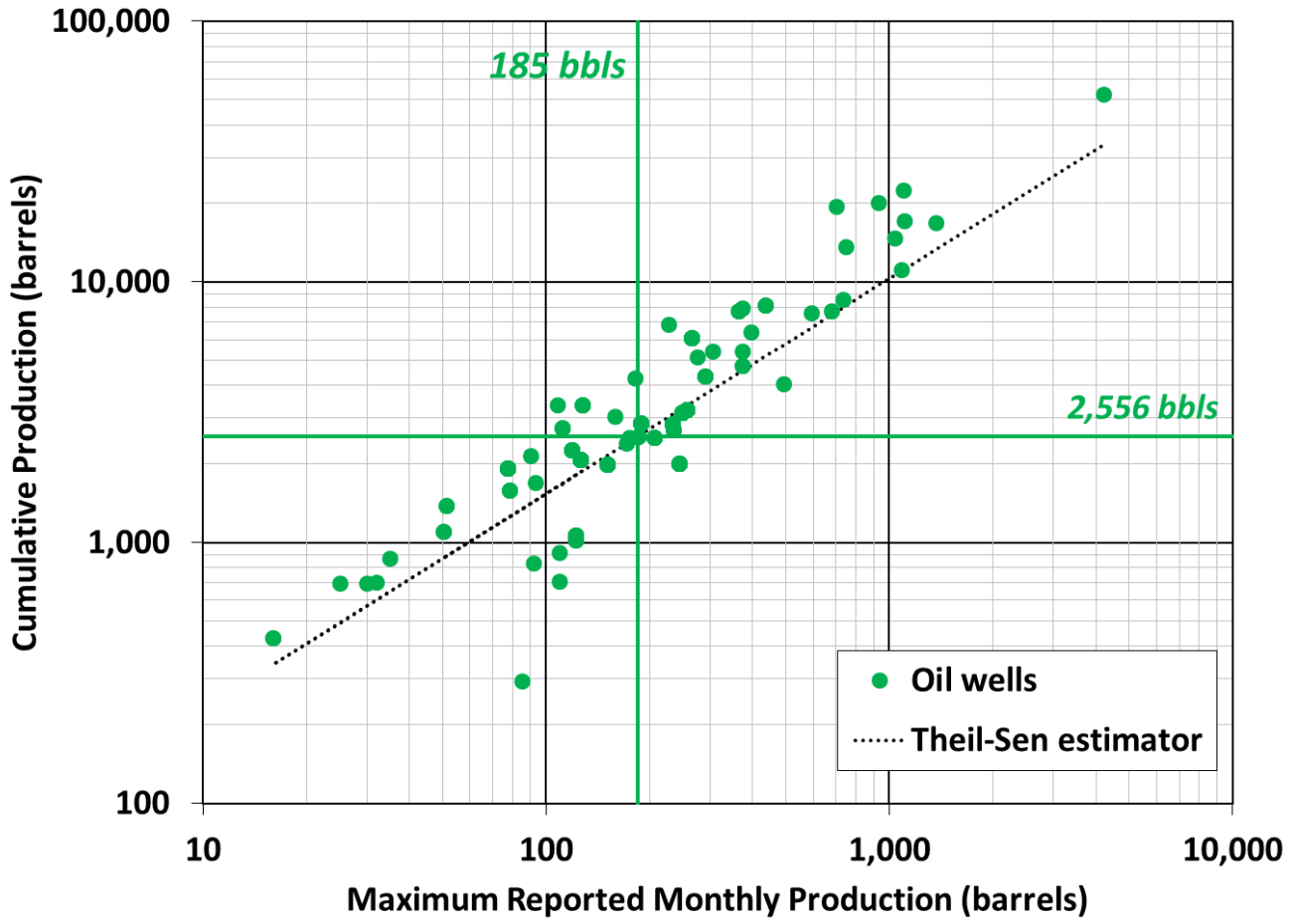

Figure 13. Three-year cumulative oil production (barrels) as a function of the maximum monthly production in barrels reported during the first year.

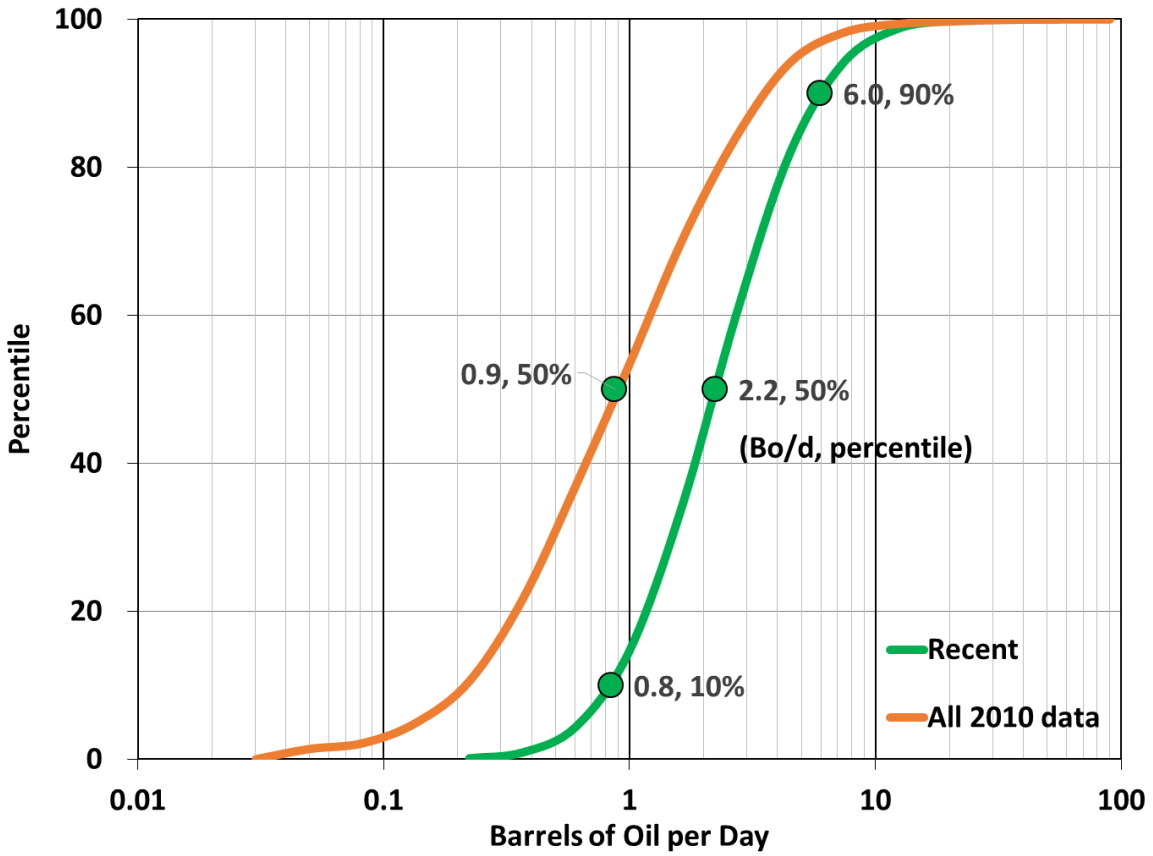

Figure 14. The performance of selected recently completed oil wells compared to the performance of all oil wells with production data reported in 2010.

(74.6 Mcf/d) (Table 8, Fig. 15). The three-year cumulative gas production ranged from 0.44 MMcf to 426 MMcf, with a median of 33.5 MMcf. Of the gas wells reported, 251 (17 percent) were horizontal completions (most of which were Devonian black shale completions in eastern Kentucky). In general, these horizontal wells outperform vertical wells.

Recently completed natural gas wells generally perform better than is indicated by the range of all well data reported in the 2010 yearly production report that includes information for many older wells (Fig. 16). These more recently completed wells are representative of performance during the early part of the expected production decline over the lifetime of a well. The average daily production of wells calculated from the reported cumulative production and total number of months operated range from 0.49 Mcf/d to 341.7 Mcf/d, with a median of 28 Mcf/d. Gas wells are most likely to produce between 7.8 Mcf/d (10th percentile) and 96.9 Mcf/d (90th percentile). A total of 345 wells (23.5 percent) exceeded the stripper production rate of 60 Mcf/d over the span of their reported production.

Table 8. Comparison of median production rates for horizontal and vertical wells.

	Median Maximum Monthly Production (Mcf/m)	*Median Maximum Daily Production (Mcf/d)*	*2010 Daily Average Production (Mcf/d)*	*Three-Year Cumulative Production (MMcf)*	*Number of Wells*
Horizontal	8,649	284.0	75.4	114.1	251
Vertical	1,844	60.6	15.4	26.7	1,217
Overall	2,271	74.6	19.9	33.5	1,468

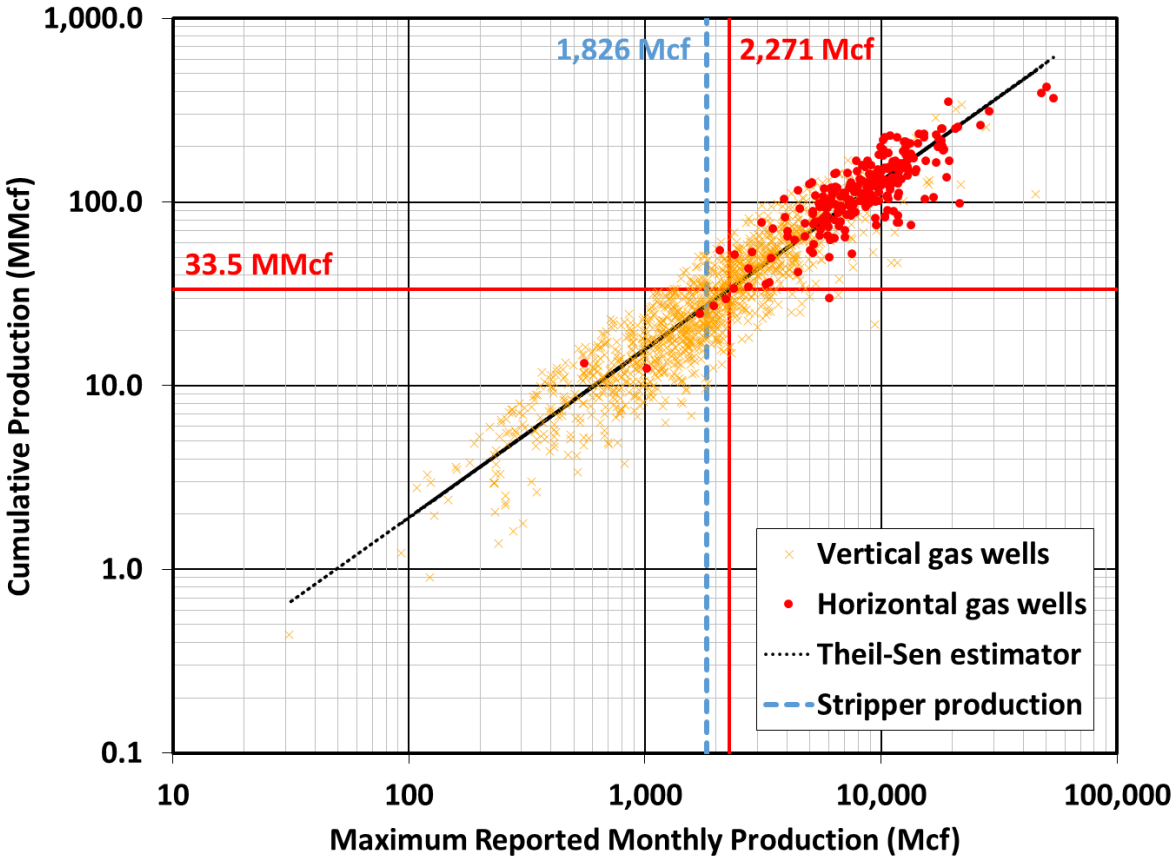

Figure 15. Three-year cumulative natural gas production (million cubic feet) as a function of the maximum monthly production (thousand cubic feet of gas) reported during the first year with median monthly and cumulative production (red) and monthly stripper well (blue) rates.

Conclusion

Given that the vast majority of Kentucky's producing wells are low-volume stripper wells, profit margins are necessarily small and operators face daily challenges to remain active in a competitive and increasingly worldwide market. Oil and gas production rates and volumes summarized in this report provide a snapshot of the industry and indicate that new technologies such as horizontal drilling and advanced fracture stimulations and emerging resources in Kentucky's mature oil and gas provinces present opportunities for future growth.

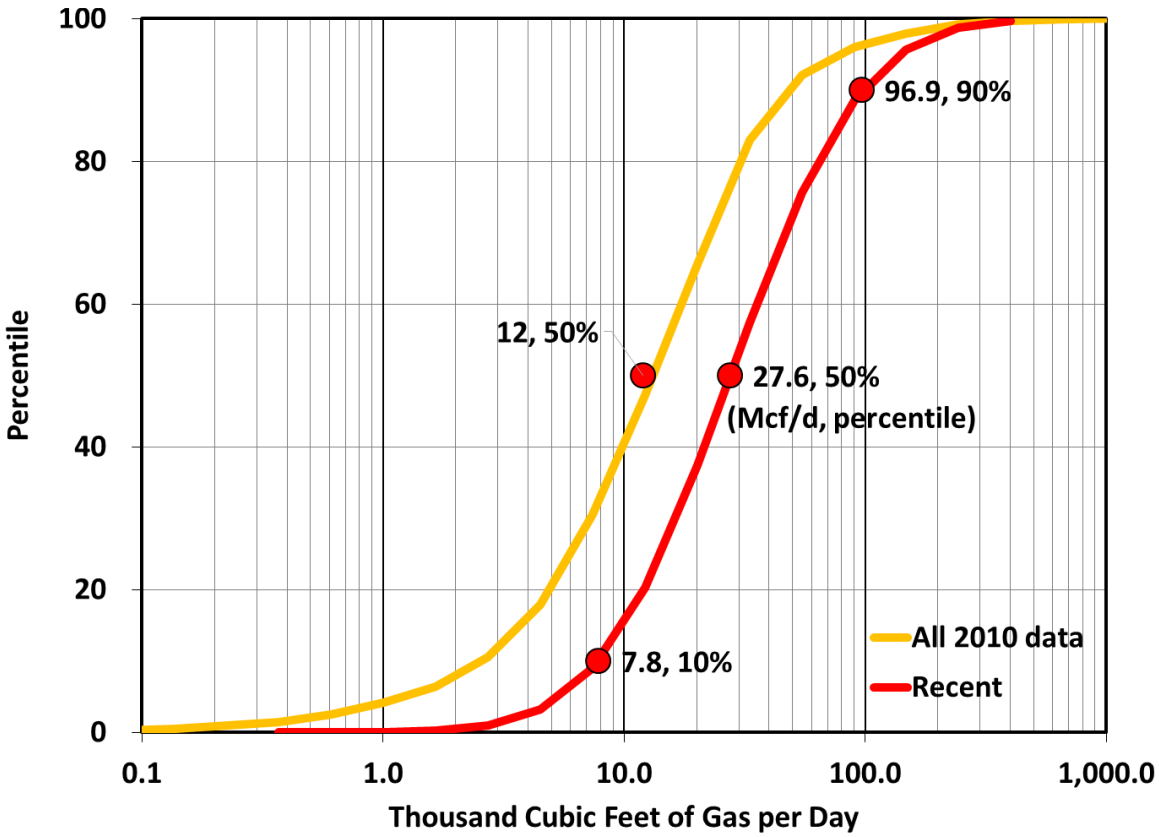

Figure 16. The performance of selected recently completed natural gas wells compared to the performance of all natural gas wells with production data reported in 2010.

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