Appendix 7
Initial Estimates of Remaining Proved Ultimate Recovery Growth

The Proved Ultimate Recovery (PUR) of an oil or gas field at a particular point in time is defined as the sum of its estimated proved reserves and its recorded cumulative production at that time.

$$PURG_n = R_n + CumProd_n$$

where:

PUR	=	Proved Ultimate Recovery
PR	=	Proved Reserves
CumProd	=	Cumulative Production
n	=	Years after First Production (or Discovery)

Proved Ultimate Recovery Growth (PURG) is the increase in proved ultimate recovery over time that is observed for most oil and gas fields.

$$PURG_n = PUR_n - PUR_{n=1}$$

where:

PURG	=	Proved Ultimate Recovery Growth
PUR	=	Proved Ultimate Recovery
n	=	Years after First Production (or Discovery)

A field's PUR estimate normally increases significantly in the early post-discovery years as it is developed for production and its areal limits are better discerned. The PUR estimates may also be conservative early in a field's life owing to the smaller knowledge base than available regarding its potential productive performance. A field's later years are usually characterized by slower growth arising from a variety of possible causes including the installation of improved recovery techniques, increased knowledge of the field's productive performance, the addition of new reservoirs to the field, and infill drilling. Cumulative growth factors calculated from most fields' ultimate recovery histories thus usually increase rapidly as initial field development occurs and then asymptotically approach a maximum value as growth slows in later years. A more complete discussion of this phenomenon and its many causes is presented in The Intricate Puzzle of Oil and Gas "Reserves Growth," available online at http://www.eia.doe.gov/pub/oil_gas/petroleum/feature_articles/1997/intricate_puzzle_reserves_growth/m07fa.pdf.

The PURG, and the remaining (future) portion thereof, Remaining Proved Ultimate Recovery Growth (RPURG), can be estimated from the observed historical PUR. In a given year (n) for a group of fields of the same vintage (age) the Annual Growth Factor (AGF) is the sum of the estimated proved ultimate recovery of the fields in that year divided by the sum of estimated proved ultimate recovery of the same fields for the prior year.

$$AGF_n = \frac{PUR_n}{PUR_{n-1}}$$

where:

AGF	=	Annual Growth Factor
PUR	=	Proved Ultimate Recovery
n	=	Years after First Production (or Discovery)

Going one step further, for a basin the Basin Median Annual Growth Factor (BMAGF) for its multiple fields in multiple vintages is the Median of the Annual Growth Factors of all fields in all vintages at the same point in time (n) (the same year after first production or after field discovery).

$$BMAGF_n = MedianAGF_n$$

where:

BMAGF	=	Basin Median Annual Growth Factor (multiple vintages)
AGF	=	Annual Growth Factor (multiple vintages)
n	=	Years after First Production (or discovery)

The Cumulative Growth Factor (CGF) for the Basin in a particular year is the product of the Basin Median Annual Growth Factors for all vintages through that year beginning with the first production or discovery year.

$$BCGF_n = 1 * BMAGF_2 * BMAGF_3 \ldots BMAGF_n$$

where:

BCGF	=	Basin Cumulative Growth Factor (multiple vintages)
BMAGF	=	Basin Median Annual Growth factor (multiple vintages)
n	=	Years after First Production (or discovery)

Final PUR for the basin (BFPUR) at some final time can be calculated as the product of the ratio of the final time Basin Cumulative Growth Factor (BCGF) to the current time BCGF and the current Basin Proved Ultimate Recovery (BPUR).

$$BFPUR_t = \frac{BCGF_t}{BCGF_n} * BPUR_n$$

where:

BFPUR	=	Basin Future Proved Ultimate Recovery Volume at Final Time (t)
BCGF	=	Basin Cumulative Growth Factor
BPUR	=	Basin Proved Ultimate Recovery Volume at Current Time (n)
n	=	Current Time Years After First Production (or discovery)
t	=	Final Time Years After First Production (or discovery) (300 years)

Equivalently, the estimate of additional ultimate recovery that may be realized in the future based on reserves growth during the future can be stated as:

$$RPURG_{t-n} = FPUR_t - PUR_{n=1}$$

where:

RPURG	=	Remaining Proved Ultimate Recovery Growth Volume at Time (n)
FPUR	=	Final Proved Ultimate Recovery at Time (t)
PUR	=	Proved Ultimate Recovery at Current Time (n)
n	=	Current Time Years After First Production (or discovery)
t	=	Final Time Years After First Production (or discovery) (300 years)

Database Preparation

A database was created containing annual oil and gas production, estimates of cumulative production for that production which occurred prior to the beginning date of the available annual production, annual oil and gas proved reserves, field name, date of first production, and field discovery date for fields located in the EPCA Phase I basins (Southwestern Wyoming, Montana Thrust Belt, Powder River Basin, Paradox-San Juan Basin, and Uinta-Piceance Basin), the EPCA Phase II basins (Denver Basin, Black Warrior Basin, and Wyoming Thrust Belt), and the EPCA Phase III basins (Alaska, Eastern Great Basin, Ventura Basin, and Williston Basin). The available data for the Appalachian Basin were insufficient for PURG analysis. Data sources included the EIA Reserves and Production Division's Oil and Gas Integrated Field File, the EIA Field Code Master List, the EIA-23 Reserves Survey, various state web sites, and commercial data vendors.

Each field in a basin was assigned to a vintage year according to its date of first production or its date of discovery dependent on which date was available or which date was deemed the most reliable indicator of initial production when both dates were available. While the earliest field vintage was 1901, the annual proved reserves estimates and therefore the PUR estimates were usually available only from 1977 to present. The resulting files contained vintage year, number of fields in each vintage, annual barrel of oil equivalent proved ultimate recovery for each vintage, annual natural gas proved ultimate recovery for each vintage, and annual liquid proved ultimate recovery for each vintage.

Significant effort went into quality control of the data. Many field names and codes had to be altered, corrected, and matched across the multiple data sources in order to properly accumulate the field data. Quality control beyond that point was, however, deliberately conservative. While obvious major errors had to be corrected, the desire to seek "correction" of things that were merely suspicious had to be resisted for two reasons: first they might well be correct, and second the available task resources and time were limited. Therefore, for example, the reserves data were used as reported by the field operators unless very obvious errors were found. Data discontinuities and variations within vintages mostly had to be accepted "as-is." Specific vintages that did not fit the trend of most of the data of a basin were excluded from the history matching and forecasting. Attempts to divide the data within a basin into conventionally reservoired, tight formation, and coal gas sources were largely unsuccessful because of the limited number of vintages, the short histories available for some of the fields, and frequent inability to separate the data by reservoir type within a field.

Estimation of Remaining Proved Ultimate Recovery Growth

The remainder of this appendix describes the model that was used to estimate RPURG by basin and fuel type within a basin for the EPCA Phase III study areas. Because this model is a new one that differs significantly from the two models used to develop the initial RPURG estimates for the Phase I and II study areas, the RPURG values of those study areas have been re-estimated using the new model too.

The new model implements a hyperbolic function with three fit parameters that is dependent on incremental growth factors by vintage and is an asymptotic function for which time serves as the sole driver. Even though other potential drivers such as drilling rates or wellhead prices are not directly used, they have affected the historical data that feeds into the model. The initial dataset was limited to PUR estimates from 1977 to 2003 and there were significant data gaps in some of the data series. To limit the influence of data extremes, the median annual reserves growth across vintages for the same number of years since first production was selected for use as a central tendency measure of basin-wide PURG. Unlike the mean value, which can be greatly influenced by a few extreme values, the median value is not subject to their influence.

The methodology for fitting and using the hyperbolic model involves the following sequential steps:

A) Sort the field-level PUR estimates by fuel and vintage year.

B) Calculate the annual growth factors for each year of a vintage by dividing successive PUR estimates by the previous year estimate.

C) Determine the Annual Growth Factor for common years since first production for all vintages as the median of the data (BMAGF).

D) Calculate the Cumulative Growth Factor.

E) Create a time-based hyperbolic model curve using the following formula:

$$CGF_{TBHM} = \left[C * \left(1 - \frac{1}{(1 + A * (n))^{B-1}} \right) \right] + 1$$

where:

CGFTBHM	=	Cumulative Growth Factor of the Time-Based Hyperbolic Model.
A, B, and C	=	Curve Fit Parameters
n	=	Years After First Production (or discovery), a time difference factor that is the number of years between the current year and the vintage year (i.e., 1995-1901).

F) Perform a least squares fit of the cumulative increase of the model with the actual data, solving for A, B, and C. In some cases, A was constrained to: A ≥ 0.

G) Calculate the CGF to a time of 300 years from first basin production.

H) Plot the results by basin and fuel using 300 years as x-axis length.

I) Using the known current PUR for the basin, and the actual years after first production (or discovery) time difference, use the performance of the model curve fit to predict the RPURG volume from current time to a final time of 300 years after first basin production.

The results obtained using this model for EPCA I, EPCA II, and EPCA III are presented by basin and fuel in Tables A7-1, A7-2, and A7-3 and Figures A7-1 through A7-11. The EPCA I Montana Thrust Belt study area had just 3 vintages, insufficient for modeling purposes.

Table A7-1. EPCA I Median Method, Hyperbolic Fit, 300 Year Ultimate Recovery Growth

Basin	Type	Cumulative Growth Factor		Future Growth Factor Ratio	2003 Ultimate	300 Year Ultimate	Remaining Ultimate	Future Growth as % of 2003 Ultimate
Paradox-San Juan	Oil Equivalent	**2003**	**2222**		**boeult x 10^9**	**boeult x 10^9**	**boeult x 10^9**	
		2.7194	3.5907	1.320	1.763	2.328	0.565	32.0%
					bliq x 10^9	**bliq x 10^9**	**bliq x 10^9**	
	Liquids	2.3703	2.6809	1.131	0.903	1.021	0.118	13.1%
	Gas				**tcf**	**tcf**	**tcf**	
		4.6412	6.6924	1.442	5.157	7.436	2.279	44.2%
Powder River	Oil Equivalent	**2003**	**2215**		**boeult x 10^9**	**boeult x 10^9**	**boeult x 10^9**	
		6.6600	8.1861	1.229	4.112	5.054	0.942	22.9%
					bliq x 10^9	**bliq x 10^9**	**bliq x 10^9**	
	Liquids (1)	6.5552	7.9853	1.218	3.458	4.212	0.754	21.8%
	Liquids (2)	7.6210	10.0889	1.324	3.458	4.578	1.12	32.4%
	Gas				**tcf**	**tcf**	**tcf**	
		9.4613	10.7815	1.140	3.925	4.473	0.548	14.0%
Uinta-Piceance	Oil Equivalent	**2003**	**2226**		**boeult x 10^9**	**boeult x 10^9**	**boeult x 10^9**	
		3.5633	5.5676	1.588	1.756	2.788	1.032	58.8%
					bliq x 10^9	**bliq x 10^9**	**bliq x 10^9**	
	Liquids	3.4801	5.4126	1.555	0.782	1.216	0.434	55.5%
	Gas				**tcf**	**tcf**	**tcf**	
		3.4228	5.389	1.574	5.838	9.192	3.354	57.4%
Southwestern Wyoming	Oil Equivalent	**2003**	**2201**		**boeult x 10^9**	**boeult x 10^9**	**boeult x 10^9**	
		6.7172	8.921	1.328	6.391	8.488	2.097	32.8%
					bliq x 10^9	**bliq x 10^9**	**bliq x 10^9**	
	Liquids	5.5068	6.5566	1.191	1.059	1.261	0.202	19.1%
	Gas				**tcf**	**tcf**	**tcf**	
		6.7728	8.9447	1.321	31.995	42.255	10.26	32.1%
Montana Thrust Belt	Insufficient Data (3 Vintages)							

Source: Energy Information Administration, Reserves and Production Division

Table A7-2. EPCA II Median Method, Hyperbolic Fit, 300 Year Ultimate Recovery Growth

Basin	Type	Cumulative Growth Factor		Future Growth Factor Ratio	2003 Ultimate	300 Year Ultimate	Remaining Ultimate	Future Growth as % of 2003 Ultimate
Denver	Oil Equivalent	**2003**	**2201**		**boeult x 10^9**	**boeult x 10^9**	**boeult x 10^9**	
		3.417	3.7704	1.103	2.579	2.846	0.267	10.3%
					bliq x 10^9	**bliq x 10^9**	**bliq x 10^9**	
	Liquids	3.2578	3.6864	1.132	1.290	1.460	0.170	13.2%
	Gas				**tcf**	**tcf**	**tcf**	
		2.799	3.1022	1.109	7.730	8.569	0.839	10.9%
Black Warrior	Oil Equivalent	**2003**	**2252**		**boeult x 10^9**	**boeult x 10^9**	**boeult x 10^9**	
		3.5877	4.5408	1.266	0.808	1.023	0.215	26.6%
					bliq x 10^9	**bliq x 10^9**	**bliq x 10^9**	
	Liquids	2.3306	2.7072	1.162	0.016	0.019	0.003	16.2%
	Gas				**tcf**	**tcf**	**tcf**	
		4.2045	5.2206	1.242	4.756	5.905	1.149	24.2%
Wyoming Overthrust	Oil Equivalent	**2003**	**2275**		**boeult x 10^9**	**boeult x 10^9**	**boeult x 10^9**	
		1.5985	1.721	1.076	1.756	1.890	0.134	7.6%
					bliq x 10^9	**bliq x 10^9**	**bliq x 10^9**	
	Liquids	1.6427	1.6772	1.021	0.351	0.358	0.007	2.1%
	Gas				**tcf**	**tcf**	**tcf**	
		2.8208	3.4721	1.231	4.788	5.894	1.106	23.1%

Source: Energy Information Administration, Reserves and Production Division

Table A7-3. EPCA III Median Method, Hyperbolic Fit, 300 Year Ultimate Recovery Growth

Median method, post-1985 data, 3-parameter hyperbolic fit

Basin	Type	Cumulative Growth Factor		Future Growth Factor Ratio	2004 Ultimate	300 Year Ultimate	Remaining Ultimate	Future Growth as % of 2003 Ultimate
Alaska	Oil Equivalent	**2004**	**2257**		**boeult x 10^9**	**boeult x 10^9**	**boeult x 10^9**	
		1.703	2.805	1.647	22.171	36.518	14.347	64.7%
					bliq x 10^9	**bliq x 10^9**	**bliq x 10^9**	
	Liquids	1.971	2.585	1.312	18.375	24.099	5.724	31.2%
	Gas				**tcf**	**tcf**	**tcf**	
		2.588	4.211	1.627	22.779	37.064	14.285	62.7%
Eastern Great Basin	Oil Equiv. - w/o '54 vintage	**2004**	**2254**		**boeult x 10^6**	**boeult x 10^6**	**boeult x 10^6**	
		5.871	7.339	1.250	57.356	71.697	14.341	25.0%
					bliq x 10^6	**bliq x 10^6**	**bliq x 10^6**	
	Liquid - w/o '54 vintage	5.865	7.329	1.250	57.291	71.592	14.301	25.0%
Ventura	Oil Equivalent	**2004**	**2192**		**boeult x 10^9**	**boeult x 10^9**	**boeult x 10^9**	
		1.383	2.053	1.484	2.804	4.162	1.358	48.4%
					bliq x 10^9	**bliq x 10^9**	**bliq x 10^9**	
	Liquids	1.374	2.013	1.465	2.149	3.148	0.999	46.5%
	Gas				**tcf**	**tcf**	**tcf**	
		1.202	1.556	1.295	3.926	5.082	1.156	29.5%
Williston	Oil Equivalent	**2004**	**2251**		**boeult x 10^9**	**boeult x 10^9**	**boeult x 10^9**	
		4.781	7.506	1.570	3.692	5.796	2.104	57.0%
					bliq x 10^9	**bliq x 10^9**	**bliq x 10^9**	
	Liquids	4.531	6.944	1.533	3.082	4.723	1.641	53.3%
	Gas				**tcf**	**tcf**	**tcf**	
		4.489	7.924	1.765	3.66	6.461	2.801	76.5%

Source: Energy Information Administration, Reserves and Production Division

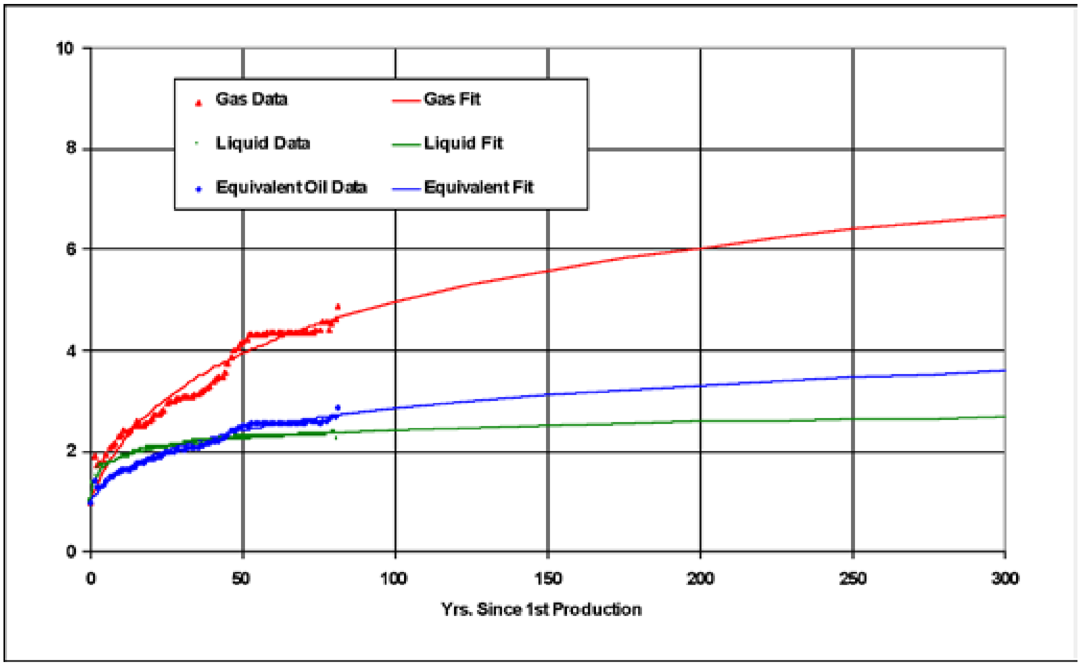

Figure A7-1. Paradox-San Juan Ultimate Reserve Growth, Median Method, Hyperbolic Fit

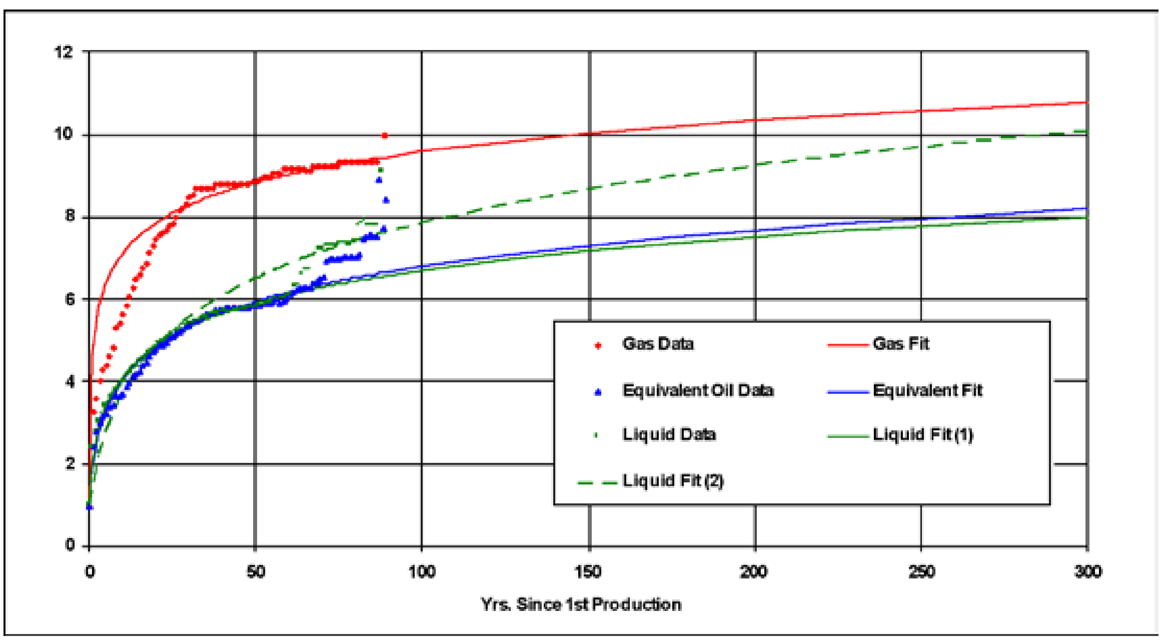

Figure A7-2. Powder River Basin Ultimate Reserve Growth, Median Method, Hyperbolic Fit

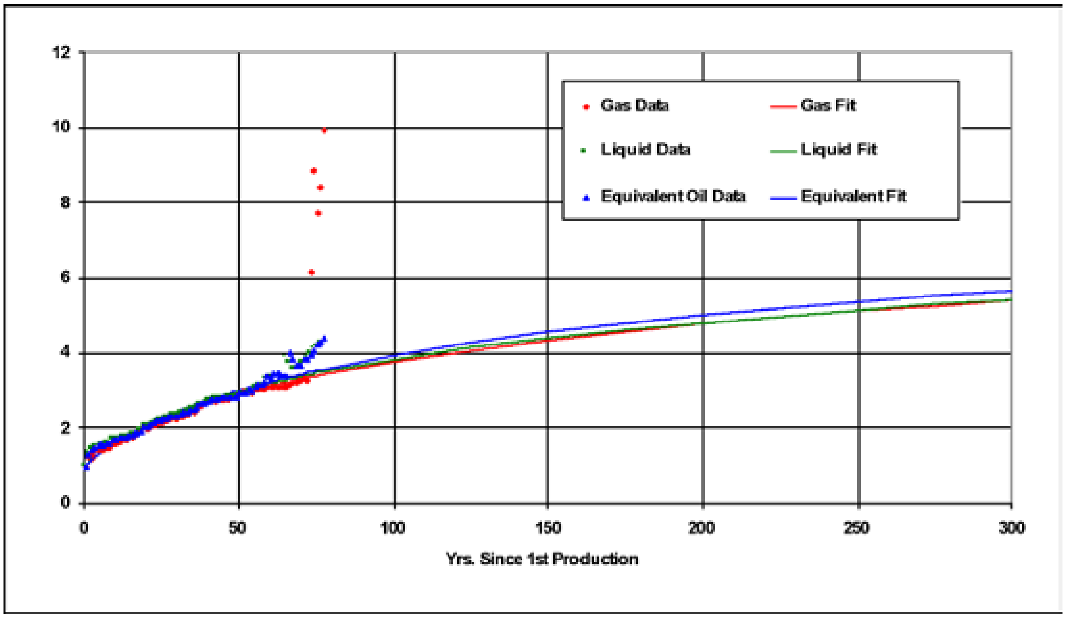

Figure A7-3. Uinta-Piceance Basin Ultimate Reserve Growth, Median Method, Hyperbolic Fit

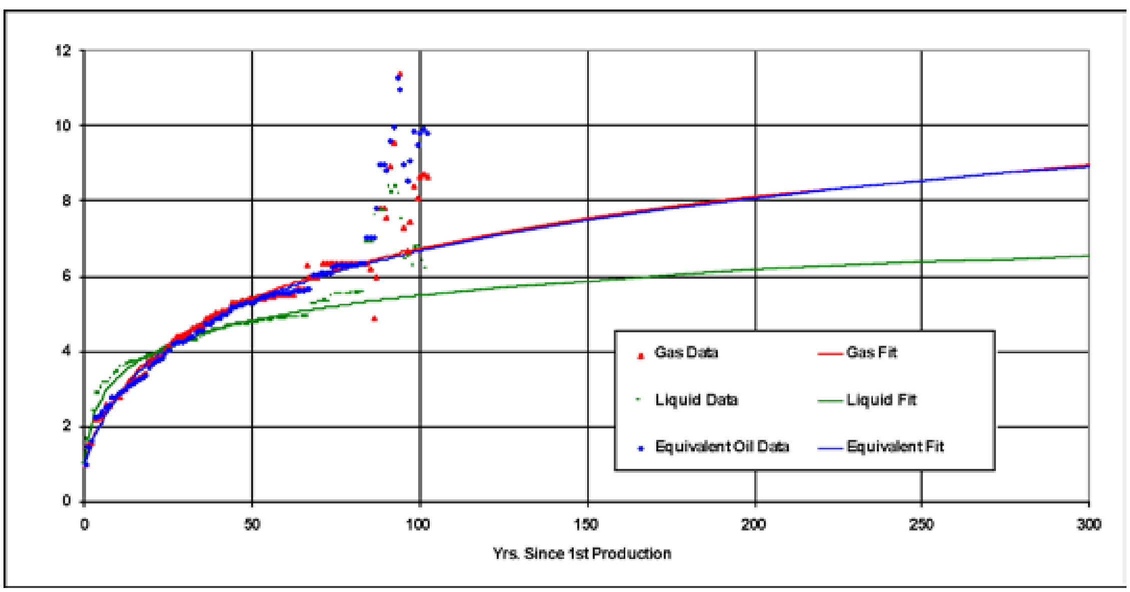

Figure A7-4. Southwestern Wyoming Ultimate Reserve Growth, Median Method, Hyperbolic Fit

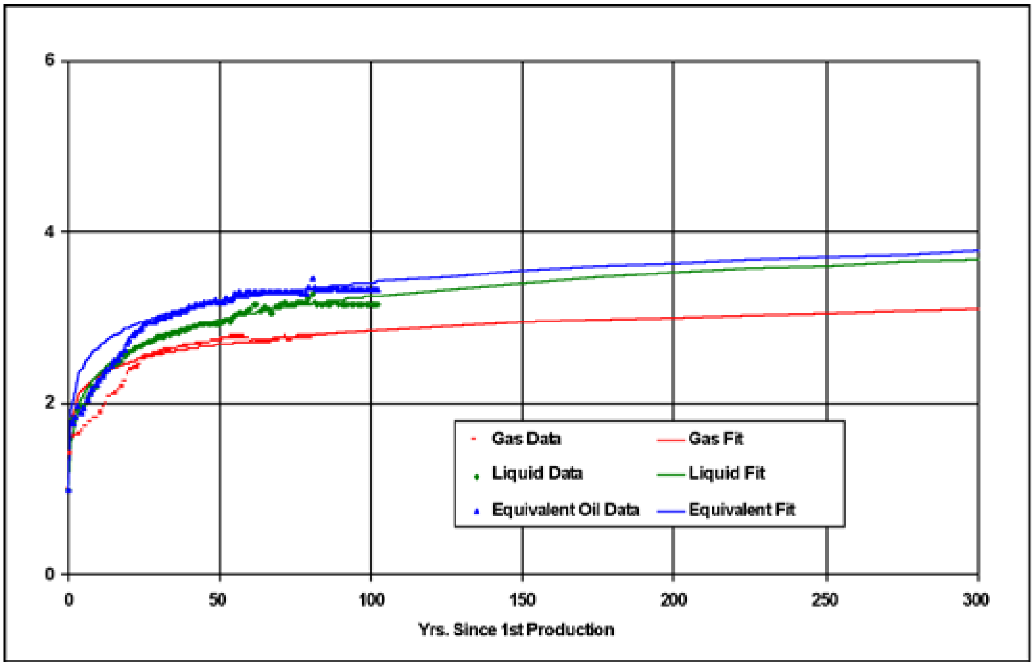

Figure A7-5. Denver Basin Ultimate Reserve Growth, Median Method, Hyperbolic Fit

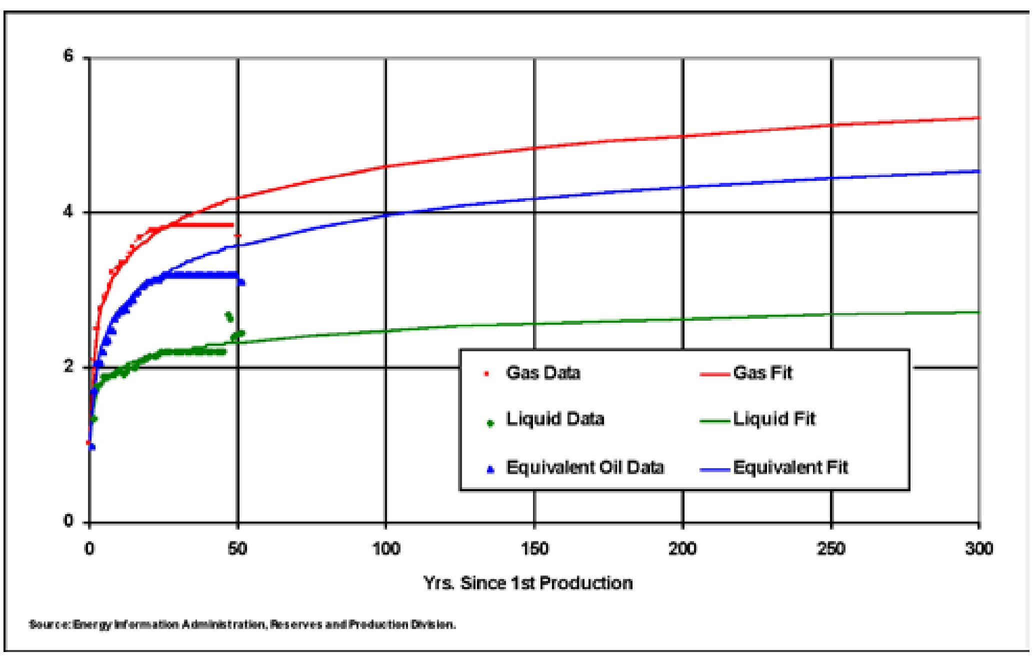

Figure A7-6. Black Warrior Basin Ultimate Reserve Growth, Median Method, Hyperbolic Fit

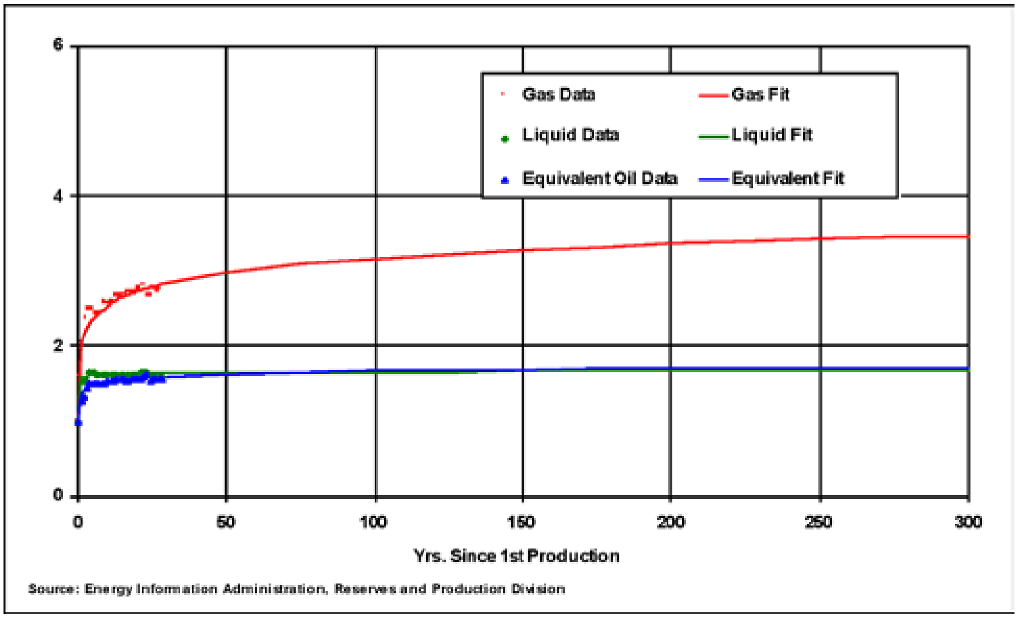

Figure A7-7. Wyoming Overthrust Belt Ultimate Reserve Growth, Median Method, Hyperbolic Fit

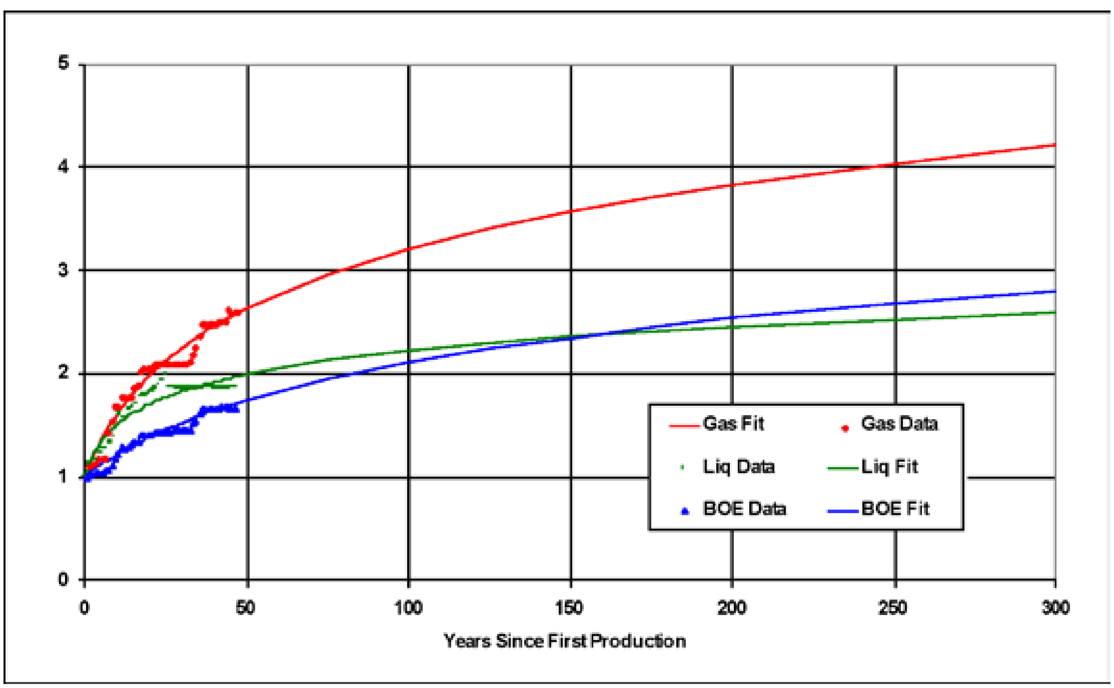

Figure A7-8. Alaska Basin Ultimate Reserve Growth, Median Method, Hyperbolic Fit

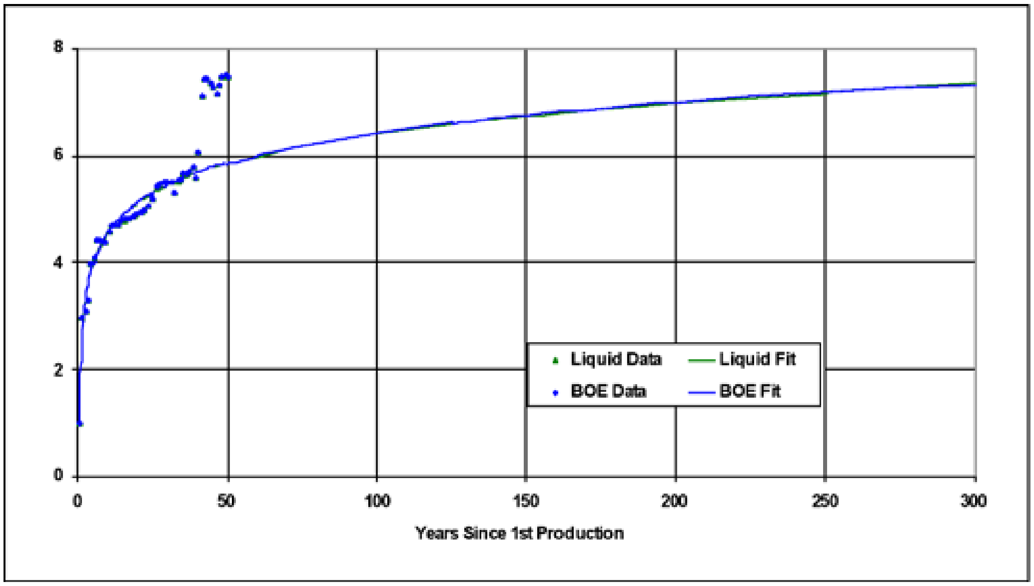

Figure A7-9. Eastern Great Basin Ultimate Reserve Growth, Median Method, Hyperbolic Fit

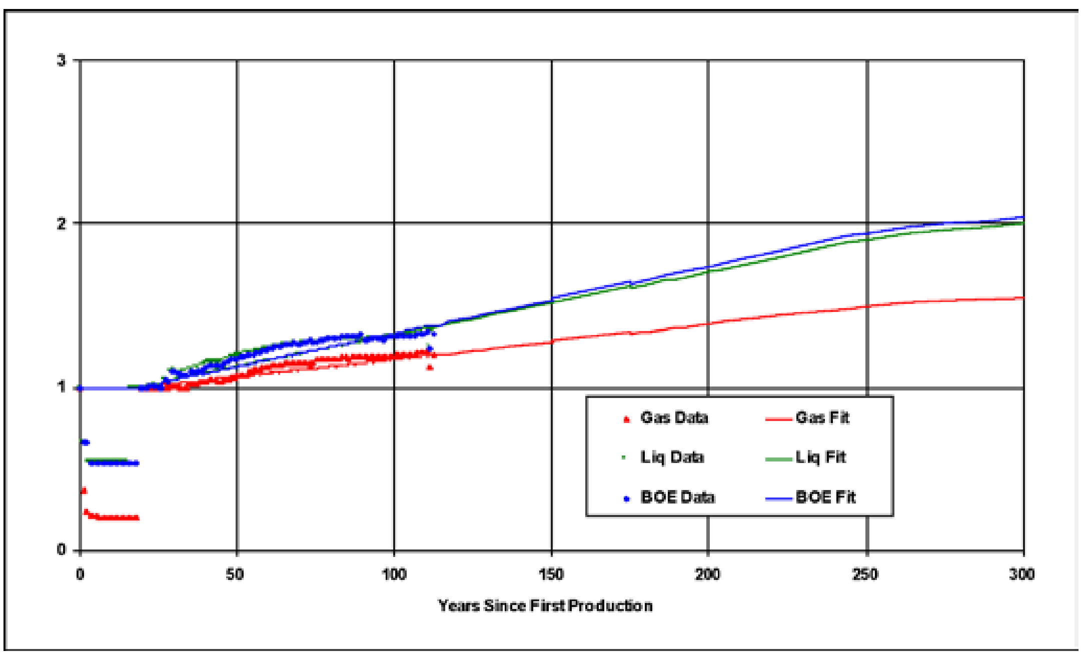

Figure A7-10. Ventura Basin Ultimate Reserve Growth, Median Method, Hyperbolic Fit

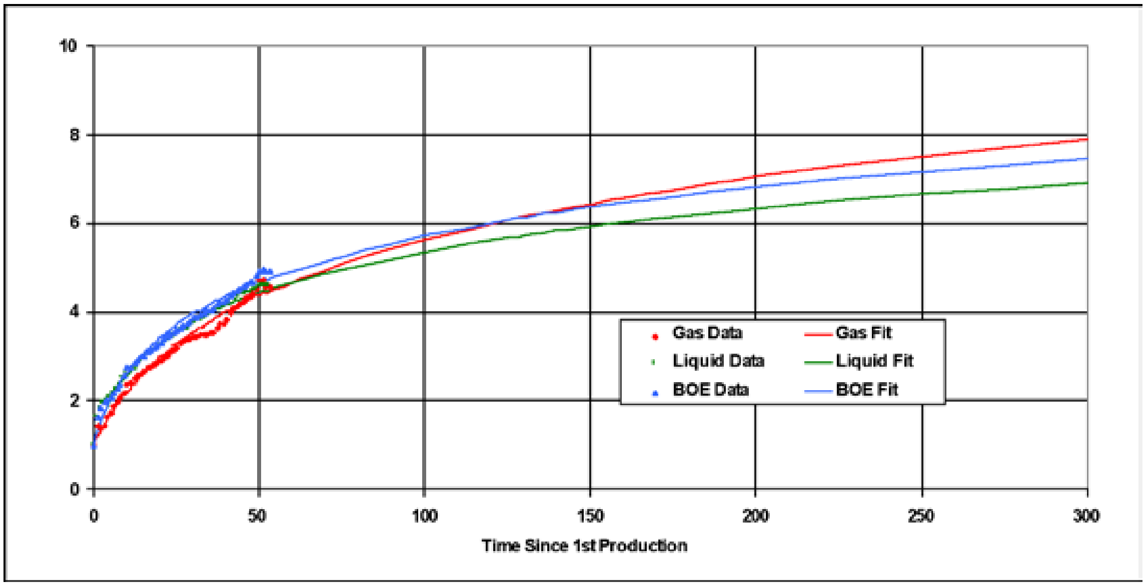

Figure A7-11. Williston Basin Ultimate Reserve Growth, Median Method, Hyperbolic Fit