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Variability of Distributions of Well-Scale Estimated Ultimate Recovery for Continuous (Unconventional) Oil and Gas Resources in the United States

By U.S. Geological Survey Oil and Gas Assessment Team

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Contents

Figures

Tables

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Abstract

Since 2000, the U.S. Geological Survey has completed assessments of continuous (unconventional) resources in the United States based on geologic studies and analysis of well-production data. This publication uses those 132 continuous oil and gas assessments to show the variability of well productivity within and among the 132 areas. The production from the most productive wells in an area commonly is more than 100 times larger than that from the poorest productive wells. The 132 assessment units were classified into four categories: shale gas, coalbed gas, tight gas, and continuous oil. For each category, the mean well productivity in the most productive assessment units is considerably greater than that of the least productive assessment units.

Introduction

The U.S. Geological Survey (USGS) conducts quantitative assessments of potential oil and gas resources of the onshore United States and State waters. Since 2000, 132 assessments have been performed for continuous (unconventional) oil and gas resources, based on geologic studies and analysis of well-production data. Assessment methods are documented in Crovelli (2000, 2003), Klett and Charpentier (2003), Klett and Schmoker (2003), and Schmoker (2003). Each assessment unit (AU) was divided into cells, with each cell representing a well-drainage area. The estimates of resource potential were derived from estimates of the potential number of undrilled productive cells and of the productive capacities of those cells.

Estimated ultimate recovery (EUR) distributions were estimated for each AU, based on decline-curve analysis from monthly production data (IHS Energy, 2011) of hundreds to thousands of wells per AU. The EUR distribution used for each assessment calculation was specifically that for undrilled cells. Commonly, this EUR distribution for undrilled cells is closely similar to the distribution for drilled cells. In general, wells drilled early in the development of an AU, before drilling and completion techniques are optimized, have relatively low EURs. This can cause the estimated EURs for undrilled cells to be higher than those for drilled wells. Conversely, if the geologically most favorable parts of the AU have already been drilled, the EURs for undrilled cells may be lower than those of drilled wells.

The 132 AUs were classified into four categories: shale gas, coalbed gas, tight gas, and continuous oil. This categorization facilitated use of these data as analogs for hypothetical AUs. Sources for reports of these assessments are listed in appendix 1.

Estimated Ultimate Recovery Distributions

Shifted truncated lognormal distributions were fit using the minimum, median, and maximum input values of estimated ultimate recovery (EUR). The upper end of the distribution was truncated at the 0.1 percent (1 in 1000) fractile.

$$\mu = \ln(EUR_{med} - EUR_{min})$$

$$\sigma = \frac{\ln((EUR_{max} - EUR_{min})/(EUR_{med} - EUR_{min}))}{3.09}$$

$$E(x) = exp\left(\mu + (\sigma^2/2)\right) * \frac{normsdist((\ln(EUR_{max}) - \mu - \sigma^2)/\sigma)}{normsdist((\ln(EUR_{max}) - \mu)/\sigma)}$$

$$E(x^2) = exp(2\mu + 2\sigma^2) * \frac{normsdist((\ln(EUR_{max}) - \mu - 2\sigma^2)/\sigma)}{normsdist((\ln(EUR_{max}) - \mu)/\sigma)}$$

$$EUR_{mean} = EUR_{min} + E(x)$$

$$EUR_{sd} = \sqrt{E(x^2) - E(x)^2}$$

where:

EUR_{min} = minimum EUR

EUR_{med} = median EUR

EUR_{max} = maximum EUR

EUR_{mean} = mean EUR

EUR_{sd} = standard deviation of EUR

normsdist = normal distribution function

The input values, as well as the calculated mean for each distribution, are given in tables 1 to 4.

Table 1. Input data for estimated ultimate recovery distributions for United States shale-gas assessment units, values in billions of cubic feet of natural gas. [AU, assessment unit; and EUR, estimated ultimate recovery]

AU number	AU name	Province	Year assessed	Minimum EUR	Median EUR	Maximum EUR	Mean EUR
50490161	Haynesville Sabine Platform Shale Gas	Gulf Coast Mesozoic	2010	0.02	2	20	2.617
50490163	Mid-Bossier Sabine Platform Shale Gas	Gulf Coast Mesozoic	2010	0.02	1	10	1.308
50580161	Woodford Shale Gas	Anadarko Basin	2010	0.02	0.8	15	1.233
50670468	Interior Marcellus	Appalachian Basin	2011	0.02	0.8	12	1.158
50490167	Eagle Ford Shale Gas	Gulf Coast Mesozoic	2010	0.02	0.8	10	1.104
50620362	Fayetteville Shale Gas - High Gamma-Ray Depocenter	Arkoma Basin	2010	0.02	0.8	10	1.104
50450161	Greater Newark East Frac-Barrier Continuous Barnett Shale Gas	Bend Arch-Fort Worth Basin	2003	0.02	0.7	10	1.000
50440161	Delaware/Pecos Basins Woodford Continuous Shale Gas	Permian Basin	2007	0.02	0.6	8	0.842
50440162	Delaware/Pecos Basins Barnett Continuous Shale Gas	Permian Basin	2007	0.02	0.6	8	0.842
50580261	Thirteen Finger Limestone-Atoka Shale Gas	Anadarko Basin	2010	0.02	0.5	10	0.785
50620261	Woodford Shale Gas	Arkoma Basin	2010	0.02	0.5	10	0.785
50210364	Gothic, Chimney Rock, Hovenweep Shale Gas	Paradox Basin	2011	0.02	0.4	10	0.672
50630561	Devonian Antrim Continuous Gas	Michigan Basin	2004	0.02	0.4	4	0.523
50620363	Fayetteville Shale Gas - Western Arkansas Basin Margin	Arkoma Basin	2010	0.02	0.3	6	0.470
50210362	Cane Creek Shale Gas	Paradox Basin	2011	0.02	0.3	5	0.446
50440163	Midland Basin Woodford/Barnett Continuous Gas	Permian Basin	2007	0.02	0.3	5	0.446
50490165	Maverick Basin Pearsall Shale Gas	Gulf Coast Mesozoic	2010	0.02	0.25	5	0.391
50450162	Extended Continuous Barnett Shale Gas	Bend Arch-Fort Worth Basin	2003	0.02	0.2	5	0.334
50390761	Niobrara Chalk	Denver Basin	2001	0.025	0.2	2	0.261
50620262	Chattanooga Shale Gas	Arkoma Basin	2010	0.02	0.1	6	0.223
50670467	Foldbelt Marcellus	Appalachian Basin	2011	0.02	0.1	5	0.208
50620364	Caney Shale Gas	Arkoma Basin	2010	0.02	0.08	5	0.179
50670469	Western Margin Marcellus	Appalachian Basin	2011	0.02	0.05	5	0.129
50640361	Devonian to Mississippian New Albany Continuous Gas	Illinois Basin	2007	0.01	0.08	1	0.110
50670462	Northwestern Ohio Shale	Appalachian Basin	2002	0.01	0.04	0.5	0.055
50670463	Devonian Siltstone and Shale	Appalachian Basin	2002	0.01	0.03	0.5	0.044

Table 2. Input data for estimated ultimate recovery distributions for United States coalbed-gas assessment units, values in billions of cubic feet of natural gas. [AU, assessment unit; and EUR, estimated ultimate recovery]

AU number	AU name	Province	Year assessed	Minimum EUR	Median EUR	Maximum EUR	Mean EUR
50220181	Fruitland Fairway Coalbed Gas	San Juan Basin	2002	0.02	8	40	9.125
50200181	Northern Coal Fairway/Drunkards Wash	Uinta-Piceance	2000	0.05	0.8	12	1.156
50220182	Basin Fruitland Coalbed Gas	San Juan Basin	2002	0.02	0.6	20	1.110
50200182	Central Coal Fairway/Buzzards Bench	Uinta-Piceance	2000	0.05	0.4	10	0.666
50010181	Nanushuk Formation Coalbed Gas	Northern Alaska	2006	0.02	0.25	12	0.524
50410182	Vermejo Coalbed Gas	Raton Basin-Sierra Grande Uplift	2004	0.02	0.25	9.5	0.481
50200281	Uinta Basin Blackhawk Coalbed Gas	Uinta-Piceance	2000	0.05	0.25	10	0.480
50360281	Frontier-Adaville-Evanston Coalbed Gas	Wyoming Thrust Belt	2003	0.02	0.4	2	0.456
50410181	Raton Coalbed Gas	Raton Basin-Sierra Grande Uplift	2004	0.02	0.25	8	0.453
50650281	Warrior Basin	Warrior Basin	2002	0.01	0.25	5	0.392
50620481	Arkoma Coalbed Gas	Arkoma Basin	2010	0.02	0.3	3	0.392
50330182	Upper Fort Union Formation	Powder River Basin	2000	0.02	0.23	4	0.345
50200183	Southern Coal Fairway	Uinta-Piceance	2000	0.05	0.2	5	0.328
50210581	Kaiparowits Plateau	Paradox Basin	2011	0.02	0.2	4	0.312
50010183	Sagavanirktok Formation Coalbed Gas	Northern Alaska	2006	0.02	0.18	5	0.310
50330181	Wasatch Formation	Powder River Basin	2000	0.02	0.18	3	0.267
50370882	Fort Union Coalbed Gas	Southwestern Wyoming	2002	0.02	0.2	1.5	0.246
50670581	Pocahontas Basin	Appalachian Basin	2002	0.01	0.15	2	0.210
50350281	Mesaverde Coalbed Gas	Wind River Basin	2005	0.02	0.1	5	0.208
50030281	Cook Inlet Coalbed Gas	Southern Alaska	2011	0.02	0.16	1.5	0.206
50370881	Lance Coalbed Gas	Southwestern Wyoming	2002	0.02	0.15	1	0.180
50200282	Mesaverde Group Coalbed Gas	Uinta-Piceance	2000	0.02	0.08	5	0.179
50220381	Menefee Coalbed Gas	San Juan Basin	2002	0.02	0.08	5	0.179
50200185	Southern Coal Outcrop	Uinta-Piceance	2001	0.05	0.1	3	0.165
50670582	Eastern Dunkard Basin	Appalachian Basin	2002	0.01	0.1	2	0.156
50040381	Eocene Coalbed Gas	Western Oregon-Washington	2009	0.02	0.1	2	0.155
50010182	Prince Creek–Tuluvak Formations Coalbed Gas	Northern Alaska	2006	0.02	0.1	1.5	0.143
50340281	Mesaverde-Meeteetse Formation Coalbed Gas	Big Horn Basin	2008	0.02	0.1	1.2	0.136
50350282	Meeteetse Coalbed Gas	Wind River Basin	2005	0.02	0.08	2	0.131
50350283	Fort Union Coalbed Gas	Wind River Basin	2005	0.02	0.08	2	0.131
50370682	Fort Union Coalbed Gas	Southwestern Wyoming	2002	0.02	0.1	1	0.130
50370981	Wasatch-Green River Coalbed Gas	Southwestern Wyoming	2002	0.02	0.1	0.8	0.124
50311081	Fort Union Coalbed Gas	Williston Basin	2008	0.02	0.085	1	0.114
50330183	Lower Fort Union-Lance Formations	Powder River Basin	2000	0.02	0.085	1	0.114
50340282	Fort Union Formation Coalbed Gas	Big Horn Basin	2008	0.02	0.08	1	0.109
50370581	Mesaverde Coalbed Gas	Southwestern Wyoming	2002	0.02	0.06	2	0.106
50370681	Mesaverde Coalbed Gas	Southwestern Wyoming	2002	0.02	0.06	2	0.106
50470381	Wilcox Coalbed Gas	Western Gulf	2007	0.01	0.05	0.5	0.065
50640481	Desmoinesian-Virgilian Coalbed Gas	Illinois Basin	2007	0.01	0.03	0.25	0.037
50470281	Cretaceous Olmos Coalbed Gas	Western Gulf	2007	0.01	0.03	0.1	0.032

Table 3. Input data for estimated ultimate recovery distributions for United States tight-gas assessment units, values in billions of cubic feet of natural gas. [AU, assessment unit; and EUR, estimated ultimate recovery]

AU number	AU name	Province	Year assessed	Minimum EUR	Median EUR	Maximum EUR	Mean EUR
50370661	Mesaverde-Lance-Fort Union Continuous Gas	Southwestern Wyoming	2002	0.02	1.2	15	1.657
50370561	Almond Continuous Gas	Southwestern Wyoming	2002	0.02	0.9	20	1.460
50200261	Uinta Basin Continuous Gas	Uinta-Piceance	2000	0.02	0.5	40	1.293
50030161	Tuxedni-Naknek Continuous Gas	Southern Alaska	2011	0.02	0.6	30	1.286
50620161	Arkoma-Ouachita Foredeep Continuous	Arkoma Basin	2010	0.02	0.6	30	1.286
50350261	Frontier-Muddy Continuous Gas	Wind River Basin	2005	0.02	0.7	15	1.123
50370261	Mowry Continuous Gas	Southwestern Wyoming	2002	0.02	0.7	15	1.123
50350265	Lance-Fort Union Sandstone Gas	Wind River Basin	2005	0.02	0.6	20	1.110
50370861	Lance-Fort Union Continuous Gas	Southwestern Wyoming	2002	0.02	0.8	10	1.104
50370761	Lewis Continuous Gas	Southwestern Wyoming	2002	0.02	0.6	15	1.009
50200362	Uinta Basin Continuous Gas	Uinta-Piceance	2000	0.02	0.5	16	0.911
50200263	Piceance Basin Continuous Gas	Uinta-Piceance	2000	0.02	0.5	15	0.892
50350264	Mesaverde-Meeteetse Sandstone Gas	Wind River Basin	2005	0.02	0.5	15	0.892
50350262	Cody Sandstones Continuous Gas	Wind River Basin	2005	0.02	0.4	20	0.855
50670364	Tuscarora Basin Center	Appalachian Basin	2002	0.01	0.7	4	0.817
50220261	Lewis Continuous Gas	San Juan Basin	2002	0.02	0.5	6	0.683
50220361	Mesaverde Central-Basin Continuous Gas	San Juan Basin	2002	0.02	0.5	6	0.683
50220363	Dakota-Greenhorn Continuous Gas	San Juan Basin	2002	0.02	0.4	8	0.627
50370461	Hilliard-Baxter-Mancos Continuous Gas	Southwestern Wyoming	2002	0.02	0.4	8	0.627
50200161	Deep (6,000 feet plus) Coal and Sandstone Gas	Uinta-Piceance	2000	0.2	0.5	4	0.617
50200262	Uinta Basin Transitional Gas	Uinta-Piceance	2000	0.02	0.25	15	0.570
50340261	Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas	Big Horn Basin	2008	0.02	0.35	7.5	0.560
50220362	Mancos Sandstones Continuous Gas	San Juan Basin	2002	0.02	0.35	5	0.499
50370562	Rock Springs-Ericson Continuous Gas	Southwestern Wyoming	2002	0.02	0.4	3	0.491
50200361	Piceance Basin Continuous Gas	Uinta-Piceance	2000	0.02	0.25	10	0.490
50280163	Eagle Sandstone and Claggett Shale West	North-Central Montana	2000	0.01	0.25	9	0.475
50220161	Pictured Cliffs Continuous Gas	San Juan Basin	2002	0.02	0.25	7	0.434
50280162	Eagle Sandstone and Claggett Shale East	North-Central Montana	2000	0.01	0.2	7	0.375

Table 3. Input data for estimated ultimate recovery distributions for United States tight-gas assessment units, values in billions of cubic feet of natural gas. [AU, assessment unit; and EUR, estimated ultimate recovery]—Continued

AU number	AU name	Province	Year assessed	Minimum EUR	Median EUR	Maximum EUR	Mean EUR
50200363	Uinta-Piceance Transitional and Migrated Gas	Uinta-Piceance	2000	0.02	0.2	7	0.373
50200264	Piceance Basin Transitional Gas	Uinta-Piceance	2000	0.02	0.25	4	0.367
50280166	Greenhorn-Upper Belle Fourche	North-Central Montana	2000	0.01	0.2	6	0.356
50280167	Bowdoin Dome	North-Central Montana	2000	0.01	0.2	5	0.336
50340263	Cody Sandstone Continuous Gas	Big Horn Basin	2008	0.02	0.2	5	0.334
50340264	Mesaverde Sandstone Continuous Gas	Big Horn Basin	2008	0.02	0.2	5	0.334
50280165	Greenhorn-Lower Belle Fourche	North-Central Montana	2000	0.01	0.25	2.5	0.327
50050161	Columbia Basin Continuous Gas	Eastern Oregon and Washington	2006	0.02	0.2	3	0.288
50390662	Dakota Group Basin-Center Gas	Denver Basin	2001	0.02	0.2	2.5	0.275
50670461	Greater Big Sandy	Appalachian Basin	2002	0.01	0.15	2	0.210
50330461	Shallow Continuous Biogenic Gas	Powder River Basin	2002	0.01	0.08	1.5	0.122
50670361	Clinton-Medina Basin Center	Appalachian Basin	2002	0.01	0.08	1.2	0.115
50670465	Catskill Sandstones and Siltstones	Appalachian Basin	2002	0.01	0.07	1.5	0.111
50280161	Judith River Formation	North-Central Montana	2000	0.01	0.06	2	0.109
50280164	Niobrara-Carlile	North-Central Montana	2000	0.01	0.07	1	0.099
50670363	Clinton-Medina Transitional	Appalachian Basin	2002	0.01	0.06	1	0.089
50670362	Clinton-Medina Transitional Northeast	Appalachian Basin	2002	0.01	0.06	0.9	0.086
50670466	Berea Sandstone	Appalachian Basin	2002	0.01	0.03	0.5	0.044

Table 4. Input data for estimated ultimate recovery distributions for United States continuous-oil assessment units, values in millions of barrels of oil. [AU, assessment unit; and EUR, estimated ultimate recovery]

AU number	AU name	Province	Year assessed	Minimum EUR	Median EUR	Maximum EUR	Mean EUR
50310164	Eastern Expulsion Threshold	Williston Basin	2008	0.002	0.12	5	0.241
50310163	Nesson-Little Knife Structural	Williston Basin	2008	0.002	0.09	4	0.185
50210361	Cane Creek Shale Oil	Paradox Basin	2011	0.002	0.08	3	0.154
50310165	Northwest Expulsion Threshold	Williston Basin	2008	0.002	0.065	4	0.151
50310161	Elm Coulee-Billings Nose	Williston Basin	2008	0.002	0.08	2	0.135
50270561	Marias River Shale Continuous Oil	Montana Thrust Belt	2002	0.001	0.08	1.6	0.126
50370361	Niobrara Continuous Oil	Southwestern Wyoming	2002	0.001	0.08	1.6	0.126
50300361	Niobrara Continuous Oil	Hanna, Laramie, Shirley Basins	2005	0.001	0.04	1.6	0.079
50310162	Central Basin-Poplar Dome	Williston Basin	2008	0.002	0.025	2	0.064
50210363	Gothic, Chimney Rock, Hovenweep Shale Oil	Paradox Basin	2011	0.002	0.03	1.5	0.064
50580162	Woodford Shale Oil	Anadarko Basin	2010	0.003	0.03	1.5	0.064
50200561	Deep Uinta Overpressured Continuous Oil	Uinta-Piceance	2000	0.003	0.045	0.45	0.059
50440165	Spraberry Continuous Oil	Permian Basin	2007	0.001	0.045	0.4	0.057
50490170	Eagle Ford Shale Oil	Gulf Coast Mesozoic	2010	0.002	0.03	1	0.055
50490168	Austin Pearsall-Giddings Area Oil	Gulf Coast Mesozoic	2010	0.002	0.04	0.5	0.055
50330361	Niobrara Continuous Oil	Powder River Basin	2002	0.002	0.028	0.5	0.042
50330261	Mowry Continuous Oil	Powder River Basin	2002	0.002	0.025	0.35	0.035
50340262	Mowry Fractured Shale Continuous Oil	Big Horn Basin	2008	0.002	0.025	0.35	0.035
50390261	Fractured Niobrara Limestone (Silo Field Area)	Denver Basin	2001	0.002	0.022	0.4	0.033
50390661	Niobrara-Codell (Wattenberg Area)	Denver Basin	2001	0.003	0.008	0.1	0.011

Results

The results are presented in figures 1 through 4. Each line shows the range of EURs for a single AU. Only those EURs greater than the minimum assessed value (for that particular AU assessment) are included. Individual AU distributions show approximately two orders of magnitude difference between the smallest and largest EURs within a single AU. This range would be even larger if the distributions were not truncated.

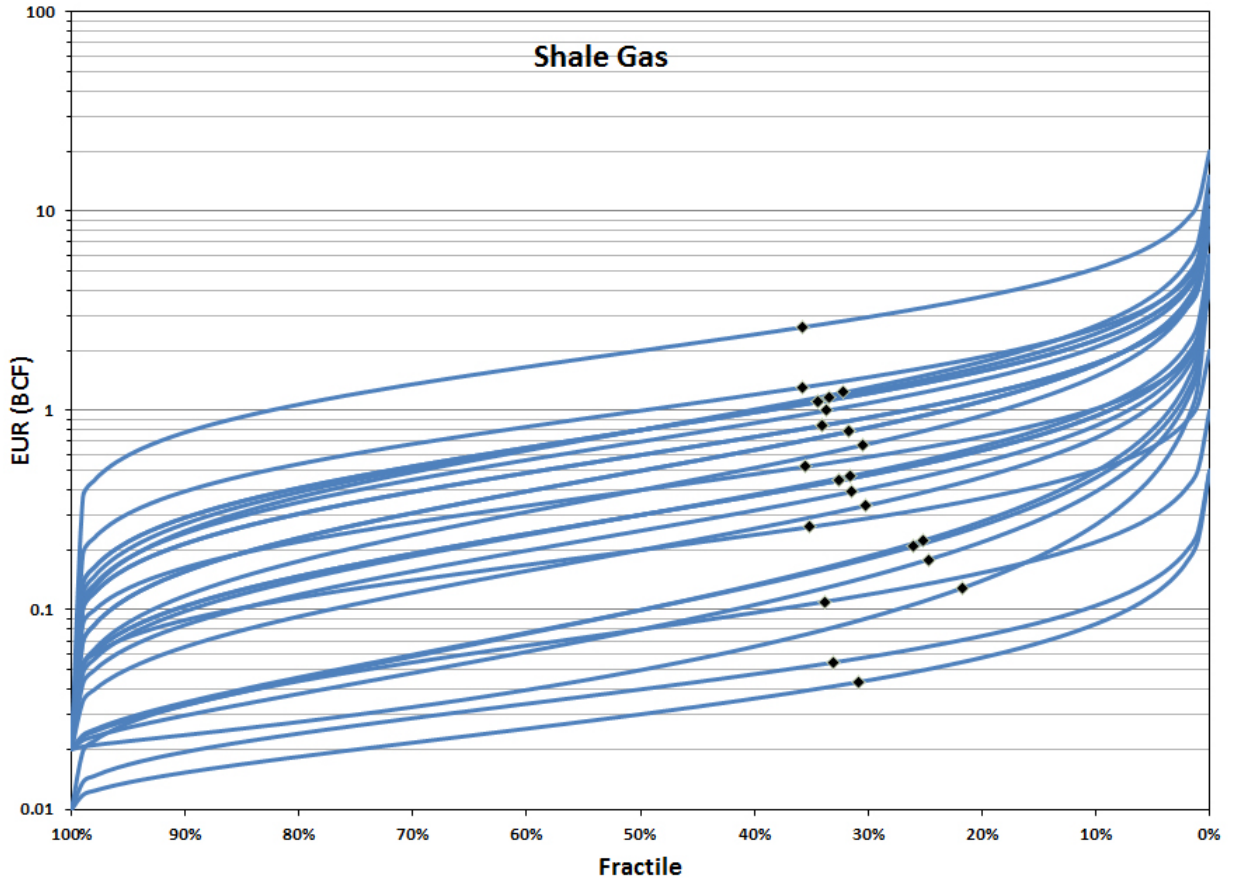

Figure 1. Cloud plot for United States shale-gas assessment units. Each curve represents one assessment unit and is based on the input data in table 1. Black diamonds indicate the mean value for each curve. [AU, assessment unit; EUR, estimated ultimate recovery; and BCF, billions of cubic feet]

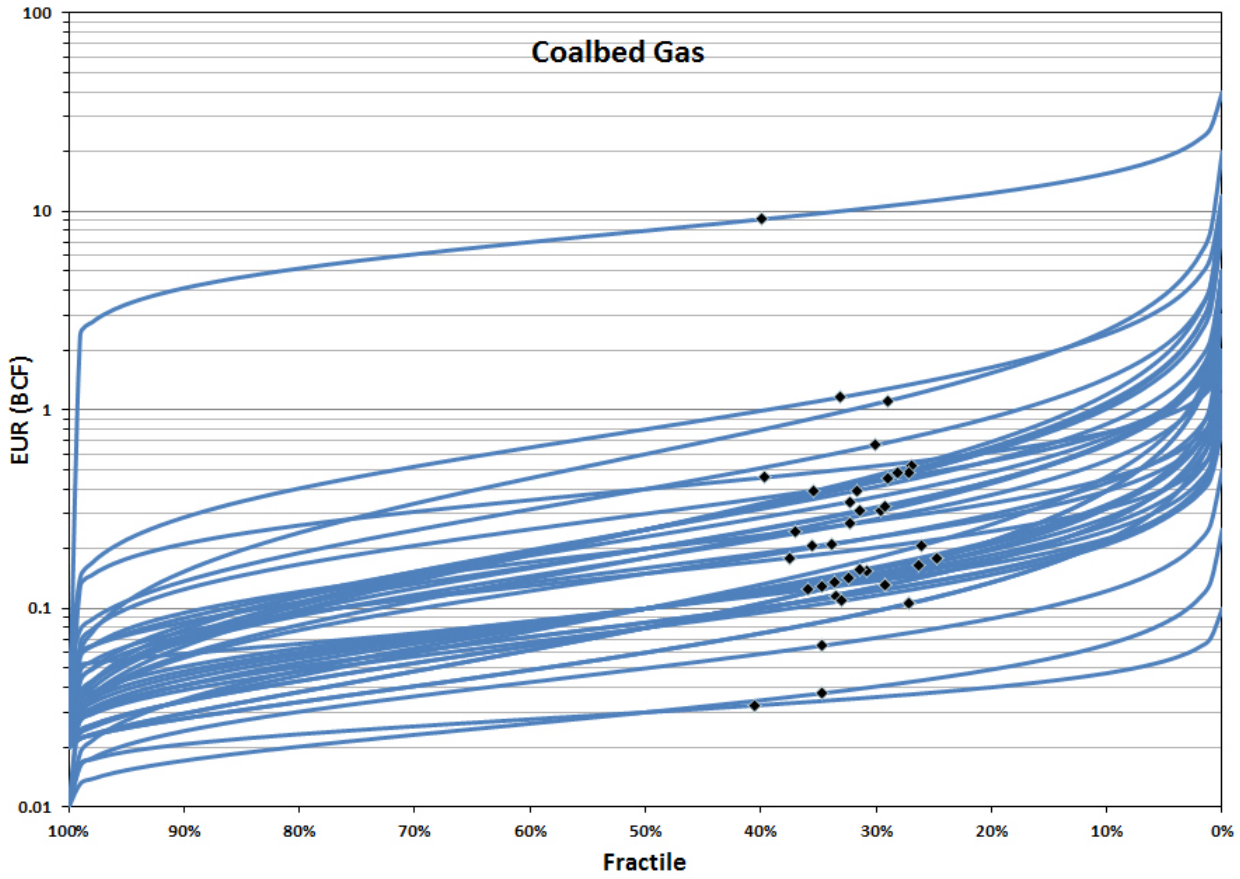

Figure 2. Cloud plot for United States coalbed-gas assessment units. Each curve represents one assessment unit and is based on the input data in table 2. Black diamonds indicate the mean value for each curve. [AU, assessment unit; EUR, estimated ultimate recovery; and BCF, billions of cubic feet]

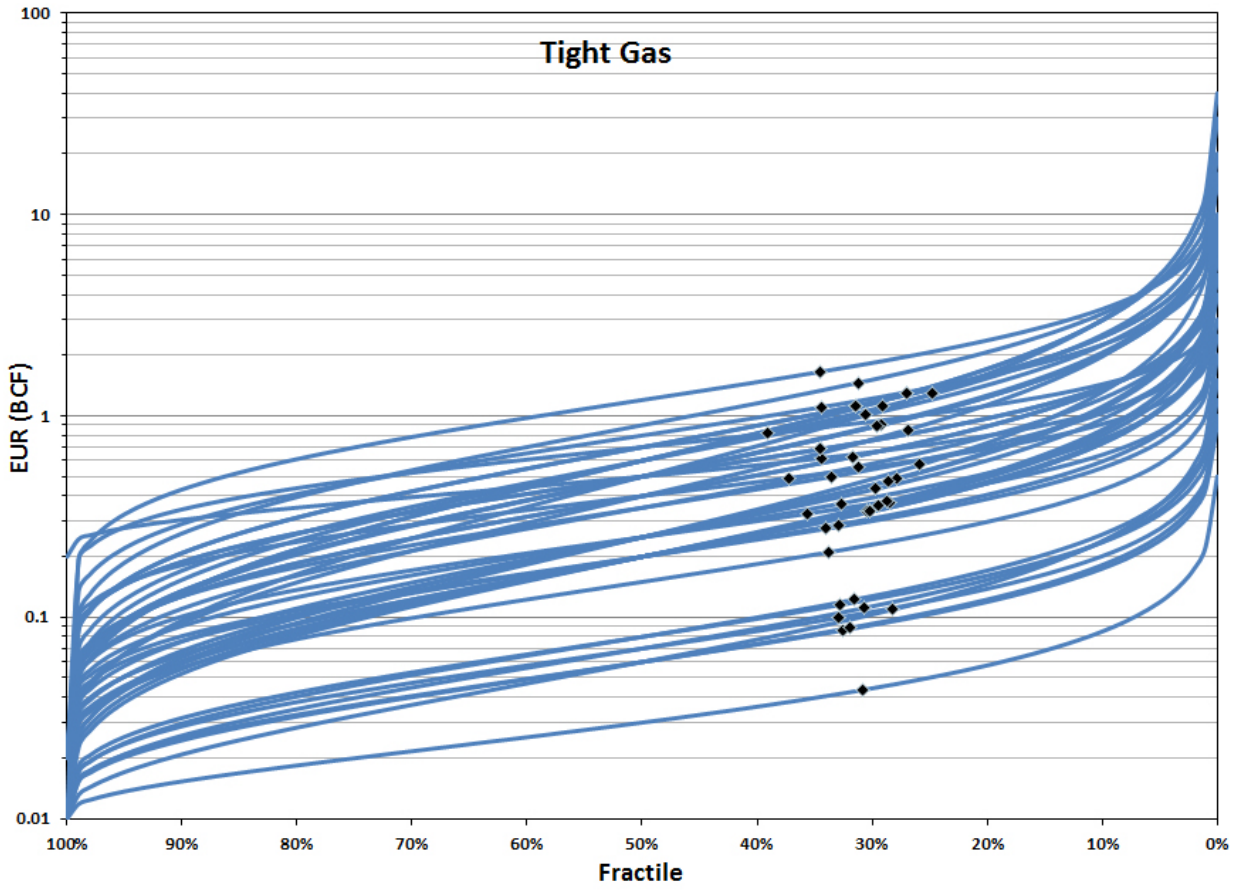

Figure 3. Cloud plot for United States tight-gas assessment units. Each curve represents one assessment unit and is based on the input data in table 3. Black diamonds show the mean value for each curve. [AU, assessment unit; EUR, estimated ultimate recovery; and BCF, billions of cubic feet]

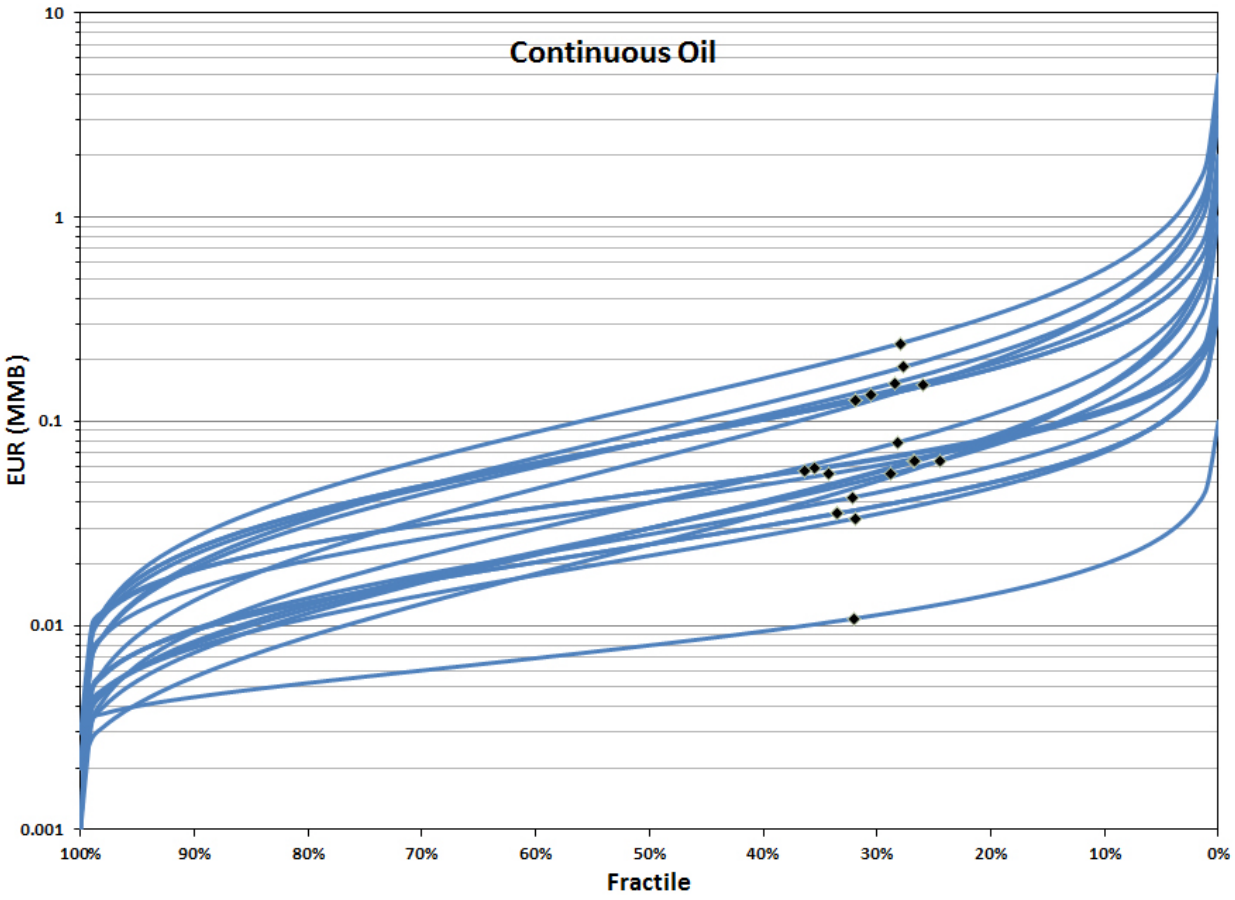

Figure 4. Cloud plot for United States continuous-oil assessment units. Each curve represents one assessment unit and is based on the input data in table 4. Black diamonds indicate the mean value for each curve. [AU, assessment unit; EUR, estimated ultimate recovery; and MMB, millions of barrels]

Each figure shows the EUR curves for a single category (shale gas, coalbed gas, tight gas, and continuous oil), allowing comparison of EUR distributions among AUs. The four figures are termed "cloud plots," which show the "cloud" of data representing the distribution of EUR distributions. Cloud plots of the distributions of drilled wells show similar ranges of variability.

Individual cloud plots show the wide variability among AUs of a particular category. The most productive AUs have average EURs from 22 to almost 300 times those of the least productive AUs. Also note the strong similarity of the shale gas and tight gas clouds (figs. 1, 3).

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Appendix 1. Assessments Used in this Report

CD-ROMs

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