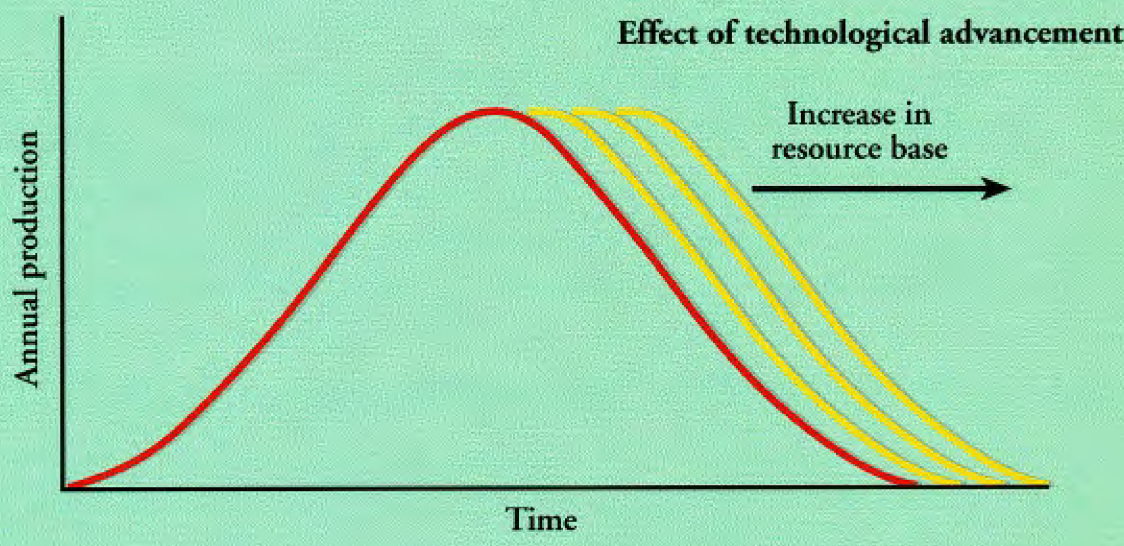
FINAL REPORT

Benefit/Cost Analysis of GRI's Gas Supply Research Initiative:
Economics of a Gas Supply Research Trust Fund to Increase Gas Production on Federal Lands

E. M. Kim, S. W. Tinker, W. L. Fisher, and S. C. Ruppel



Submitted to GRI

BUREAU OF ECONOMIC GEOLOGY
Scott W. Tinker, Director
The University of Texas at Austin
Austin, Texas 78713-8924

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EXECUTIVE SUMMARY

This report analyzes past natural gas projection trends on Federal lands and describes, not only the impact of technological advancements on those trends, but also the impact of GRI-funded technology research on past natural gas production. It forecasts the economic value of continued GRI research on future production and revenue streams. Studies by the National Petroleum Council indicate that investment in technological research and development (R&D) has played a major role in U.S. natural gas production and that increased investment is necessary if U.S. natural gas production is to keep pace with demand.

Nearly all growth in U.S. natural gas production, including Federal lands, which accounts for more than one-third the total U.S. production, is expected to come from the deep-water/subsalt plays in the Gulf of Mexico and from unconventional sources such as low-permeability sandstones and coalbed methane. Production from each of these potential resources is critically dependent on continuing advances in technology.

Annual natural gas production from Federal lands is forecast to increase from 7.3 Tcf to 10.2 Tcf by 2015. Increased production, however, depends on continued development and application of technology. By 2015, the value of technology in terms of incremental natural gas production on Federal lands is estimated to be 45 Tcf from deep-water/subsalt and unconventional resources alone. This technology-dependent production represents a potential incremental royalty revenue of more than $22 billion.

Past GRI programs are estimated to account for approximately 15 percent of total natural gas R&D in the U.S.; for unconventional natural gas resources, GRI's contribution has been even greater. By 2015, continued technological R&D by GRI can be expected to deliver more than 10 Tcf in incremental production to the total U.S. natural gas supply. On Federal lands, GRI's impact is estimated to achieve an incremental production of more than 6.7 Tcf. These scenarios assume a fully funded GRI program throughout this period.

A benefit/cost analysis of a proposed GRI natural gas technological research program, funded by a 10-percent annual nomination of royalty revenue from Federal OCS natural gas production, shows positive economics. Using a base-price case of $3/Mcf, escalating it 1 percent annually and a discount rate of 10 percent, this program is projected to produce an internal rate of return of 101 percent, with a net present value of $5 billion. This amount is based on projected incremental natural gas production and royalty revenue on Federal lands alone. In the context of the broader impact of GRI technological R&D on total U.S. natural gas production, and using the same project economics, the program is projected to produce an internal rate of return of 143 percent, with a net present value of $8 billion.

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INTRODUCTION

The present study provides an economic analysis of the value of establishing a natural gas supply research trust fund built by nominations of 10 percent of royalty payments from natural gas production on the Federal offshore continental shelf (OCS). Analysis consists of

(1) Compilation and management of production and economic data.
(2) Analysis of historical U.S. and Federal lands natural gas production.
(3) Documentation of GRI's historical natural gas supply research programs.
(4) Forecasts of natural gas production and royalty revenue from Federal lands.
(5) Analysis of the potential impact of future GRI projects targeted at increasing natural gas production and royalty payments from Federal lands.
(6) Economic analysis of incremental natural gas production attained through future gas supply research programs.

The study establishes and illustrates

(1) The historical impact of past GRI natural gas supply research programs on incremental gas production on Federal lands.
(2) The potential impact of future GRI natural gas supply research programs on incremental gas production on Federal lands.
(3) The potential return on investment of the proposed natural gas supply research trust fund.

Natural gas resources in the U.S. have recently been analyzed by the National Petroleum Council (NPC) (National Petroleum Council, 1999 a, b, c). Natural gas was concluded to be an important component of the U.S. energy demand, representing approximately one-quarter of that demand. Natural gas demand was forecast to increase from 22 Tcf in 1998 to 31 Tcf in 2015. Increased demand is predicted from economic growth and increased environmental concerns that favor natural gas over oil and coal. U.S. Lower-48 natural gas production was also forecast to increase from 19 Tcf in 1998 to 26 Tcf in 2015. The shortfall in supply relative to demand is expected to come from imports, mainly from Canada. Major findings of the Supply Task Group included the following.

Sufficient resources, mainly from old-field reserve appreciation and new-field discoveries primarily in the deepwater Gulf of Mexico, exist to meet growing demand.

(1) Restricted access on Federal lands limits the availability of supply.
(2) A healthy oil and gas industry is necessary for natural gas supply to satisfy expected increase in demand.
(3) Investment in research and development (R&D) is critical to maintaining the pace of advancements in technology.

Recommendations of the NPC for meeting the challenges of the nation's growing natural gas demand are listed below.

(1) Government and industry must take leadership positions in establishing, at the highest level, a strategy for natural gas in the nation's energy portfolio.
(2) A balanced, long-term approach for responsibly developing the nation's natural gas resource base must be established.
(3) Research and technology development must be driven rapidly.
(4) Capital, infrastructure, and human resource needs must be planned.
(5) Processes that impact gas development must be streamlined.
(6) The impact of environmental regulation on natural gas supply and demand must be assessed.
(7) New services to meet changing customer needs must be designed.

The recent NPC study on U.S. natural gas supply concluded that, in the future, increased gas demand can be met with the currently adequate domestic resource base. The goal of 31 Tcf of supply by 2015 can be achieved at reasonable prices, however, only if exploration and production technology improvements continue. Major increases in natural gas supply are attributable to successes in technologically difficult areas such as deep-water, deep conventional formations, and unconventional formations.

Additionally, the 1999 NPC study assessed the growing importance of the role of independent producers in achieving increases in gas supply. Many independents do not have their own research departments or labs and must rely on collaborative R&D. In the past, GRI's Natural Gas Supply Research Program focused on public-benefit R&D for independents and E&P service companies by funding research performed by the private sector, research organizations, and academe. GRI's previous multiyear, high-risk, high-cost natural gas supply research programs, such as those on coalbed methane, advanced stimulation technologies, and Antrim shales, have proven to result in an economic increase in natural gas production. These increases contributed to increased Federal royalty revenue.

NATURAL GAS IN THE U.S. AND ITS FEDERAL LANDS

With a few exceptions, natural gas resources have historically been underestimated largely because technology and human ingenuity have been ignored, undervalued, or thought to be irrelevant to finite natural gas resources. Changing perceptions of U.S. domestic natural gas resources provide an excellent example of the impact of rigorously applied technology and human ingenuity (Fisher, 1994). During the 1970's and into the early 1980's, the consensus was that U.S. domestic natural gas resources were being exhausted rapidly. Prospects were that long-term natural gas supply would rely increasingly on foreign sources and remote domestic locations at significantly higher prices. Contrary to forecasts, today's inflation-adjusted natural gas prices are only about one-half of what they were in the mid-1980's, and U.S. domestic natural gas production is at a record high. Expectations are for continued growth in U.S. domestic natural gas supply.

Technological advances such as 3-D seismic, hydraulic fracturing, and horizontal/directional drilling have reduced the risks and costs associated with reserve additions. Notably these technological advances came during a period of inordinately low natural gas prices, when technological application was the only alternative. Natural gas activity was, perhaps for the first time in U.S. natural gas exploration and development history, purely technological play. As a direct result, natural gas supplies, curtailed in the 1970's, have exceeded demand. Moreover, natural gas resource estimates made in the 1970's are now exceeded by at least an order of magnitude (Fisher, 1994).

U.S. Natural Gas Statistics

In 1998, total U.S. natural gas annual production and proved reserves were 19,622 and 172,443 Bcf, respectively (Energy Information Administration, 1999a). Historically, estimates of U.S. natural gas ultimate recovery have shown a steady increase with a relatively stable proved-reserve base (fig. 1). With the exception of the abnormally high, but remarkably accurate, U.S. Geological Survey (USGS) estimates of the early

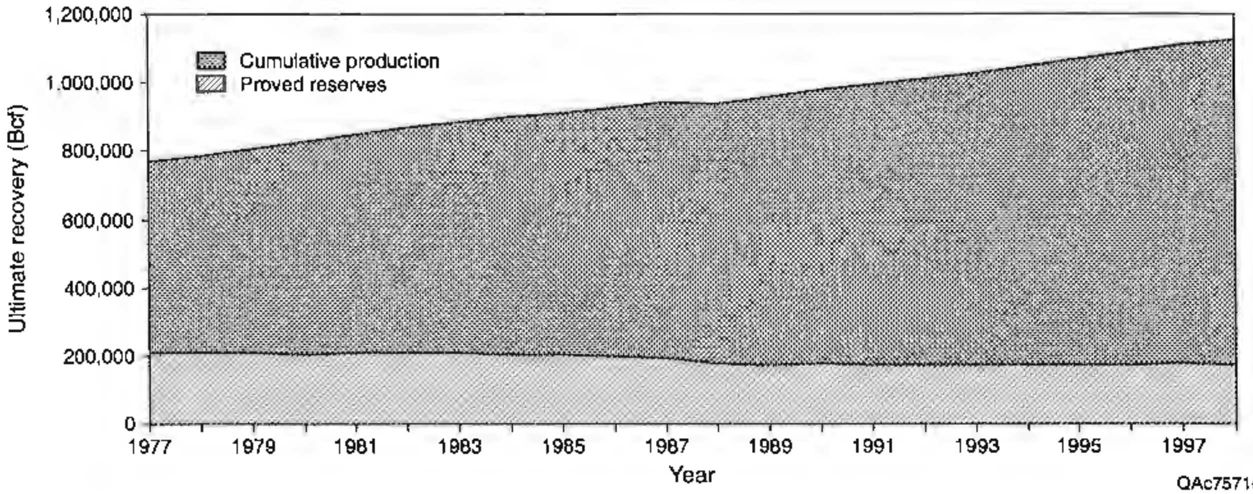

Figure 1. Historical U.S. natural gas ultimate recovery. Data from Energy Information Administration (1999a).

1970's, estimates of remaining U.S. natural gas resources have increased steadily (fig. 2). The turning point in the perception of remaining U.S. natural gas resources came with the Department of Energy (DOE) estimate published in 1988 that doubled an earlier Department of Interior (DOI) estimate made in 1987. The doubled DOE natural gas resource estimate was influenced largely by improvements in yield per effort in gas drilling, unconventional resources, and new perceptions of ultimate gas recovery growth based on extrapolated experience in oil reserve growth. Subsequent estimates of remaining U.S. domestic natural gas resources from a variety of industry, professional, and governmental agencies increased substantially.

According to the 1999 NPC study, a large natural gas resource base remains to be developed in the U.S. The U.S. Lower-48 natural gas resource base was estimated to be 1,466 Tcf. When compared with the 1992 NPC study, the resource base had increased by 171 Tcf. The increase was concluded to be due largely to technology breakthroughs that have opened new frontiers, such as the deep-water Gulf of Mexico and the Rocky Mountain Foreland region, and that have provided improved information and better tools for evaluation and recovery of resources. Deeper wells, deeper water, and unconventional resources were cited as being the keys to future supply (National Petroleum Council, 1999a).

Although present views indicate an ample remaining U.S. natural gas resource base, many factors have constantly changed this outlook. U.S. Lower-48 natural gas production peaked in the early 1970's, with a stabilized decline through the early 1980's (fig. 3). As average wellhead prices and drilling costs increased severalfold through the decade, demand for U.S. natural gas production declined in the early 1980's, creating a surplus (figs. 4, 5). From the late 1980's through the present, U.S. natural gas production has increased steadily.

Driven by a widespread perception of scarcity in the mid-1970's and early 1980's, average wellhead natural gas prices rose dramatically (fig. 4). Then, in the face of persistent surplus in the late 1980's, average natural gas wellhead prices subsequently dropped substantially. With an increase in natural gas wellhead prices in the 1970's, natural gas drilling responded comparably, but it fell dramatically in the face of falling demand and prices in the middle 1980's (fig. 6). Success rates and average well depths increased with the drop in drilling.

Except for negative reserve additions in 1988, which occurred because of the large negative revision from the decrease to North Slope dry natural gas reserves made in 1988 as a result of economic and market conditions, a fairly stable trend in U.S. dry natural gas annual production, proved reserves, and reserve additions has been

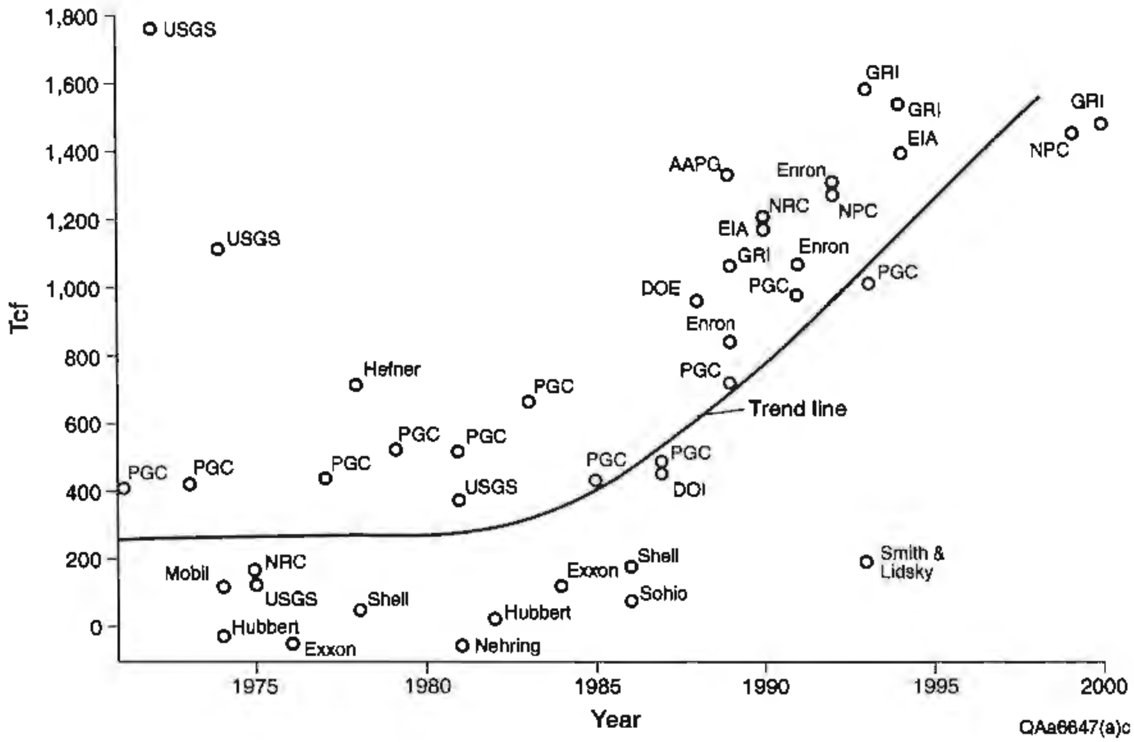

Figure 2. Estimates of remaining U.S. natural gas resources. Modified from Fisher (1994).

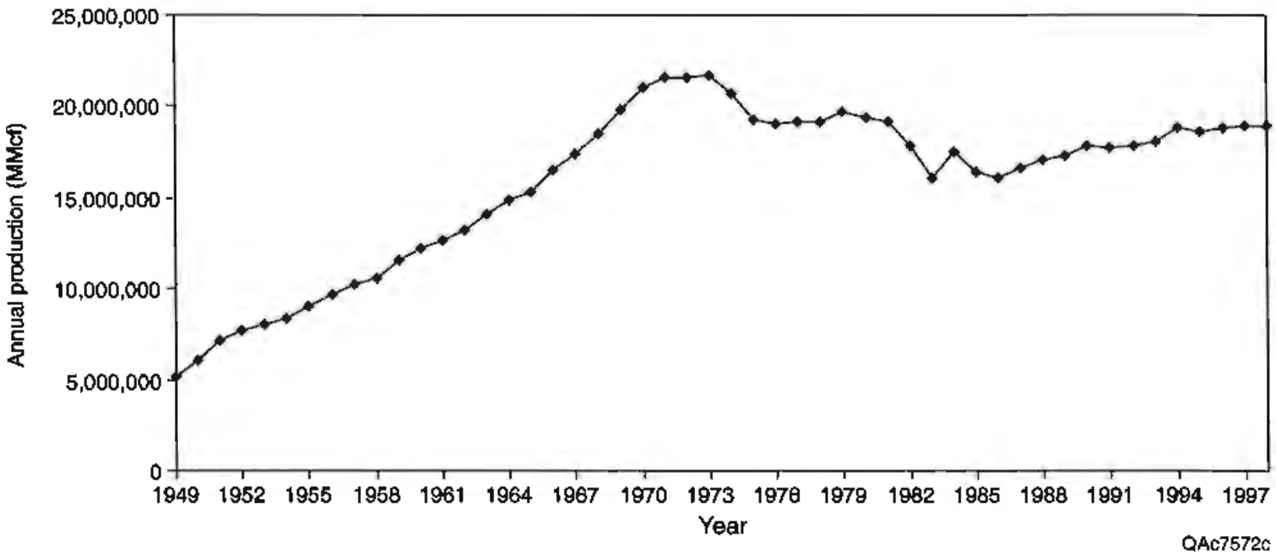

Figure 3. Historical U.S. dry natural gas production. Data from Energy Information Administration (2000).

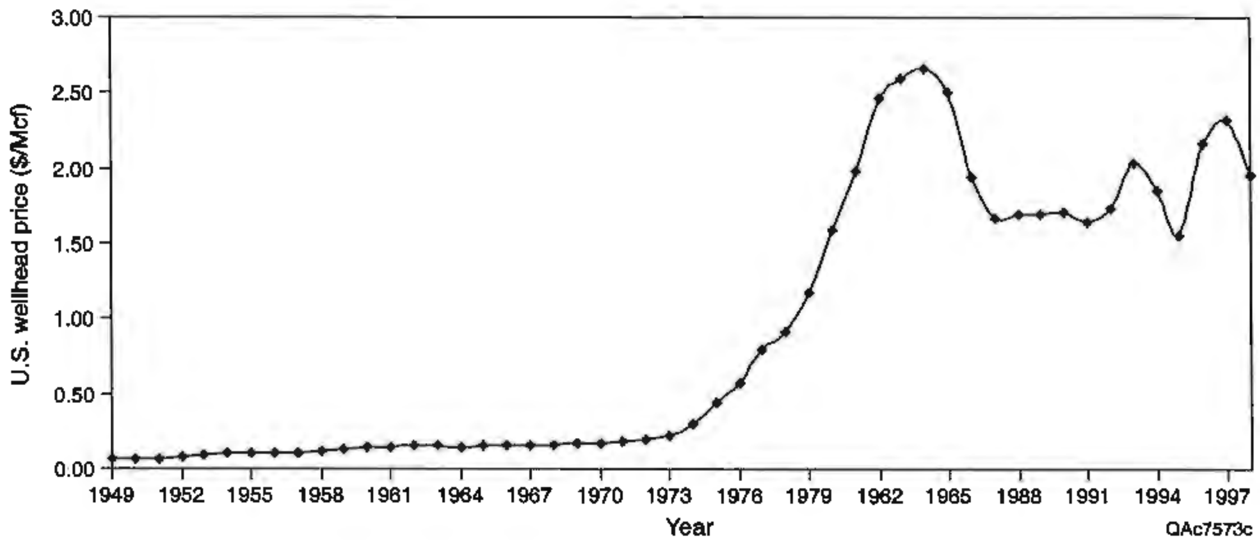

Figure 4. Historical natural gas wellhead price. (Not adjusted for inflation.) Data from Energy Information Administration (2000).

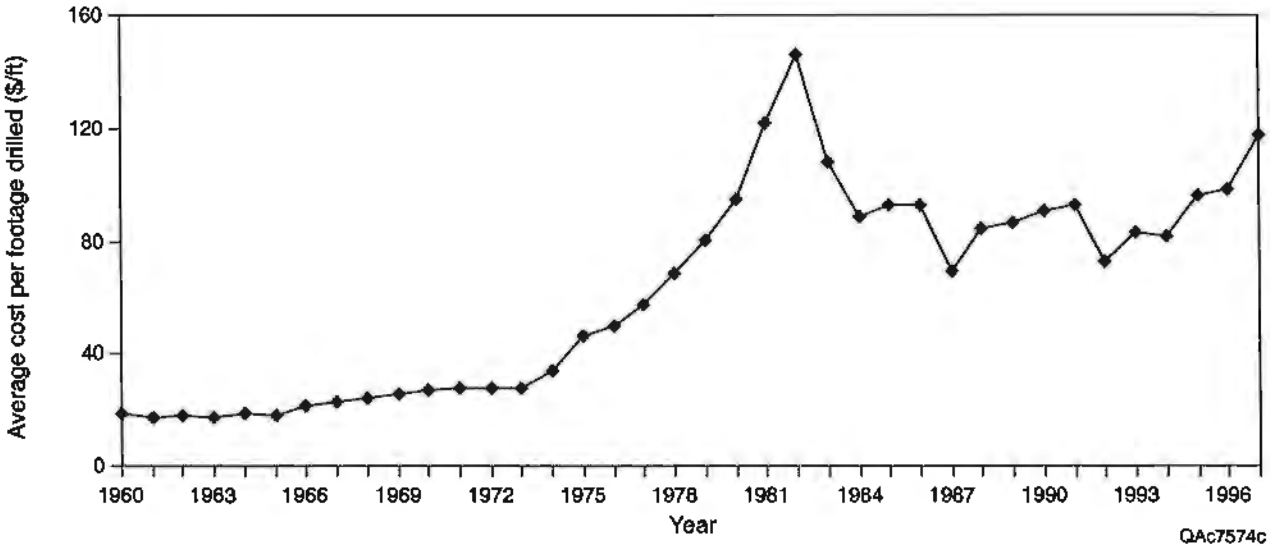

Figure 5. Historical natural gas well average cost per footage drilled. (Not adjusted for inflation.) Data from Energy Information Administration (2000).

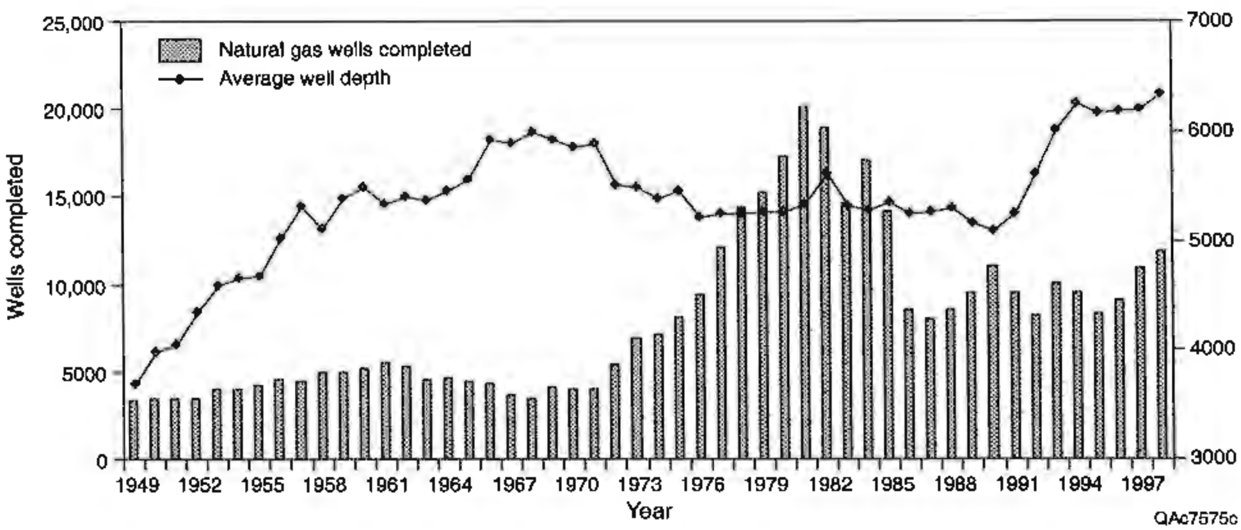

Figure 6. Historical natural gas drilling. Data from Energy Information Administration (2000).

maintained since the mid-1980's (fig. 7). A drop in drilling in relation to price decreases was expected. However, maintaining relatively stable annual production, proved reserves, and reserve additions under lower levels of drilling and reduced prices was an unanticipated phenomenon. This phenomenon over the past few years has become critical to assessing future U.S. natural gas supply and deliverability.

Was the phenomenon an anomaly or a has a trend of substance been established? The answer may be revealed by taking a closer look at reserve additions. In the late 1980's, the fact that reserve additions were maintained or even increased with declines in both drilling and price was argued by some to be due to increase in revisions that were judged to be only "paper" reserves. However, the sustained natural gas supply made this argument less persuasive. Subsequently, arguments have been raised that the extra margin of reserve additions may be real but short lived. This argument is nevertheless also losing ground because natural gas reserve additions have actually replaced annual production since 1994.

A trend of substance has been established since the middle 1980's. Essentially, necessity has become the mother of invention and ingenuity. Survival during a period of low prices induced changed perceptions and strategies, and technology was vigorously applied as a substitute for price in increasing yields and reducing costs. High grading prospects and reduced drilling costs by a rig surplus probably played a role in the current trend. However, the trend in U.S. natural gas supply will most likely continue for three fundamental reasons: (1) increased efficiency of exploration and development, shown by increased reserve additions and discoveries with decreased number of well completions and by increased gas well completion success rates and yield per gas completion; (2) the realization that natural gas reserve growth is much greater than was earlier thought and quite amenable to advanced technology, low-cost recovery, and rapid production response; and (3) steady advances in technology and its applications to unconventional and deep natural gas resources (Fisher, 1993).

Federal Lands Natural Gas Statistics

Federal lands are divided into Federal offshore, Federal onshore, and American Indian. American Indian lands are administered by the Bureau of Land Management (BLM), whereas the Federal offshore and onshore are administered by the Minerals Management Service (MMS). Natural gas production on Federal lands has been increasing in a trend similar to total U.S. production (fig. 8).

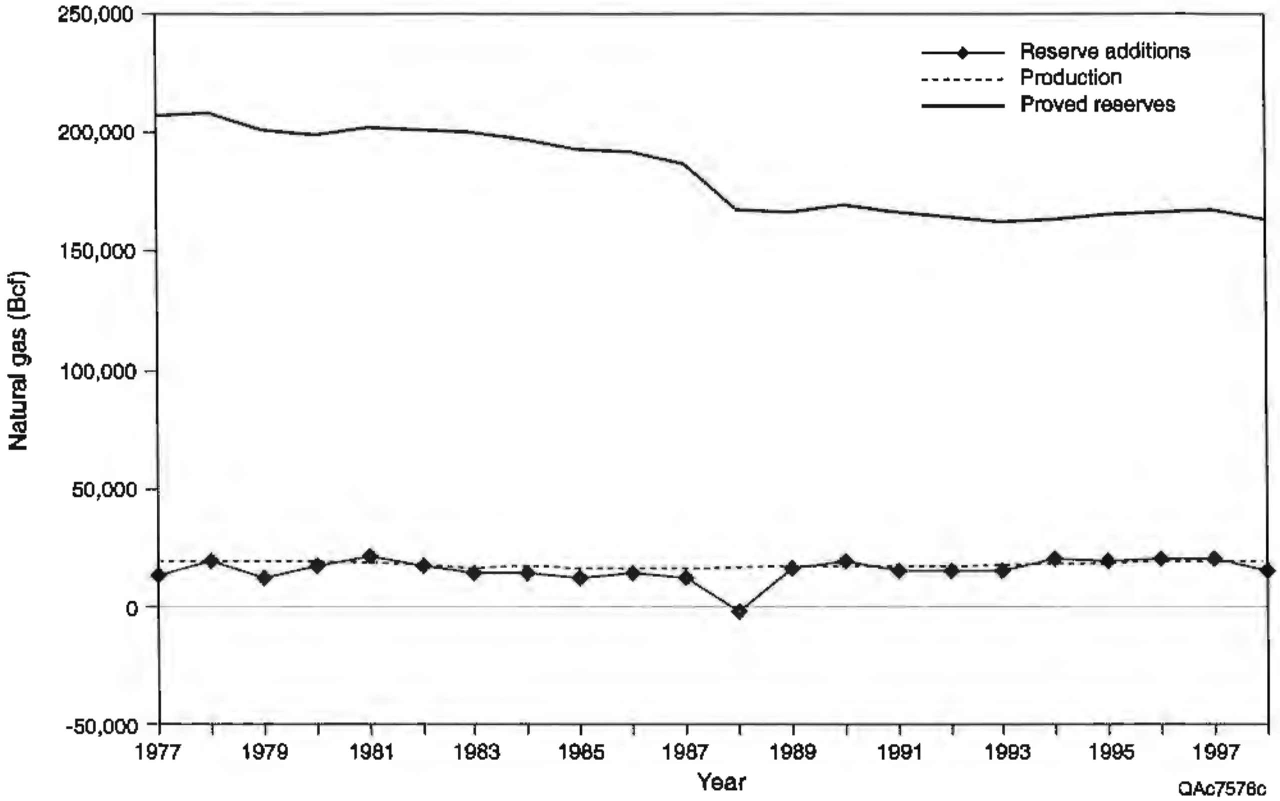

Figure 7. U.S. natural gas proved reserves, production, and reserve additions. Data from Energy Information Administration (1999a).

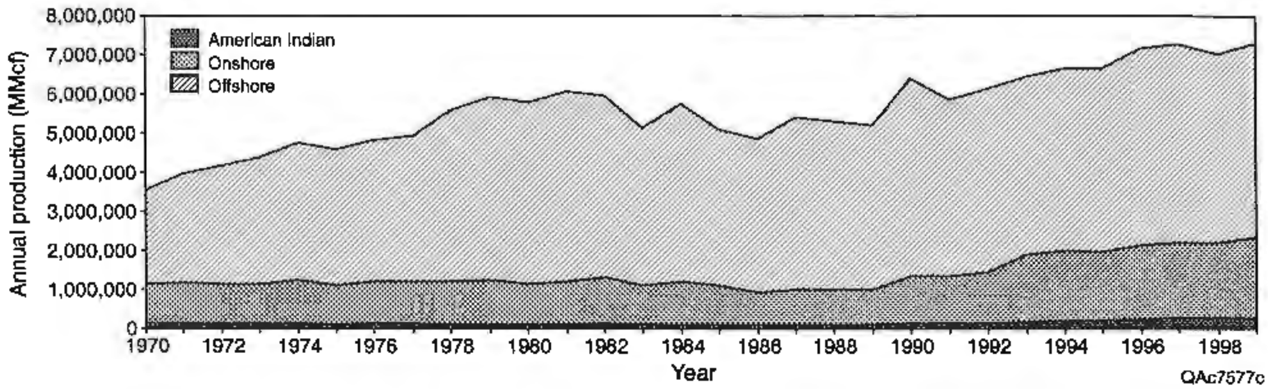

Figure 8. Federal lands natural gas production. Data from Minerals Management Service (2000d).

The total onshore component of the Federal lands comprises approximately 29 percent of total land area of the United States (Bureau of Land Management, 1996). Geographic distribution of the onshore component of Federal lands is very uneven. States with a large percentage of Federal lands include Nevada, Alaska, Utah, Idaho, Oregon, Wyoming, California, and Arizona. For natural gas resources evaluated in the 1995 National Oil and Gas Assessment, the United States Geological Survey (USGS) estimated mean undiscovered technically recoverable conventional natural gas accumulations on Federal lands to be 57.9 Tcf. Most undiscovered, technically recoverable conventional resources on Federal lands are in northern Alaska, the Powder River Basin of Montana and Wyoming, and the Wyoming Thrust Belt. Continuous-type accumulations (those pervasive throughout a large area that is not significantly affected by hydrodynamic influences and for which the standard methodology for assessment of sizes and numbers of discrete accumulations is not appropriate) on Federal lands, largely in southeast Wyoming, account for a mean volume of 127.1 Tcf. Coalbed methane on Federal lands, largely in the Uinta-Piceance Basin of Utah and Colorado and the San Juan Basin of New Mexico, accounts for an additional mean volume of 16 Tcf (U.S. Geological Survey, 1998). Federal lands comprise 22 percent, 41 percent, and 32 percent of U.S. total mean undiscovered technically recoverable conventional natural gas, continuous type, and coalbed methane accumulations on onshore and State waters, respectively (U.S. Geological Survey, 1995, 1998).

For 1998, total U.S. Federal lands natural gas production was approximately 7 Tcf. This constitutes approximately 36 percent of total U.S. natural gas production in 1998. The Federal offshore comprises the bulk of Federal lands natural gas production. The Federal offshore comprises four offshore continental shelf (OCS) provinces managed by MMS: Alaska, Atlantic, Pacific, and Gulf of Mexico (GOM). Undiscovered, conventionally recoverable natural gas in the Federal OCS was estimated at 268 Tcf. Although a large resource base exists in the Alaska OCS (125.9 Tcf), economically recoverable resources are minor because of transportation and access problems. Most Federal OCS production and remaining reserves are from the Gulf of Mexico (Minerals Management Service, 2000b).

FORECAST OF U.S. LOWER-48 AND FEDERAL LANDS NATURAL GAS PRODUCTION

U.S. natural gas production has been forecast by a variety of organizations. A common characteristic of all U.S. natural gas production forecasts is that increased production levels in the near future are perceived to meet increasing consumption levels (figs. 9, 10). The 1999 NPC natural gas study was utilized in this report to forecast future production, Federal royalty revenues, and the effects of technology on maintaining and increasing current production level after it was determined to be the most current and extensive assessment available.

The 1999 NPC natural gas study was conducted at the request of the U.S. Secretary of Energy to reassess its 1992 *Potential for Natural Gas in the United States*, taking into account past experience and evolving market conditions that will affect the potential for natural gas in the U.S. to 2015 and beyond. The growing importance of natural gas in the U.S. energy mix was assessed. Natural gas demand, contributing one-quarter of U.S. energy demand, was forecast to increase in the future as a result of economic growth and growing environmental concerns. Demand has exceeded the 1992 NPC study high-case projections. Demand growth was forecast by the 1999 NPC study to increase to 29 Tcf by 2010 and to increase beyond 31 Tcf by 2015. In particular, almost 50 percent of demand growth for natural gas in electricity generation was forecast. Because natural gas demand was 22 Tcf in 1998, an additional 7 and 9 Tcf would be required by 2010 and 2015, respectively.

U.S. Lower-48 natural gas resources were estimated at 1,466 Tcf by the 1999 NPC study (table 1). This represents a 23 percent increase from the 1992 NPC study estimate of 1,295 Tcf if the 124 Tcf of production that occurred in between the two study years is accounted for. U.S. Lower-48 natural gas production forecasts conducted by the 1999 NPC study reflect production increases from 19 Tcf in 1998 to 25 Tcf in 2010 and 26 Tcf in 2015. The remaining supply needed was contributed by Alaska and imports, mainly from Canada. In addition to the reference case projection, several cases were assessed on the basis of high and low economic development, high and low oil prices, faster and slower technology advancements, larger and smaller resource bases, and increased and reduced access (fig. 11).

Highest growth in U.S. Lower-48 natural gas production by areas was forecast to be from the GOM and the Rocky Mountain region. The two areas combined to comprise approximately 50 percent of the remaining natural gas resources in the U.S. Lower-48. Major production growth by reservoir type was assessed to be from deeper water production from the GOM, onshore production from unconventional resources, and onshore production from deep conventional formations.

Natural gas production forecasts on U.S. Federal lands can be divided into offshore and onshore production (table 2). U.S. offshore natural gas production was forecast separately by the 1999 NPC study. State offshore comprises a very small amount

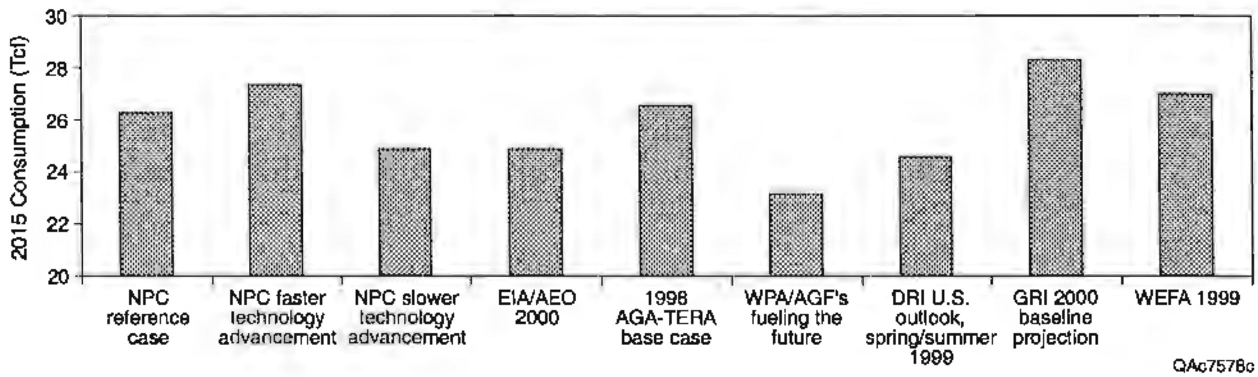

Figure 9. U.S. natural gas consumption in the year 2015. Data from National Petroleum Council (1999c).

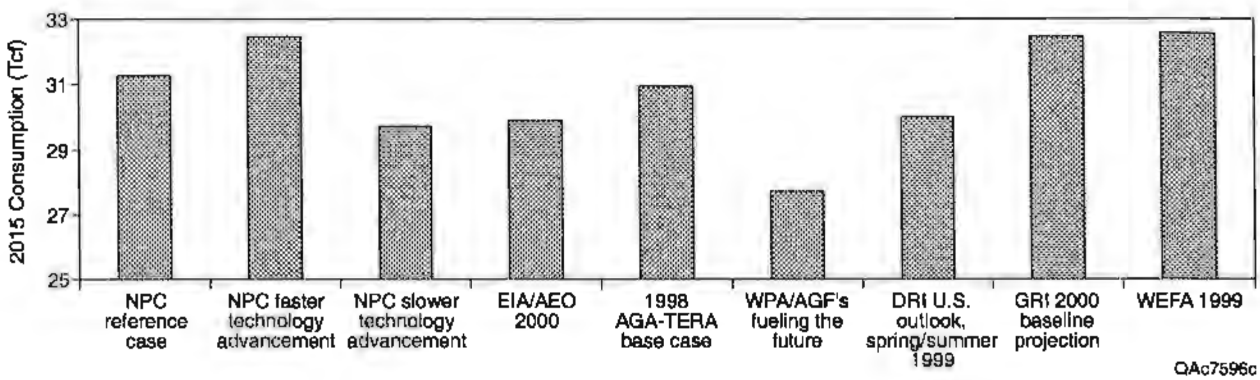

Figure 10. U.S. natural gas production in the year 2015. Data from National Petroleum Council (1999c).

Table 1. U.S. and Canadian Natural Gas Resources (Tcf)

	1992 NPC Study (1-1-91)	1999 NPC Study (1-1-98)
Lower-48 Resources		
Proved Reserves	160	157
Assessed Additional Resources	1,135	1,309
Oil Fields (Reserve Appreciation)	236	305
New Fields	493	633
Unconventional	406	371
Total Remaining Resources (Proved + Assessed Additional)	**1,295**	**1,466**
Cumulative Production	758	881
Total All-Time Recovery	2,053	2,347
Alaskan Resources		
Proved Reserves	9	10
Assessed Additional Resources	171	303
Oil Fields (Reserve Appreciation)	30	32
New Fields	84	214
Unconventional	57	57
Total Remaining Resources (Proved + Assessed Additional)	**180**	**313**
Cumulative Production	5	9
Total All-Time Recovery	185	322
Canadian Resources		
Proved Reserves	72	64
Assessed Additional Resources	668	603
Oil Fields (Reserve Appreciation)	24	22
Discovered Undeveloped	47	35
New Fields	379	384
Unconventional	218	162
Total Remaining Resources (Proved + Assessed Additional)	**740**	**667**
Cumulative Production	65	103
Total All-Time Recovery	805	770

(Data from National Petroleum Council, 1999b)

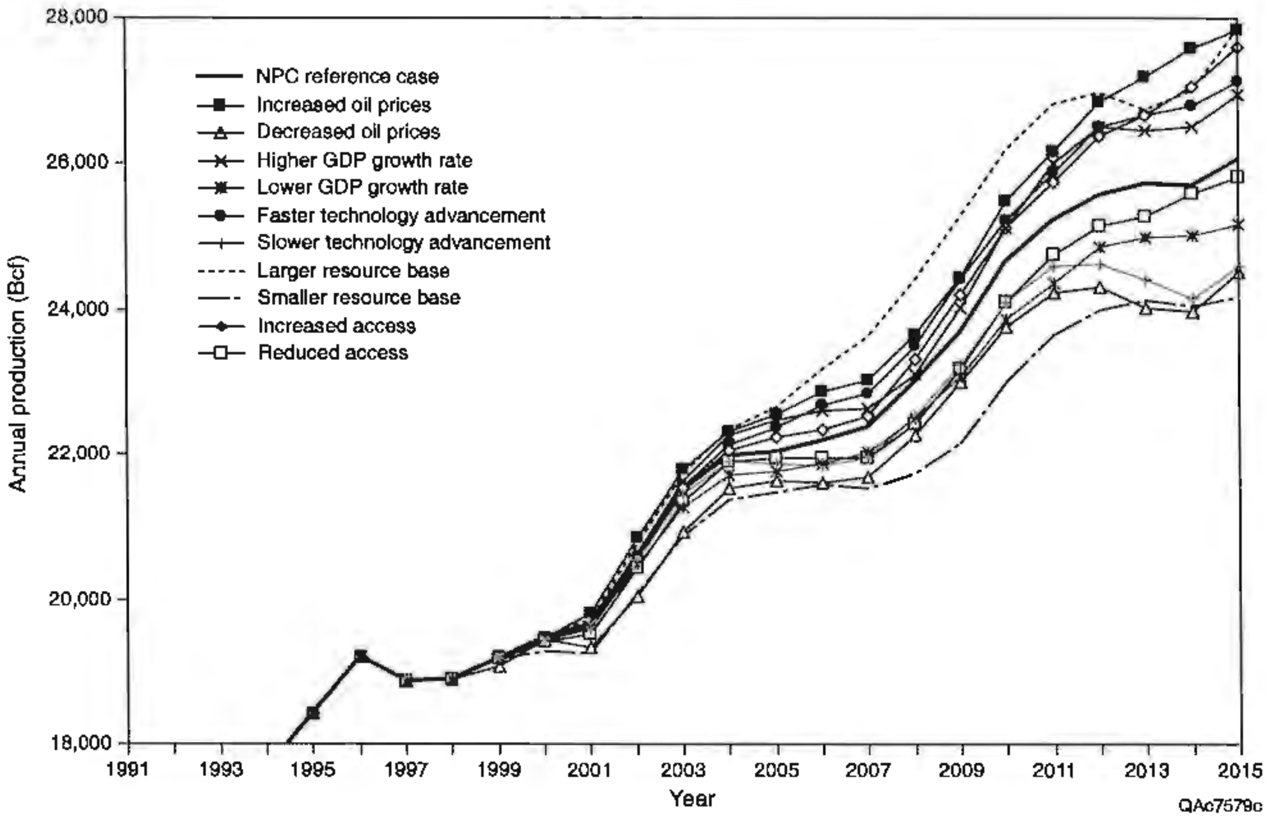

Figure 11. 1999 NPC study's Lower-48 natural gas production forecast. Data from National Petroleum Council (1999c).

Table 2. Historical Natural Gas Production on Federal Lands (Bcf)

Year	Offshore	Onshore	American Indian	Total
1970	2,419	1,002	137	3,557
1971	2,777	1,045	130	3,953
1972	3,039	999	128	4,166
1973	3,212	1,031	124	4,366
1974	3,515	1,111	125	4,751
1975	3,459	1,003	110	4,571
1976	3,596	1,092	127	4,815
1977	3,738	1,077	123	4,937
1978	4,385	1,106	112	5,603
1979	4,673	1,134	118	5,926
1980	4,641	1,031	115	5,788
1981	4,850	1,083	119	6,052
1982	4,680	1,161	133	5,974
1983	4,041	971	116	5,128
1984	4,538	1,113	100	5,751
1985	4,001	993	103	5,097
1986	3,949	822	98	4,868
1987	4,426	888	108	5,421
1988	4,310	902	103	5,315
1989	4,200	897	114	5,211
1990	5,093	1,201	127	6,421
1991	4,516	1,214	132	5,862
1992	4,686	1,289	150	6,124
1993	4,533	1,709	189	6,432
1994	4,657	1,789	209	6,655
1995	4,692	1,738	218	6,649
1996	5,024	1,900	248	7,173
1997	5,077	1,941	269	7,287
1998	4,835	1,920	282	7,037
1999	4,994	2,043	289	7,327

(Data from Minerals Management Service, 2000d) of the U.S. offshore natural gas production forecast by the 1999 NPC study. U.S. offshore production, dominantly from the GOM, was forecast in its reference case to grow from 5.3 Tcf in 1998 to 7.7 Tcf in 2015. Particularly noteworthy is that gradual decline is forecast for shallow shelf production (0 to 200 m), whereas deep-water production (>200 m) is forecast to show rapid increases. For example, deep-water production in the GOM is forecast to increase from less than 0.8 Tcf to more than 4.3 Tcf in 2015 (National Petroleum Council, 1999b).

Increased offshore natural gas production, particularly from deep-water, was forecast also by recent assessments by several organizations including the Energy Information Administration (1999b) and the Minerals Management Service (2000b). EIA's forecast of increased offshore natural gas production, 6.39 Tcf, is conservative compared with that of the 1999 NPC study. MMS reported a variety of forecasts to year 2020 for the GOM OCS region on the basis of different methodologies: 4.3 Tcf (base case) and 5.5 Tcf (aggressive case) utilizing development projection; 7.2 Tcf utilizing statistical trend extrapolation; and 6.6 Tcf (most likely low case) and 6.9 Tcf (most likely high case) utilizing econometric forecasting. Interestingly, utilizing development projection methodology, MMS forecast a decline of offshore natural gas production beginning in 2006.

U.S. onshore natural gas production was forecast by the 1999 NPC study according to conventional and unconventional reservoir formations (fig. 12). Particularly noteworthy growth is forecast for onshore unconventional reservoirs. Onshore production from unconventional formations is projected to increase from 4.4 Tcf to 8.5 Tcf, with most such production coming from tight, low-permeability reservoirs (National Petroleum Council, 1999a). This total represents an approximate doubling of current onshore unconventional production. Other organizations, such as EIA, also reported increased production from unconventional formations.

For the Federal offshore, onshore, and American Indian lands, it is assumed that natural gas production will mirror U.S. natural gas trends forecast in the 1999 NPC study results (table 3). The annual percentage increases/decreases for U.S. natural gas production onshore and offshore are assumed to hold true also for natural gas production on Federal lands. This assumption was used by MMS to calculate future Federal lands natural gas production and projections of Federal onshore revenues (Minerals Management Service, 2000a). The annual percentage increases/decreases forecast by the 1999 NPC study for the onshore component of U.S. Lower-48 natural gas production can be applied to historical Federal onshore and American Indian lands natural gas production to obtain a future production forecast. Likewise, the U.S. Lower-48 natural

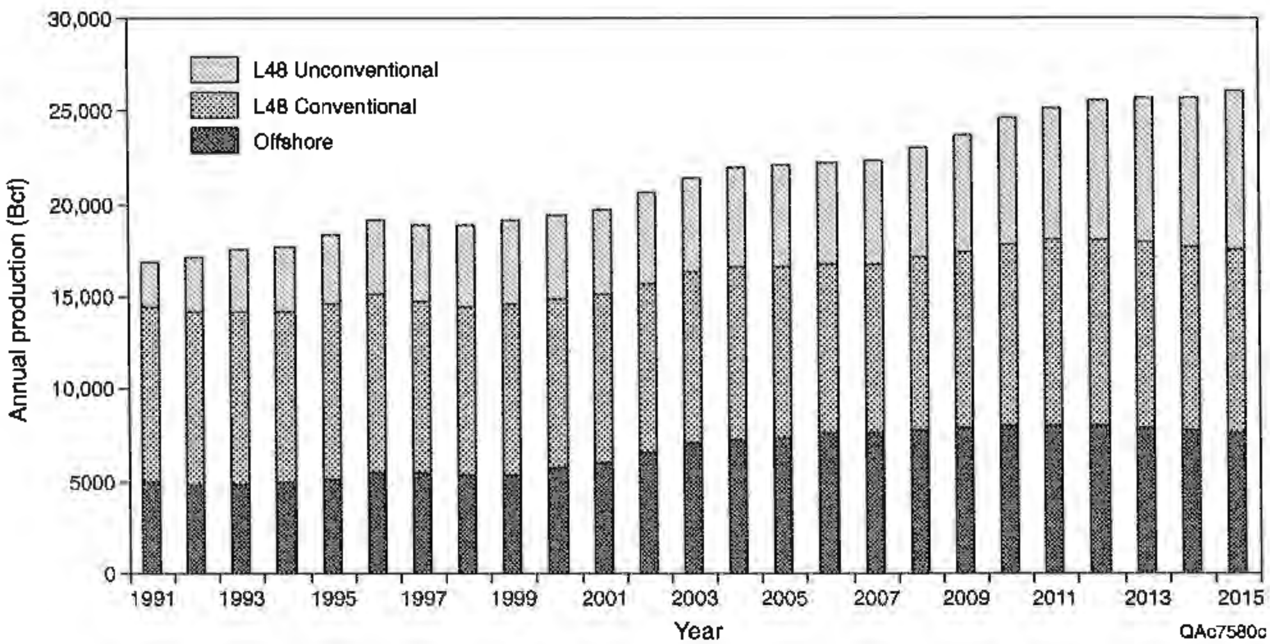

Figure 12. 1999 NPC study's reference case natural gas production forecast. Data from National Petroleum Council (1999c).

Table 3. U.S. Natural Gas Production Forecast Annual Percentage Increase/Decrease for 1999 NPC Study's Reference Case (Bcf)

Year	Offshore Total	Onshore			L48 Total
		Conventional	Unconventional	Onshore Total	
1991	4,981	9,472	2,450	11,922	16,903
1992	4,851	9,380	2,885	12,265	17,116
1993	4,783	9,393	3,320	12,713	17,496
1994	4,916	9,219	3,521	12,740	17,656
1995	5,153	9,428	3,832	13,260	18,413
1996	5,448	9,656	4,113	13,769	19,217
1997	5,441	9,231	4,202	13,433	18,874
1998	5,317	9,183	4,396	13,579	18,896
1999	5,395	9,219	4,558	13,777	19,172
2000	5,720	9,175	4,570	13,745	19,465
2001	6,083	8,999	4,554	13,553	19,636
2002	6,599	9,103	4,883	13,986	20,585
2003	7,044	9,242	5,208	14,450	21,494
2004	7,263	9,322	5,402	14,724	21,987
2005	7,398	9,216	5,425	14,641	22,039
2006	7,665	9,078	5,436	14,514	22,179
2007	7,697	9,081	5,588	14,669	22,366
2008	7,801	9,297	5,915	15,212	23,013
2009	7,859	9,523	6,304	15,827	23,686
2010	8,047	9,808	6,785	16,593	24,640
2011	8,046	9,993	7,189	17,182	25,228
2012	8,032	10,042	7,487	17,529	25,561
2013	7,934	10,009	7,775	17,784	25,718
2014	7,804	9,936	7,962	17,898	25,702
2015	7,671	9,920	8,481	18,401	26,072

Year	Annual Percentage Change	
	Offshore	Onshore
1991		
1992	-2.61%	2.88%
1993	-1.40%	3.65%
1994	2.78%	0.21%
1995	4.82%	4.08%
1996	5.72%	3.84%
1997	-0.13%	-2.44%
1998	-2.28%	1.09%
1999	1.47%	1.46%
2000	6.02%	-0.23%
2001	6.35%	-1.40%
2002	8.48%	3.19%
2003	6.74%	3.32%
2004	3.11%	1.90%
2005	1.86%	-0.56%
2006	3.61%	-0.87%
2007	0.42%	1.07%
2008	1.35%	3.70%
2009	0.74%	4.04%
2010	2.39%	4.84%
2011	-0.01%	3.55%
2012	-0.17%	2.02%
2013	-1.22%	1.45%
2014	-1.64%	0.64%
2015	-1.70%	2.81%

(Data from National Petroleum Council, 1999c) gas offshore component's percentage increase/decrease of future natural gas production can be applied to historical Federal offshore natural gas production. For each year, the percentage increase/decrease is multiplied to the current year's production to forecast the following year's production. Combining these results, U.S. Federal lands future natural gas production forecasts can be approximated (table 4).

FORECAST OF ROYALTY REVENUE FROM NATURAL GAS PRODUCTION ON FEDERAL LANDS

Future royalty revenues from natural gas production on U.S. Federal lands can be calculated by multiplying annual natural gas production, price, and royalty rates. Annual natural gas production forecasts for the Federal offshore, onshore, and American Indian lands were discussed in the previous section. Royalty rates are estimated through data provided by MMS, whereas natural gas prices are forecast through the use of a high-, base-, and low-price-scenario approach.

For 1999, total oil and natural gas royalty revenues from U.S. Federal lands totaled approximately $3.3 billion (fig. 13). Federal offshore lands comprised the majority of royalty revenue for both oil and natural gas (figs. 14, 15). In addition to oil and natural gas royalty revenues, mineral resource royalty revenue, lease rents, and bonuses compose the total Federal lands revenue. For the Federal offshore, onshore, and American Indian lands, MMS reported historical oil and natural gas sales volume, sales value, and royalty revenue. Annual average oil and natural gas royalty rates can be calculated by dividing the royalty revenue by the sales value. A 3-yr average royalty rate from 1997, 1998, and 1999 was utilized as the royalty rate for the projection period because it was assumed to be the most recent level of royalty rates and no programs or actions that should materially change this figure could be foreseen. Calculated 3-yr-average natural gas royalty rates for the Federal offshore, onshore, and American Indian lands were 15.72, 11.52, and 14.43 percent, respectively (table 5).

Although natural gas price forecasts have been made by a variety of organizations, it is difficult to utilize them because of the recent marked increases in natural gas wellhead prices that were unforeseen. At the time of the current analysis, spot natural gas wellhead prices were averaging more than $4.00 per thousand cubic feet (Mcf), nearly double the price at the beginning of the year 2000. Although rising crude-oil prices have encouraged natural gas prices to rise, by far the major determinant for these robust natural gas prices is the fragile natural gas supply situation. Simply put, the injection rate for natural gas into storage has been too slow to comfort the market for next

Table 4. Natural Gas Production Forecast for Federal Lands (Bcf)

Year	Offshore	Onshore	American Indian	Total
1999	4,994	2,043	289	7,327
2000	5,295	2,038	288	7,622
2001	5,631	2,010	284	7,925
2002	6,109	2,074	294	8,476
2003	6,521	2,143	303	8,967
2004	6,724	2,184	309	9,216
2005	6,848	2,171	307	9,327
2006	7,096	2,152	305	9,553
2007	7,125	2,175	308	9,609
2008	7,222	2,256	319	9,797
2009	7,275	2,347	332	9,955
2010	7,449	2,461	348	10,258
2011	7,448	2,548	361	10,357
2012	7,435	2,599	368	10,403
2013	7,345	2,637	373	10,355
2014	7,224	2,654	376	10,254
2015	7,101	2,729	386	10,216

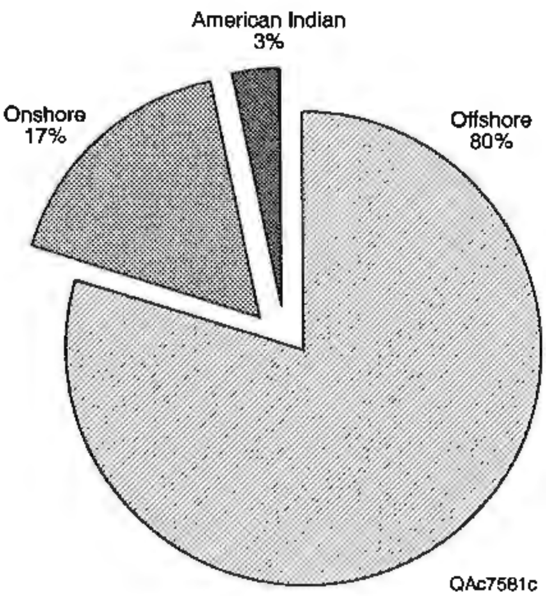

Figure 13. 1999 U.S. Federal lands total oil and natural gas royalty revenue ($3,277,647,852). Data from Minerals Management Service (2000d)

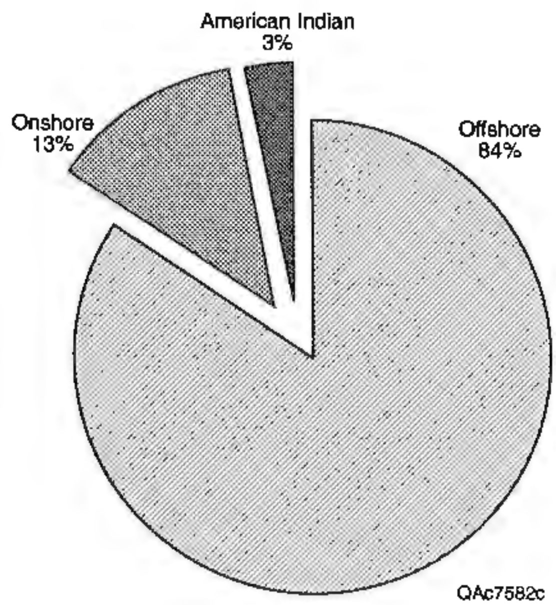

Figure 14. 1999 U.S. Federal lands oil royalty revenue ($1,094,334,830). Data from Minerals Management Service (2000d).

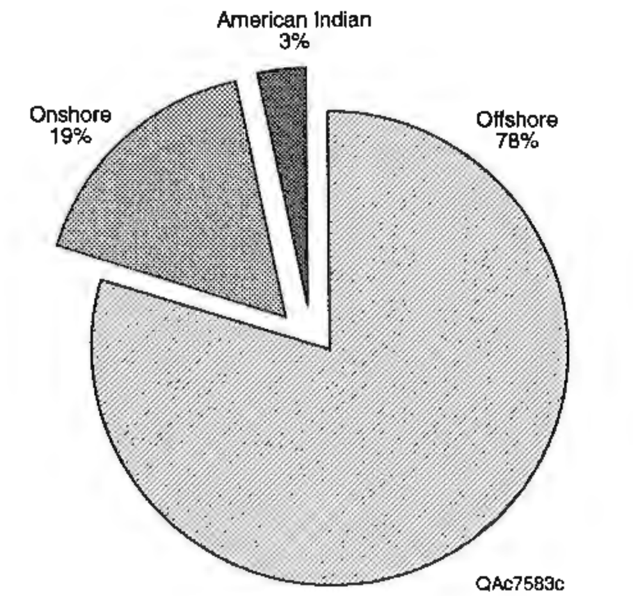

Figure 15. 1999 U.S. Federal lands natural gas royalty revenue ($2,183,313,022). Data from Minerals Management Service (2000d).

Table 5. Federal Lands Royalty Rates

	Offshore	Onshore	American Indian
3-year average	15.72%	11.52%	14.43%
5-year average	15.74%	11.49%	14.17%
10-year average	15.95%	11.72%	14.03%
Historical year average	15.85%	12.15%	13.64%

(Data from Minerals Management Service, 2000d) winter's heating season. Underground storage levels are currently about 20 percent below last year's levels. At present rates of injection, the availability of natural gas for next winter is uncertain, as reflected in the volatility and levels of current prices. Another factor contributing to this rapid price jump has been the recent hot weather in parts of the country that consume large amounts of natural gas-generated electricity. Natural gas that would otherwise be injected into storage is now being used (indirectly through electric utilities) for cooling. In addition, there has been a growing demand for natural gas, resulting from the expanding economy over the last 7 to 8 yr and the increasing role of natural gas generation at power facilities.

In the latest short-term energy forecasts by EIA, the wellhead natural gas price is projected to average more than $3.00/Mcf for 2000 and 2001. Because of the current volatile nature of natural gas prices, high-, base-, and low-price cases are utilized to forecast prices to 2015. High-, base-, and low-price cases are set at $4, $3, and $2/Mcf, respectively. For each case, prices are escalated by 1 percent/yr (table 6). The base price case falls in general agreement with the NPC reference case that utilized a natural gas price of $3.23/MMBtu in 2000 and rose to $3.81/MMBtu by 2015 (National Petroleum Council, 1999c).

Future natural gas production on the Federal offshore, onshore, and American Indian lands is forecast in figure 16. Forecast natural gas revenue and royalty revenue on Federal lands in 2015 are shown for the base-price case in figure 17 and table 7. Total natural gas royalty revenues on Federal lands are forecast to increase from $3.3 billion in 2000 to $5.2 billion in 2015 (fig. 18). As expected, most of the natural gas royalty revenues are from the Federal OCS.

VALUE OF TECHNOLOGY ADVANCEMENTS IN INCREASING THE NATURAL GAS RESOURCE BASE

Assessments of the current U.S. natural gas resource base have increased consistently over time. These have resulted primarily from the emergence of new plays and technological advancements. For example, the deep-water GOM play was not included or was greatly underestimated in various resource assessments as recently as 10 yr ago. Coalbed methane is an example of a resource that was known by industry but was not included in resource assessments because technology was inadequate and industry had not gained sufficient experience for economic production. It is through R&D in supply technology that deep-water and unconventional resources have emerged as important contributors to the future U.S. natural gas supply.

Table 6. Forecast Natural Gas Price Cases

Year	Low $/Mcf	Base $/Mcf	High $/Mcf
2000	2.00	3.00	4.00
2001	2.02	3.03	4.04
2002	2.04	3.06	4.08
2003	2.06	3.09	4.12
2004	2.08	3.12	4.16
2005	2.10	3.15	4.20
2006	2.12	3.18	4.25
2007	2.14	3.22	4.29
2008	2.17	3.25	4.33
2009	2.19	3.28	4.37
2010	2.21	3.31	4.42
2011	2.23	3.35	4.46
2012	2.25	3.38	4.51
2013	2.28	3.41	4.55
2014	2.30	3.45	4.60
2015	2.32	3.48	4.64

Escalation
1% /year

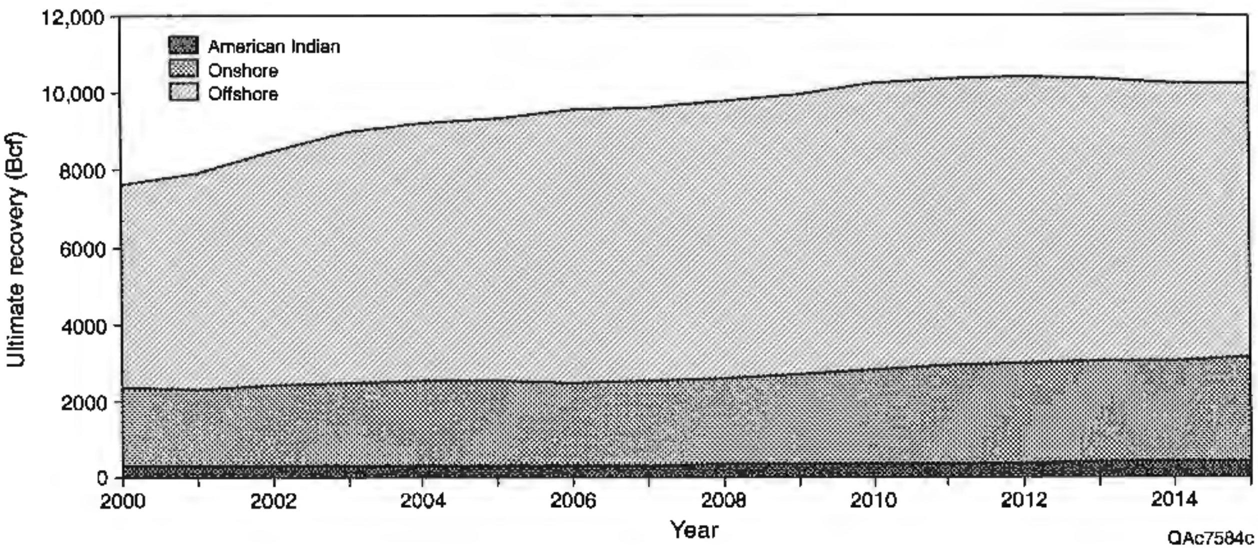

Figure 16. Federal lands natural gas production forecast.

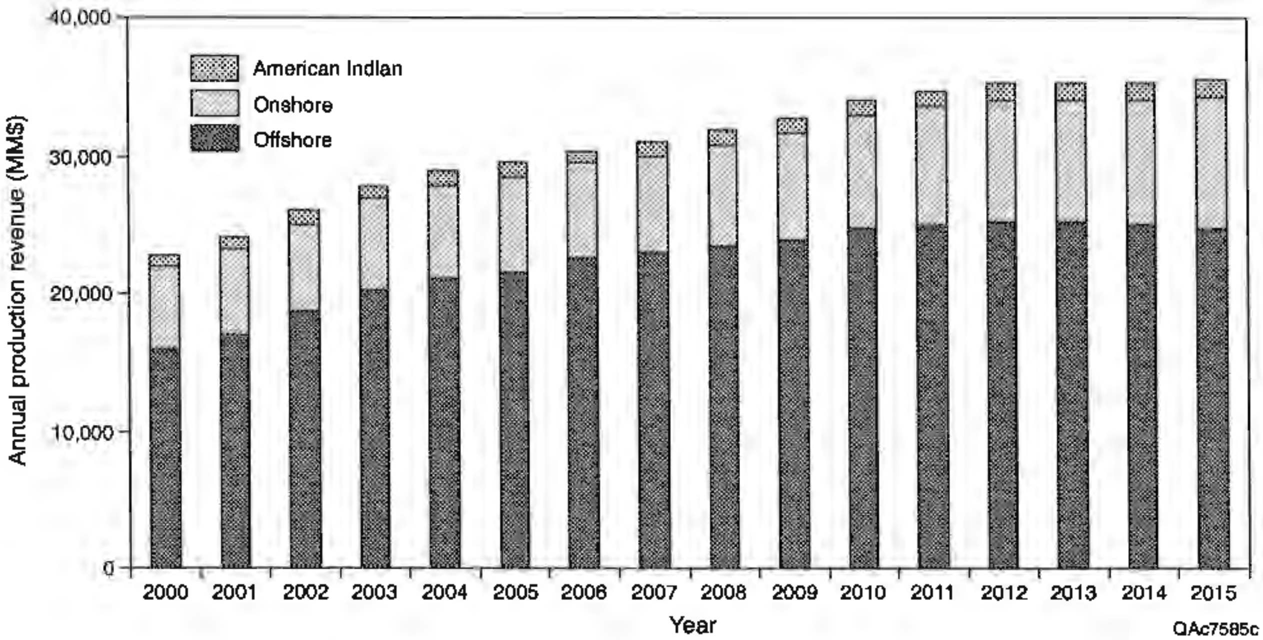

Figure 17. Federal lands natural gas production revenue.

Table 7. Forecast Federal Lands Royalty Revenue

Year	Federal Lands Natural Gas Production				Gas	Total Revenue				Royalty Rate			Royalty Revenue			
	Offshore (Bcf)	Onshore (Bcf)	Indian (Bcf)	Total (Bcf)	Price ($/Mcf)	Offshore (MM$)	Onshore (MM$)	Indian (MM$)	Total (MM$)	Offshore	Onshore	Indian	Offshore (MM$)	Onshore (MM$)	Indian (MM$)	Total (MM$)
2000	5,295	2,038	288	7,622	3.00	15,885	6,115	865	22,866	15.72%	11.52%	14.43%	2,497	704	125	3,327
2001	5,631	2,010	284	7,925	3.03	17,062	6,090	862	24,014	15.72%	11.52%	14.43%	2,682	702	124	3,508
2002	6,109	2,074	294	8,476	3.06	18,695	6,347	898	25,940	15.72%	11.52%	14.43%	2,939	731	130	3,800
2003	6,521	2,143	303	8,967	3.09	20,155	6,623	937	27,716	15.72%	11.52%	14.43%	3,168	763	135	4,067
2004	6,724	2,184	309	9,216	3.12	20,990	6,817	965	28,771	15.72%	11.52%	14.43%	3,300	785	139	4,224
2005	6,848	2,171	307	9,327	3.15	21,594	6,846	969	29,408	15.72%	11.52%	14.43%	3,395	789	140	4,323
2006	7,096	2,152	305	9,553	3.18	22,597	6,654	970	30,421	15.72%	11.52%	14.43%	3,552	790	140	4,482
2007	7,125	2,175	308	9,609	3.22	22,918	6,997	990	30,905	15.72%	11.52%	14.43%	3,603	806	143	4,552
2008	7,222	2,256	319	9,797	3.25	23,460	7,328	1,037	31,825	15.72%	11.52%	14.43%	3,688	844	150	4,682
2009	7,275	2,347	332	9,955	3.28	23,871	7,701	1,090	32,661	15.72%	11.52%	14.43%	3,752	887	157	4,797
2010	7,449	2,461	348	10,258	3.31	24,686	8,154	1,154	33,994	15.72%	11.52%	14.43%	3,881	939	167	4,987
2011	7,448	2,548	361	10,357	3.35	24,930	8,528	1,207	34,665	15.72%	11.52%	14.43%	3,919	982	174	5,078
2012	7,435	2,599	368	10,403	3.38	25,135	8,787	1,244	35,166	15.72%	11.52%	14.43%	3,951	1,012	179	5,143
2013	7,345	2,637	373	10,355	3.41	25,077	9,004	1,274	35,356	15.72%	11.52%	14.43%	3,942	1,037	184	5,163
2014	7,224	2,654	376	10,254	3.45	24,913	9,153	1,295	35,361	15.72%	11.52%	14.43%	3,916	1,054	187	5,158
2015	7,101	2,729	386	10,216	3.48	24,733	9,504	1,345	35,582	15.72%	11.52%	14.43%	3,888	1,095	194	5,177
Total	109,849	37,179	5,262	152,290		356,699	120,850	17,104	494,652				56,073	13,922	2,468	72,463

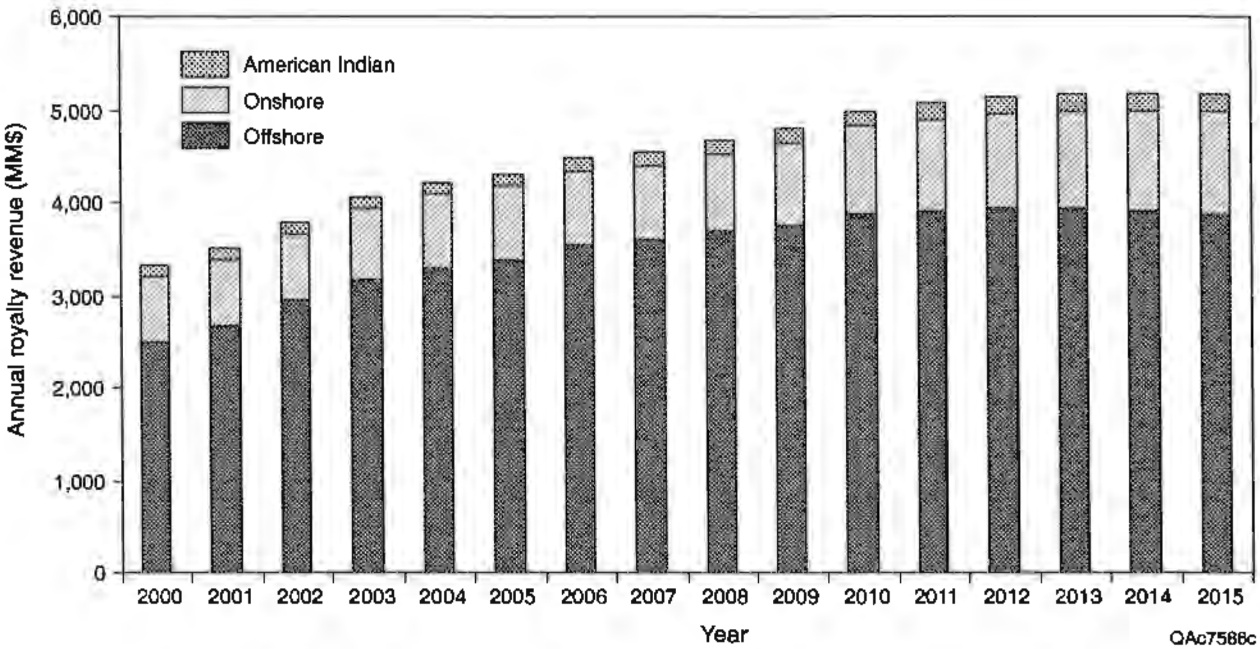

Figure 18. Federal lands natural gas royalty revenue.

Natural Gas Resource Pyramid

The concept of a resource pyramid (National Petroleum Council, 1999b; Kuuskraa, 1998) reflects the effect of technology on increasing the natural gas resource base (fig. 19). The apex of the pyramid is represented by ultimate recovery, the sum of cumulative production and proven reserves. Ultimate recovery consists largely of production from more mature, high-permeability conventional accumulations. Reserve growth in existing fields, undiscovered conventional fields, and unconventional sources occupy successively lower positions on the pyramid. In general, as one moves down the pyramid, the resource is characterized by decreasing concentration or quality, increasing developmental costs, increasing uncertainty in estimates of recoverable volumes, and increasing technological requirements. The natural gas resources within the pyramid are dynamic, able to improve in their quality ranking with the aid of new technology. Moreover, the size or resource types of the natural gas resource pyramid are not yet fully understood (Kuuskraa, 1998). The importance of the resource pyramid is an assurance that an increasing amount of gas in place is available with higher natural gas prices, reduced development costs, and/or technological advancements.

Although the resource size of geopressured brine and gas hydrates is enormous, the part of the resource pyramid that will probably serve as the major source of U.S. natural gas supply in the near future is the unassessed portions of unconventional resources, such as tight gas, coalbed methane, and gas shales. Large quantities of coal production in the U.S. have not been assessed for their coalbed methane potential. In addition, coalbed methane potential in deeper parts of the assessed basins, such as in the Piceance Basin of northwestern Colorado, has not been assessed. Perhaps the greatest potential is associated with tight gas resources. Tremendous potential exists in the Rocky Mountain Foreland Province, along with the Midcontinent and Gulf Coast. Several thousand trillion cubic feet of potential natural gas resources has been assessed by the USGS in the Green River Basin of southwest Wyoming alone. Industry has been developing technology to produce this natural gas economically, and much progress has been made over the past decade. The drilling of horizontal wells perpendicular to natural fracture sets appears to hold great promise, especially in the blanket sands, such as the Frontier Formation in the Green River Basin. Continued technological advancements are critical for this part of the resource pyramid to be exploited in the near future.

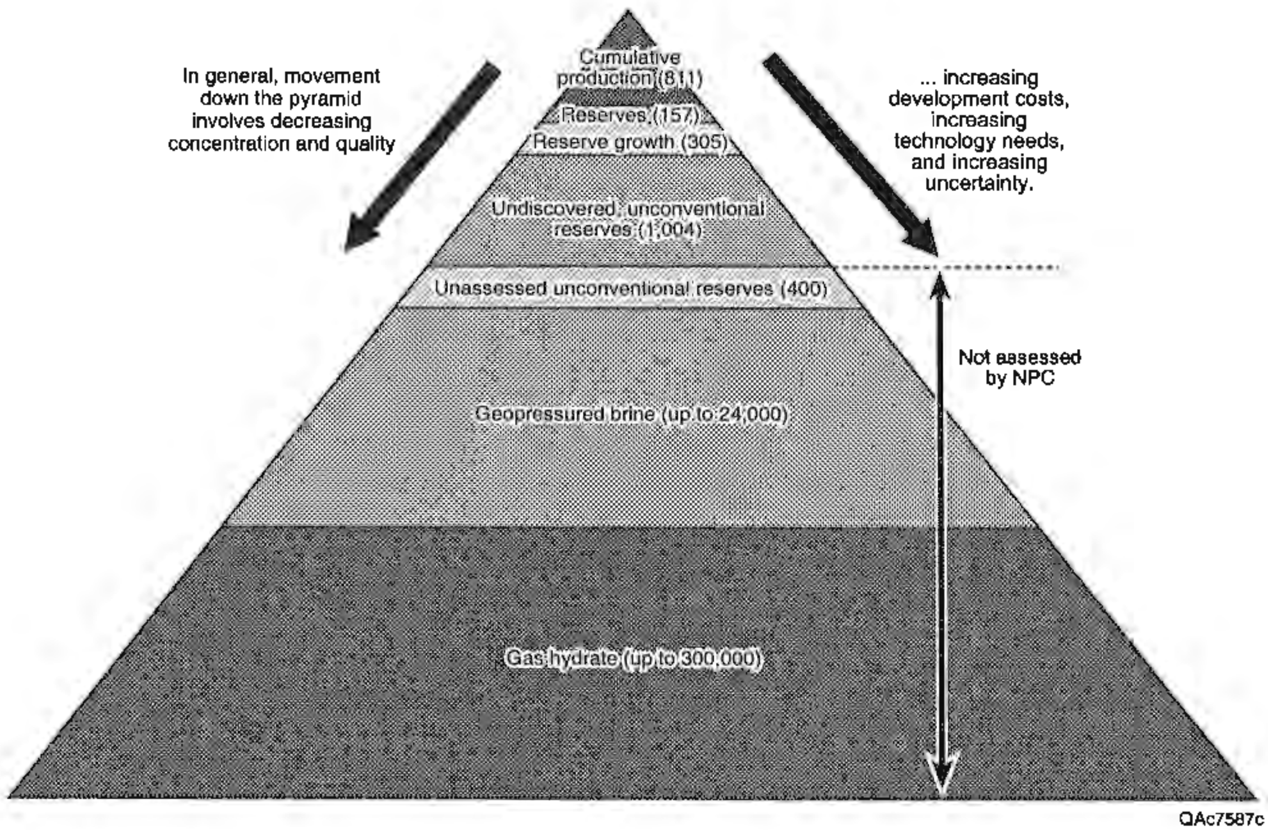

Figure 19. U.S. Lower-48 natural gas resource pyramid—1999 NPC study (National Petroleum Council, 1999b); recoverable portion of in-place gas resource (Tcf).

Role of Technological Advancements in Increasing the Natural Gas Supply

The increases in the natural gas resource base calculated by the 1999 NPC study are the result of remarkable progress in technological advancements. For example, three-dimensional (3-D) seismic imaging techniques now allow geologists to image underground rock formations in graphic detail and to reduce drilling risk by more accurately predicting locations for natural gas accumulations. Improved drilling techniques enable producers to drill targets and reach otherwise difficult formations more accurately through the use of directional/horizontal drilling. Advancements in stimulation, fracturing, and completion techniques have shown tremendous production increases in unconventional natural gas resources such as in tight gas, coalbed methane, and gas shales. Moreover, deep-water production technologies now enable producers to access natural gas supply in 5,000 to 10,000 ft of ocean waters. These examples of technological advancements have resulted in significant natural gas reserve additions and prospects for production in areas that were once considered physically or economically unreachable (National Petroleum Council, 1999b)

Even though the estimated natural gas resource base is adequate to last many decades, technological challenges and the degree of difficulty in reaching, evaluating, and producing the resource base continue to escalate. Technological improvements are particularly important, given the more difficult conditions accompanying new resources. One of the major findings of the Supply Task Group of the 1999 NPC study was that "investment in research and development is needed to maintain the pace of advancements in technology." Technological advancements play a major role in the increase of natural gas supply by

(1) improving efficiency of drilling, equipment, operating, and other costs;

(2) increasing recovery factors of discovered natural gas in place;

(3) improving success rates by reducing the number of dry holes; and

(4) revealing new areas and types of resources for exploitation through innovative geologic and engineering concepts.

Advances in technology do not happen in a vacuum. Continued and increased funding of natural gas supply technology R&D is required for the U.S. natural gas resource base to meet anticipated demand. With continued emphasis and investment, new technologies that could have a significant impact on future U.S. natural gas production include improved seismic techniques, deep wireline measurements, integrated well planning, improved drilling systems, improved stimulation techniques, advances in deep-water drilling technology, and formulation of new geologic frontiers. Should technological advancements materialize at a slower rate, or should these technologies prove less valuable than expected, the availability of future supply and cost at which they are delivered would be negatively impacted. Therefore, a major recommendation of the 1999 NPC study was to "drive research and technology at a rapid rate." Particular attention was paid to long-term technology needs for deep-water and unconventional resources that were forecast to contribute a large proportion of U.S. natural gas supply in the future.

Technological impacts were assumed by the 1999 NPC study to be through new-field exploration efficiency, platform cost reduction, drilling and completion cost reduction, and improvements in estimated ultimate recovery per well. Faster and slower technological advancement cases were analyzed by reducing and increasing the percentage effects of these variables. These variables represent what can be expected in technological advances on the basis of recent levels of R&D funding and the general effectiveness of those efforts. The faster technological advancement case assumes either a higher level of funding or a greater than expected number of significant technological breakthroughs. The slower technological advancement case considers a decline in R&D funding with a resultant halving of each technological variable. The faster technological advancement case yields an increase in natural gas production in 2015 of 1 Tcf, whereas the slower technological advancement case yields a decrease of 1.5 Tcf. Slower technological advancements were also shown, as expected, to increase natural gas prices, whereas the opposite effect was shown for faster technological advancements. These results reveal that supply technology R&D is imperative in increasing natural gas production while maintaining reasonable price levels.

This approach is adequate to examine the overall role of technology, but it does not adequately analyze independent technological effects on the separate components of natural gas production. In other words, all components of production are interrelated, causing some misleading deductions. For example, faster technological advancements incorrectly produce lower production forecasts from unconventional resources, when in reality, if technology is applied to all components equally, the unconventional resources will be a relatively higher priced production component. An alternative methodology must be developed to examine the role of technology in increasing production components independently of other factors.

Quantifying Technological Advancements in Terms of Incremental Production

Statistically based resource assessments, mainly through the highly publicized work of M. King Hubbert (1962, 1967, 1974), view U.S. natural gas as a rapidly depleting resource. Consequent expectations of high natural gas prices and restrictions on natural gas use were reflected in the 1980's. Hubbert predicted the peak of U.S. natural gas production to occur in the late 1970's, with ultimate production between 900 and 1,200 Tcf (Hubbert, 1967). In an updated analysis (Hubbert, 1974), Hubbert predicted the peak of U.S. natural gas production in 1977 at about 23 Tcf/yr, followed by a dramatic decline. It is interesting to note that Hubbert forecast that annual U.S. natural gas production would be approximately 9 Tcf by 1998.

What went wrong with Hubbert's analysis? Looking back, we now know that Hubbert's analysis was hindered by the critical assumption that the natural gas resource base was fixed in terms of the knowledge and technology of the 1970's. Improved geologic knowledge and advances in exploration technology continue to help us find new natural gas plays not yet included in the assessed resource base. New production technology will improve natural gas recovery from existing fields and plays. More efficient drilling and completions will turn formerly uneconomic resources into affordable investments. Natural gas supply R&D will convert previously overlooked natural gas resources into producing supplies. These are just some of the ways technological advancements continue to expand the natural gas resource base, enabling development of new gas resources as we continue to move down the resource pyramid from higher to lower quality resources (fig. 20).

Today the bulk of U.S. natural gas supplies comes from three resource areas not considered by Hubbert: deep-water GOM, unconventional resources, and reserve growth. Hubbert's analysis would be correct if we omitted the effect of natural gas production growth from offshore deep-water/subsalt and unconventional resources (fig. 21). If these two components of U.S. natural gas supply were omitted, a symmetrical (bell-shaped) life-cycle curve, like that predicted by Hubbert, would be valid (fig. 20). A more striking resemblance would result when we factor in that the leveling of the Lower-48 conventional onshore curve includes reserve growth and deeper conventional production. Moreover, shallow offshore production mostly from the GOM, which was considered a dead sea in the late 1970's, has contributed significantly to U.S. natural gas production as a result of technological advances.

Deep-water/subsalt offshore and unconventional resources, which constitute the bulk of future production growth, are crucial to maintaining increased U.S. natural gas production to meet the growing demand as forecast by the 1999 NPC study. These two

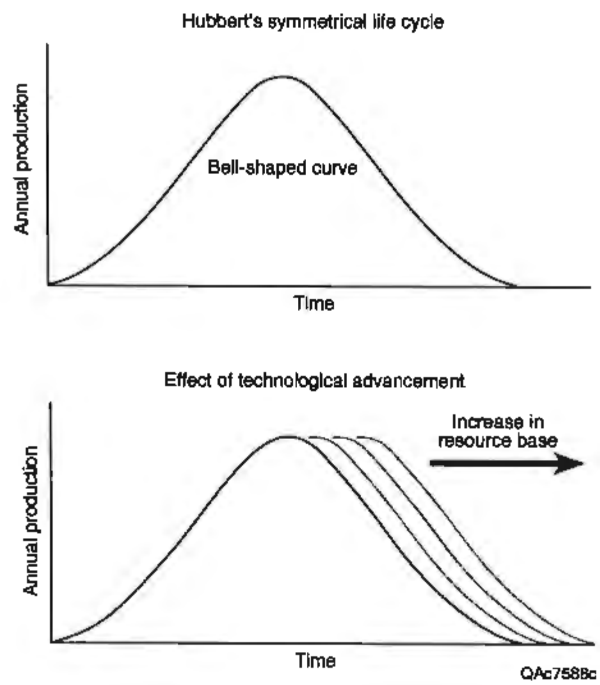

Figure 20. Hubbert's symmetrical life cycle curve and the effect of technological advancements.

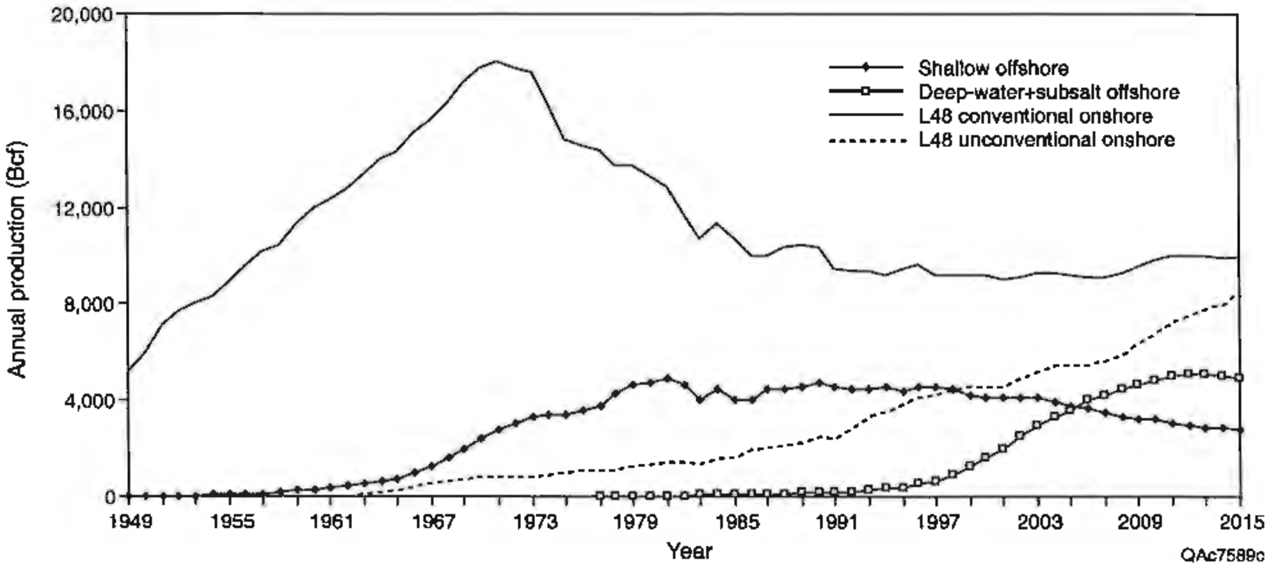

Figure 21. U.S. natural gas production by resource type. Data from National Petroleum Council (1999c).

components of future U.S. natural gas supply are extremely dependent on technological advancements. For example, 3-D seismic detection and deep-water production technological advancements have led to the discovery of new resources in the deep-water/subsalt offshore, along with increasing economic viability. Whereas shallow offshore production is forecast to decline in the future, the deep-water/subsalt offshore is expected to increase dramatically. Technological advancements in the production and completion of unconventional resources have enabled this once-considered large, but uneconomic resource to become economically viable.

Increased production forecasts from the deepwater/subsalt offshore and unconventional resources are based on continued deployment and advances in technology. It is assumed that if technology is not deployed or advanced, current production levels will remain level, if not decline, in the near future. Although technology is important in the production of Lower-48 conventional and shallow offshore resources as well, its role is relatively small compared with its tremendous impact in increasing production from the deep-water/subsalt offshore and unconventional resources, as shown by the stable or declining production forecasts.

The value of technology in the deep-water/subsalt offshore and unconventional resource components of future U.S. natural gas supply can be examined in terms of incremental natural gas production. The value of technology in terms of incremental production is assumed to be the growth in current production levels. If technology is not deployed and advanced, natural gas production from these two components will be expected to remain stable if not decline. It should be taken into account that these resources will also eventually decline because the resource base under available technology is exhausted—unless new technologies are developed.

For deep-water/subsalt offshore and unconventional resources, annual and cumulative incremental production from 2000 through 2015 is calculated assuming that production levels will remain stable from 1999. Annual and cumulative incremental natural gas production from these two resource components is shown in figure 22 and table 8. Incremental production is the difference in production assuming growth relative to production kept level from 1999. Cumulative incremental natural gas production from technological advancements in the deep-water/subsalt offshore and unconventional resources from 2000 through 2015 is calculated as 70 Tcf. When incremental production is multiplied by the natural gas price forecast cases, the total value of these two natural gas resource components can be calculated. The value of technological advancements of these two natural gas resource components in terms of cumulative incremental production from 2000 through 2015 is calculated as $230 billion by using a base-price case ($3/Mcf

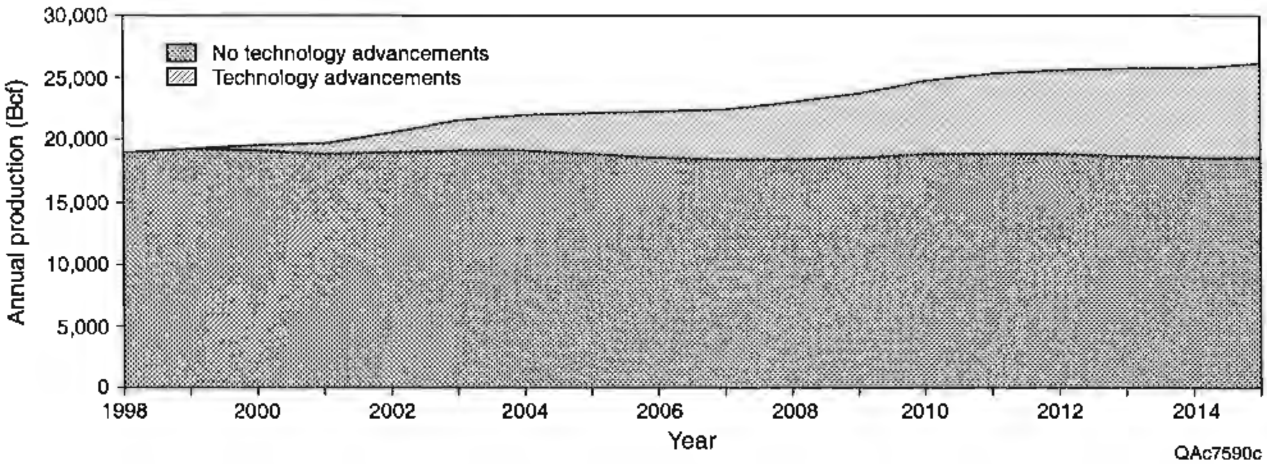

Figure 22. Value of technology in terms of incremental U.S. natural gas production.

Table 8. Value of Technology Advancements to U.S. Natural Gas Supply

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Production with Technology Advancements in Deep-water/Subsalt Offshore and Unconventionals (Bcf)	19,465	19,636	20,585	21,494	21,987	22,039	22 179	22,366	23,013	23 686
Production without Technology Advancements in Deep-water/Subsalt Offshore and Unconventionals (Bcf)	19,077	18,864	19 014	19,136	19,065	18,776	18,536	18 342	18,419	18,511
Deep-water/Subsalt Offshore Incremental Production (Bcf)	376	776	1,246	1,706	2,078	2,396	2,765	2,994	3,237	3,429
Unconventional Incremental Production (Bcf)	12	-4	325	650	844	867	878	1,030	1,357	1,746
Total Incremental Production (Bcf)	388	772	1,571	2 358	2,922	3,263	3,643	4,024	4,594	5,175
High Price ($4/Mcf) Value	$1 550 816 717	$3,120,165,694	$6 412,063,146	$9,719,296,164	$12 162 693,192	$13,719,325,571	$15,470 014,988	$17 255,801,922	$19,898,101,199	$22,640 214,592
Base Price ($3/Mcf) Value	$1,163 112,538	$2,340,124 271	$4,809,047,360	$7,289,472,123	$9 122,019,894	$10,289,494 178	$11,602,511 241	$12,941,851,442	$14,923,575,900	$16,980 160,944
Low Price ($2/Mcf) Value	$775,408,358	$1,560,082,847	$3,206,031,573	$4,859,648,082	$6 081 346,596	$6,859,862,766	$7,735,007,494	$8,627,900,961	$9,949,050,600	$11,320 107,296

	2010	2011	2012	2013	2014	2015	Cumulative 2000-2015
Production with Technology Advancements in Deep-water/Subsalt Offshore and Unconventionals (Bcf)	24,640	25,228	25,561	25,718	25,702	26,072	
Production without Technology Advancements in Deep-water/Subsalt Offshore and Unconventionals (Bcf)	18,601	18,819	18,787	18,672	18,535	18,482	
Deep-water/Subsalt Offshore Incremental Production (Bcf)	3,612	3,778	3,845	3,829	3,763	3,667	43,500
Unconventional Incremental Production (Bcf)	2,227	2,631	2 929	3,217	3,404	3,923	26,036
Total Incremental Production (Bcf)	5,839	6,409	6,774	7,046	7 167	7,590	69,536
High Price ($4/Mcf) Value	$25,798,587,737	$28,602,540,977	$30,532,421,064	$32,075,875,113	$32,953,125,589	$35 245,890,168	$307,158,933,834
Base Price ($3/Mcf) Value	$19 348 940,803	$21,451,905,733	$22,899,315,798	$24,056 906,335	$24,714,844,192	$26,434,417 626	$230 367,700,375
Low Price ($2/Mcf) Value	$12,899 293,869	$14,301,270,489	$15 266 210 532	$16 037 937 556	$16 476 562 795	$17,622,945,084	$153,578,466,917

escalating 1 percent annually). The incremental production due to technological advancements may be assumed to be a percentage of the total; however, it is unlikely that production from these two resource components would grow without technological advancements. Moreover, the overall value of technological advancements is conservative because technology has been given no role in the Lower-48 conventional onshore and shallow offshore production.

Similar analysis can be applied to Federal lands to quantify the value of technology in terms of incremental natural gas production. However, for Federal onshore and American Indian lands, the breakdown between conventional and unconventional resource types is unavailable. Federal onshore and American Indian lands are concentrated in states such as Utah and Wyoming, which are currently producing and have been identified as having large unconventional natural gas potential. Regions such as the Rocky Mountain Foreland and San Juan Basin produce mainly from unconventional natural gas formations. Therefore, a large component of Federal onshore and American Indian lands is assumed to be producing from unconventional natural gas formations.

Lower-48 onshore conventional and unconventional natural gas production in 1999 was 67 percent and 33 percent, respectively. This percentage is assumed also to apply to Federal onshore and American Indian lands. The Federal onshore and American Indian lands unconventional resource percentage is assumed for continued growth, whereas the conventional percentage will follow production forecast trends reflected in U.S. Lower-48 onshore conventional natural gas. For the Federal offshore, deep-water/subsalt will be differentiated from shallow through the 1999 NPC study's forecast, and future growth trends will be applied. Incremental production and its value for Federal lands can be calculated in a similar fashion to total U.S. natural gas supply. Annual and cumulative incremental gas production from the Federal deep-water/subsalt offshore and unconventional resources is shown in figure 23 and table 9. Cumulative incremental natural gas production from technological advancements in the Federal deep-water/subsalt offshore and unconventional resources from year 2000 through 2015 was calculated to be 45 Tcf. For Federal lands, incremental production is dominantly from the deep-water/subsalt offshore. When incremental production is multiplied by the natural gas price forecast cases, the total value of these two natural gas resource components can be calculated. The value of technological advancements for these two natural gas resource components in terms of cumulative incremental production from 2000 through 2015 was calculated as $149 billion by using the base-case price ($3/Mcf escalating 1 percent annually).

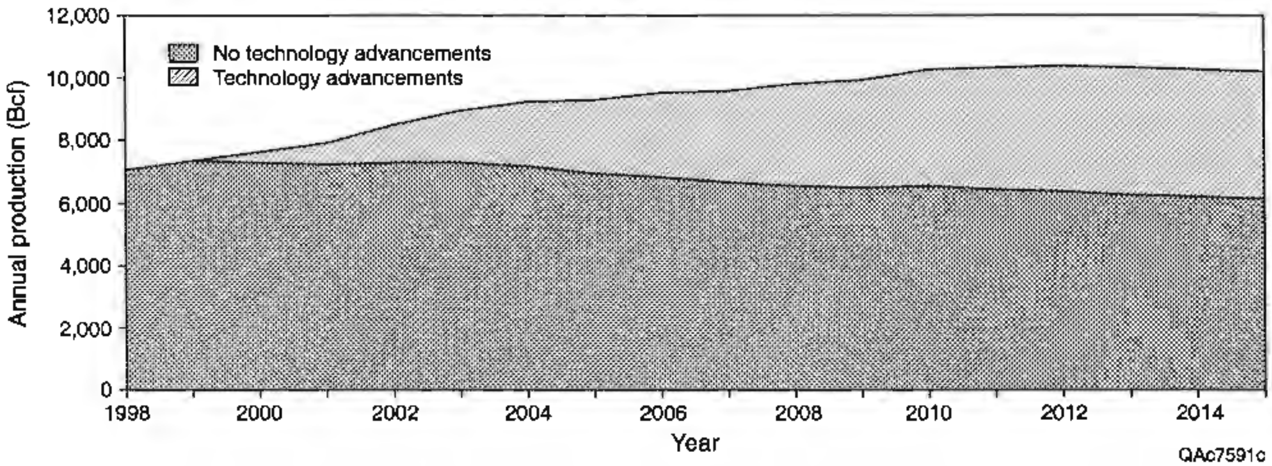

Figure 23. Value of technology in terms of incremental Federal lands natural gas production.

Table 9. Value of Technology Advancements to Federal Lands Natural Gas Supply

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Production with Technology Advancements in Deep-water/Subsalt Offshore and Unconventionals (Bcf)	7,037	7,327	7,822	7,925	8,476	8,967	9,216	9,327	9,553	9,609
Production without Technology Advancements in Deep-water/Subsalt Offshore and Unconventionals (Bcf)	7,037	7,327	7,272	7,207	7,268	7,275	7,150	6,982	6,844	6,663
Deep-water/Subsalt Offshore Incremental Production (Bcf)	348	719	1,154	1,561	1,924	2,218	2,560	2,771	2,996	3,175
Unconventional Incremental Production (Bcf)	2	-1	55	110	143	147	149	174	230	296
Total Incremental Production (Bcf)	350	718	1,209	1,692	2,067	2,365	2,709	2,846	3,226	3,470
High Price ($4/Mcf) Value	$1,427,482,192	$2,959,129,020	$5,031,907,354	$7,111,138,154	$8,774,659,529	$10,143,009,213	$11,732,198,407	$12,886,799,745	$14,254,777,926	$15,465,504,540
Base Price ($3/Mcf) Value	$1,070,611,644	$2,219,346,765	$3,773,930,516	$5,333,353,616	$6,580,994,647	$7,607,256,910	$8,799,148,805	$9,665,099,809	$10,691,083,445	$11,614,128,405
Low Price ($2/Mcf) Value	$713,741,096	$1,479,564,510	$2,515,953,677	$3,555,569,077	$4,387,329,764	$5,071,504,607	$5,866,099,203	$6,443,399,873	$7,127,388,963	$7,742,752,270

	2010	2011	2012	2013	2014	2015	Cumulative 2000-2015
Production with Technology Advancements in Deep-water/Subsalt Offshore and Unconventionals (Bcf)	10,258	10,357	10,403	10,355	10,254	10,216	
Production without Technology Advancements in Deep-water/Subsalt Offshore and Unconventionals (Bcf)	6,538	6,414	6,348	6,266	6,195	6,158	
Deep-water/Subsalt Offshore Incremental Production (Bcf)	3,344	3,498	3,559	3,545	3,463	3,394	40,269
Unconventional Incremental Production (Bcf)	377	445	496	544	578	664	4,407
Total Incremental Production (Bcf)	3,720	3,943	4,055	4,089	4,060	4,058	44,676
High Price ($4/Mcf) Value	$16,438,453,364	$17,595,723,829	$18,277,357,950	$18,614,574,177	$18,665,557,248	$18,846,491,227	$198,244,763,874
Base Price ($3/Mcf) Value	$12,328,840,023	$13,196,792,872	$13,708,018,462	$13,960,930,633	$13,999,167,934	$14,134,868,420	$148,683,572,905
Low Price ($2/Mcf) Value	$8,219,226,682	$8,797,861,915	$9,138,678,975	$9,307,287,088	$9,332,778,623	$9,423,245,614	$99,122,381,937

The value of technology for natural gas production in Federal lands can also be measured in terms of royalty revenue. Forecast royalty revenue for the Federal offshore, onshore, and American Indian lands has been previously calculated utilizing the 1999 NPC study reference case, natural gas price cases, and historical 3-yr-average royalty rates. Federal land royalty revenue based on no technological advancements in the deep-water/subsalt offshore and unconventional resources under the base-case price is shown in table 10. Forecast cumulative royalty revenue for 2000 through 2015 decreases from $72.5 billion to $49.9 billion in the no-technological-advancement scenario. Therefore, in terms of Federal royalty revenue, the cumulative value of technology is estimated at $22.6 billion. Incremental Federal land natural gas production revenue and royalty revenue are shown in figures 24, 25, and 26 and table 11.

GRI'S NATURAL GAS SUPPLY RESEARCH AND DEVELOPMENT PROGRAMS

Total R&D investment in natural gas supply was estimated in 1992 to be $408 million (National Petroleum Council, 1992b). Private industry contributed the bulk of these R&D expenditures, whereas GRI and DOE contributed the remainder. EIA publishes oil and natural gas supply research expenditures through its Financial Reporting System (FRS). Major U.S. energy-producing companies are included in the FRS. Because the FRS includes both oil and natural gas recovery R&D expenditures, it is assumed for this study that expenditures are shared equally.

Annual percentage changes in estimated private industry oil and natural gas supply R&D expenditures are shown in table 12.

For the 1992 NPC study, a detailed survey of R&D expenditures in natural gas supply by private industry was performed by ICF Resources, Inc. By utilizing the percentage changes in table 12, we can estimate private industry's natural gas supply R&D expenditures for 1993 through 1998. Annual reports by GRI and DOE include natural gas supply R&D annually. As seen in table 13, GRI's average share in natural gas supply R&D is estimated to be approximately 15 percent.

The natural gas industry formed the Gas Research Institute (GRI) in 1976 and it received Federal Energy Regulatory Commission (FERC) approval in 1978. It was established to respond to some of the regulatory constraints and has as its mission to plan and implement a coordinated, industrywide R&D effort on behalf of the overall natural gas industry. The natural gas industry and various regulatory bodies recognize GRI for doing a good job of developing and disseminating technology for all segments of the

Table 10. Federal Lands Royalty Revenue Assuming No Technology Advancements

Year	Federal Lands Natural Gas Production				Gas	Total Revenue				Royalty Rate			Royalty Revenue			
	Offshore (Bcf)	Onshore (Bcf)	Indian (Bcf)	Total (Bcf)	Price ($/Mcf)	Offshore (MM$)	Onshore (MM$)	Indian (MM$)	Total (MM$)	Offshore	Onshore	Indian	Offshore (MM$)	Onshore (MM$)	Indian (MM$)	Total (MM$)
2000	4,947	2,036	288	7,271	3.00	14,842	6,109	863	21,814	15.72%	11.52%	14.43%	2,333	704	125	3,162
2001	4,913	2,010	284	7,207	3.03	14,885	6,091	861	21,837	15.72%	11.52%	14.43%	2,340	702	124	3,166
2002	4,955	2,026	286	7,267	3.06	15,164	6,199	876	22,239	15.72%	11.52%	14.43%	2,384	714	126	3,224
2003	4,939	2,046	289	7,275	3.09	15,267	6,325	894	22,486	15.72%	11.52%	14.43%	2,400	729	129	3,258
2004	4,800	2,058	291	7,149	3.12	14,984	6,425	908	22,318	15.72%	11.52%	14.43%	2,356	740	131	3,227
2005	4,630	2,042	289	6,961	3.15	14,599	8,440	910	21,949	15.72%	11.52%	14.43%	2,295	742	131	3,168
2006	4,536	2,022	286	6,843	3.18	14,444	6,439	910	21,793	15.72%	11.52%	14.43%	2,271	742	131	3,144
2007	4,354	2,022	286	6,662	3.22	14,004	6,505	919	21,428	15.72%	11.52%	14.43%	2,201	749	133	3,083
2008	4,225	2,054	290	6,570	3.25	13,726	6,674	943	21,343	15.72%	11.52%	14.43%	2,158	769	136	3,063
2009	4,101	2,088	295	6,484	3.28	13,455	6,851	968	21,274	15.72%	11.52%	14.43%	2,115	789	140	3,044
2010	4,106	2,130	301	6,537	3.31	13,606	7,060	998	21,663	15.72%	11.52%	14.43%	2,139	813	144	3,096
2011	3,951	2,158	305	6,414	3.35	13,223	7,222	1,021	21,466	15.72%	11.52%	14.43%	2,079	832	147	3,058
2012	3,876	2,165	306	6,347	3.38	13,103	7,319	1,035	21,456	15.72%	11.52%	14.43%	2,060	843	149	3,052
2013	3,800	2,160	305	6,266	3.41	12,975	7,375	1,042	21,393	15.72%	11.52%	14.43%	2,040	850	150	3,040
2014	3,741	2,149	304	6,194	3.45	12,900	7,412	1,048	21,359	15.72%	11.52%	14.43%	2,028	854	151	3,033
2015	3,707	2,147	303	6,157	3.48	12,911	7,478	1,057	21,445	15.72%	11.52%	14.43%	2,030	861	153	3,043
Total	69,580	33,315	4,709	107,604		224,087	107,923	15,254	347,263				35,228	12,433	2,201	49,860

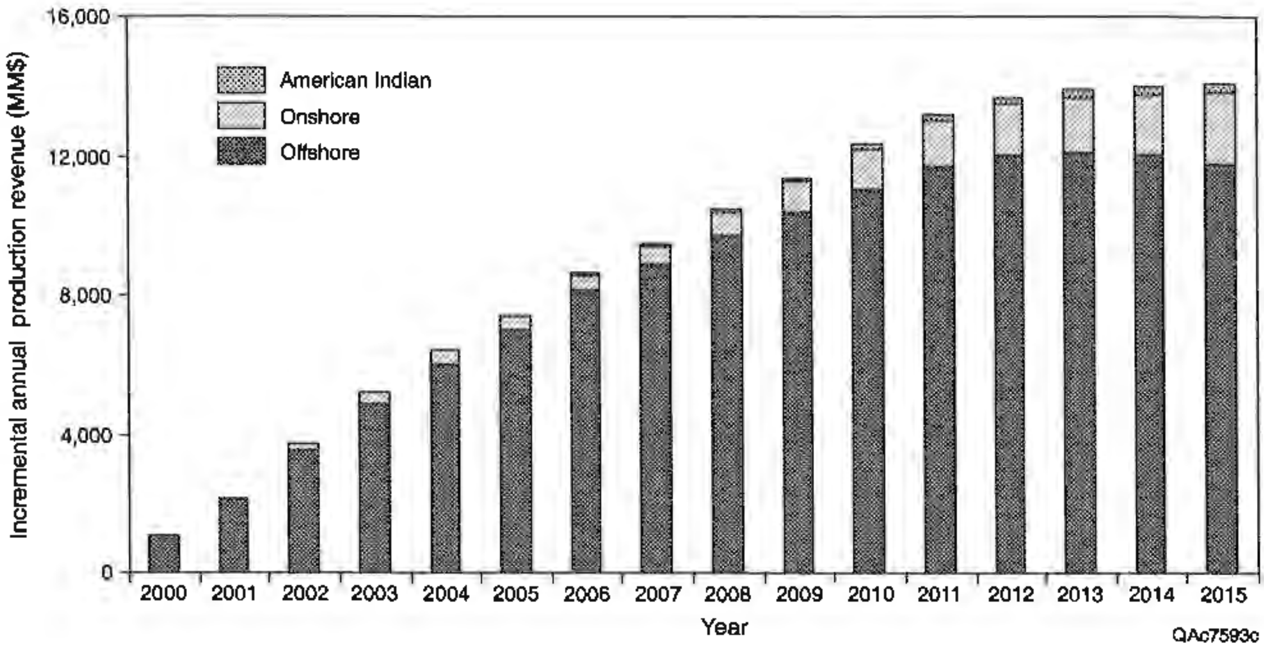

Figure 24. Incremental Federal lands natural gas production, assuming technological advancements.

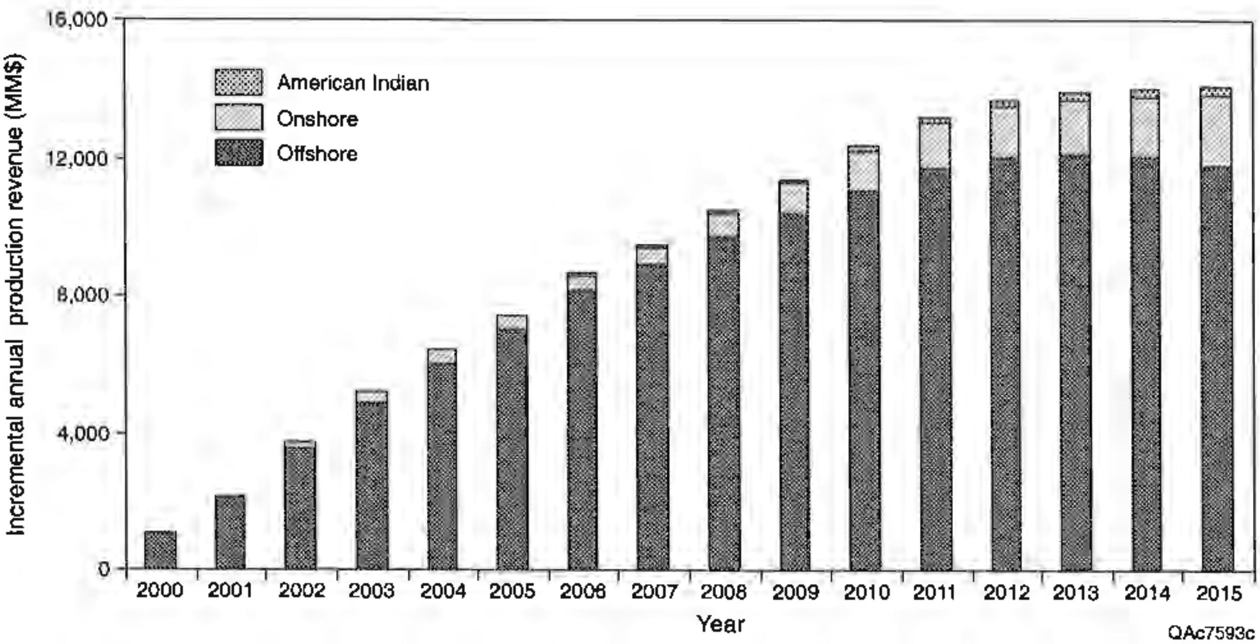

Figure 25. Incremental Federal lands natural gas revenue, assuming technological advancements and base-price case of $3/Mcf escalating 1 percent annually.

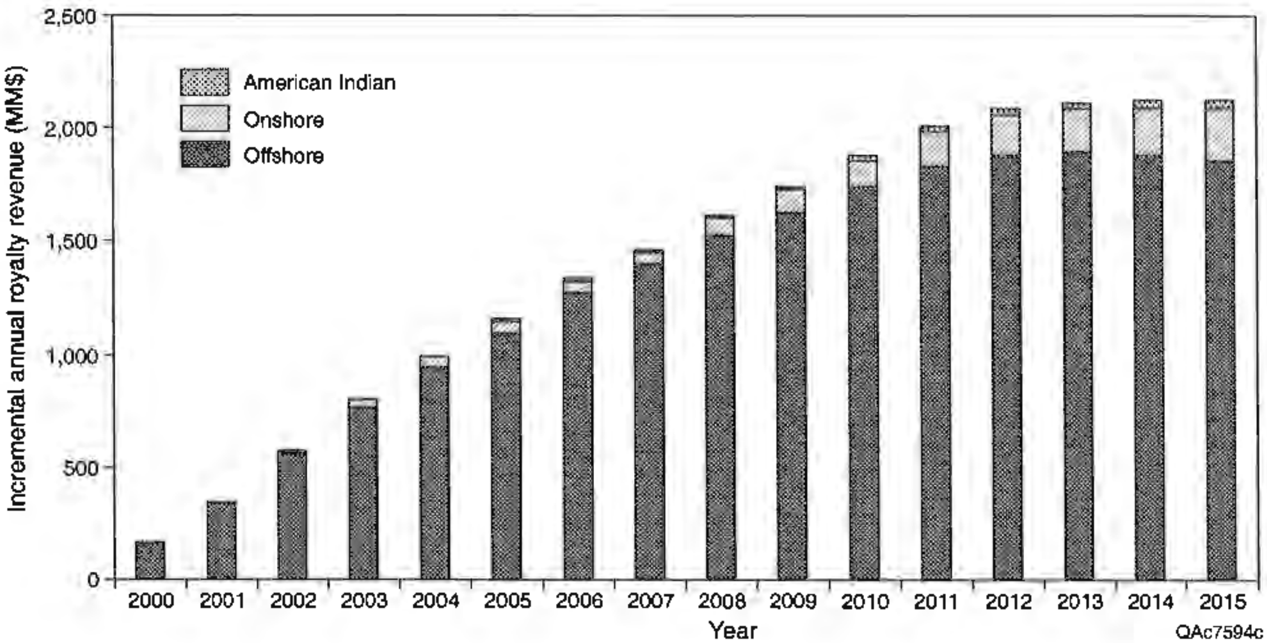

Figure 26. Incremental Federal lands natural gas royalty revenue, assuming technological advancements, base-price case of $3/Mcf escalating 1 percent annually, and 3-yr historical average royalty rates for Federal offshore, onshore, and American Indian lands as 15.72 percent, 11.52 percent, and 14.43 percent, respectively.

Table 11. Incremental Federal Lands Royalty Revenue Assuming Technology Advancements

Year	Federal Lands Natural Gas Produ				Gas	Total Revenue				Royalty Rate			Royalty Revenue				10% of
	Offshore (Bcf)	Onshore (Bcf)	Indian (Bcf)	Total (Bcf)	Price ($/Mcf)	Offshore (MM$)	Onshore (MM$)	Indian (MM$)	Total (MM$)	Offshore	Onshore	Indian	Offshore (MM$)	Onshore (MM$)	Indian (MM$)	Total (MM$)	Royalty Revenue (MM$)
2000	348	2	1	350	3.00	1,043	6	2	1,051	15.72%	11.52%	14.43%	164	1	0	165	17
2001	719	0	0	719	3.03	2,178	-1	1	2,178	15.72%	11.52%	14.43%	342	0	0	342	34
2002	1,154	48	7	1,210	3.06	3,531	148	22	3,702	15.72%	11.52%	14.43%	555	17	3	575	58
2003	1,581	97	14	1,692	3.09	4,888	299	43	5,230	15.72%	11.52%	14.43%	768	34	6	809	81
2004	1,924	125	18	2,067	3.12	6,005	391	57	6,453	15.72%	11.52%	14.43%	944	45	8	997	100
2005	2,218	129	19	2,366	3.15	6,995	406	59	7,459	15.72%	11.52%	14.43%	1,100	47	8	1,155	115
2006	2,560	130	19	2,709	3.18	8,152	415	60	8,628	15.72%	11.52%	14.43%	1,282	48	9	1,338	134
2007	2,771	153	22	2,946	3.22	8,914	492	71	9,477	15.72%	11.52%	14.43%	1,401	57	10	1,468	147
2008	2,996	201	29	3,227	3.25	9,734	654	94	10,482	15.72%	11.52%	14.43%	1,530	75	14	1,619	162
2009	3,175	259	37	3,471	3.28	10,416	850	122	11,387	15.72%	11.52%	14.43%	1,637	98	18	1,753	175
2010	3,344	330	47	3,721	3.31	11,080	1,095	156	12,331	15.72%	11.52%	14.43%	1,742	126	23	1,890	189
2011	3,498	390	56	3,944	3.35	11,707	1,306	186	13,199	15.72%	11.52%	14.43%	1,840	150	27	2,018	202
2012	3,559	434	62	4,056	3.38	12,032	1,469	209	13,710	15.72%	11.52%	14.43%	1,892	169	30	2,091	209
2013	3,545	477	68	4,090	3.41	12,102	1,629	232	13,963	15.72%	11.52%	14.43%	1,902	188	33	2,124	212
2014	3,483	505	72	4,060	3.45	12,013	1,741	248	14,001	15.72%	11.52%	14.43%	1,888	201	36	2,125	212
2015	3,394	582	83	4,059	3.48	11,822	2,027	288	14,137	15.72%	11.52%	14.43%	1,858	233	42	2,134	213
Total	40,269	3,864	553	44,686		132,612	12,927	1,850	147,389				20,847	1,489	267	22,603	2,260

Table 12. Oil and Natural Gas Supply Research and Development Expenditures (Million $) from EIA's Financial Reporting System (FRS)*

	FRS R&D	FRS %	Non-FRS R&D	Non-FRS %	Total R&D	Percentage Change from Previous Year
1992	$781	45.2	$947	54.8	$1,728	
1993	$671	43.0	$889	57.0	$1,560	-9.69%
1994	$572	43.7	$737	56.3	$1,309	-16.12%
1995	$494	44.8	$609	55.2	$1,103	-15.76%
1996	$482	43.4	$629	56.6	$1,111	0.72%
1997	$585	43.2	$769	56.8	$1,354	21.93%
1998	$606	44.8	$747	55.2	$1,353	-0.11%

(Data from Energy Information Administration, 2000)

*FRS from major U.S. energy-producing companies, which report to the EIA on FRS Form EIA-28.

Table 13. U.S. Natural Gas Supply Research and Development Expenditures (Million $)

	GRI	DOE	Industry	Total R&D	GRI's Share of Total R&D
1992	$55	$13	$340	$408	13.48%
1993	$47	$14	$307	$368	12.77%
1994	$59	$14	$258	$331	17.85%
1995	$62	$14	$217	$293	21.16%
1996	$41	$14	$219	$274	14.99%
1997	$47	$14	$266	$327	14.35%
1998	$32	$13	$266	$311	10.28%
				Average (92-98):	14.98%

industry, including supply, transmission, distribution, and end use (National Petroleum Council, 1992a). Recently GRI merged with the Institute of Gas Technology (IGT), forming the nation's premiere natural gas research and technology organization called Gas Technology Institute (GTI) (Gas Research Institute, 2000a).

Historically GRI has been a major funder of natural gas supply technology (fig. 27; table 14). One of the natural gas resource components that has benefited particularly from GRI's supply research and development is unconventional resources (fig. 28). Many unconventional natural gas resources were uneconomic until GRI's technological research and development. GRI's coalbed methane program, for example, is especially noteworthy in its role of developing a nonexistent natural gas production source into one that contributes approximately 1 Tcf of U.S. natural gas supply. GRI's supply programs in advanced stimulation techniques, Antrim shale, and emerging resources in the greater Green River Basin have also contributed to the tremendous growth of natural gas production from tight gas and gas shale (Gas Research Institute, 1999). Continued future research and development of unconventional natural gas resources are currently being funded by GTI. For unconventional resources, GRI's average share of total R&D is estimated to be much greater than the calculated 15 percent of total natural gas supply R&D.

Historical GRI natural gas supply programs were undertaken by the private sector, research organizations, and academe. However, because the private sector R&D programs have focused on foreign investments, research organizations constrained by decreased funding and staff and academe unable to supply skilled workers, future domestic research capabilities are severely constrained. In order for GRI's natural gas supply programs to maintain their share in technology, these areas will have to be addressed.

ECONOMIC ANALYSIS OF GRI'S GAS SUPPLY TRUST FUND

An economic analysis of the value of establishing a natural gas supply research trust fund built by nominations of 10 percent of royalty payments from natural gas production on the Federal OCS was determined. This analysis shows that future growth of natural gas production will come mainly from the deep-water/subsalt offshore and unconventional resources. Technology is a vital component in achieving the forecast growth in these two resource areas. The major assumptions used in the economic analysis of GRI's gas supply trust fund include the following.

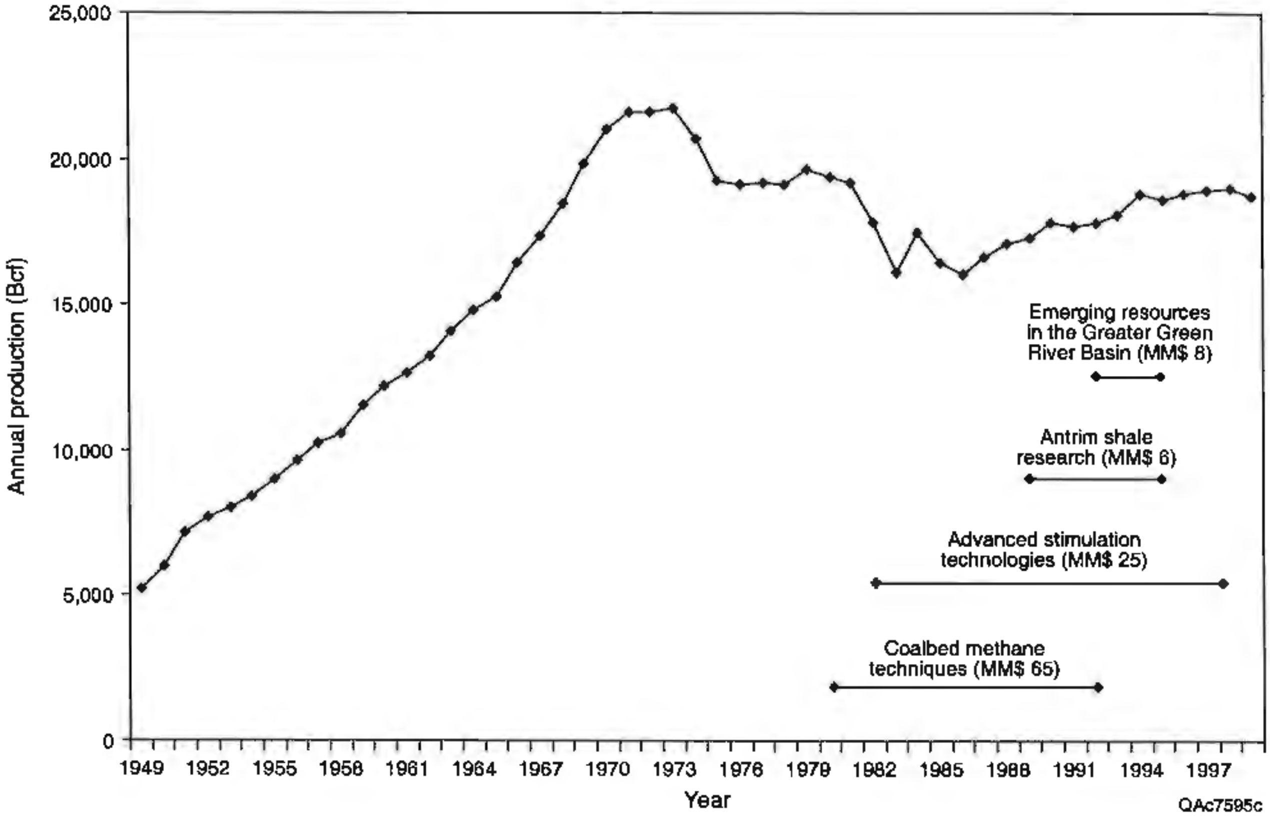

Figure 27. Historical U.S. dry natural gas production and major GRI supply programs. Data from Energy Information Administration (2000) and Gas Research Institute (2000b).

Table 14. Historical Major GRI Natural Gas Supply Research and Development Programs

Historical Projects:	Start	End	Cost (MM$)
Coalbed Methane Techniques	1980	1992	65
Advanced Stimulation Technologies	1982	1998	25
Secondary Gas Recovery	1987	1994	5
Promat Software	1987	1995	0.1
Anthrim Shale Research	1989	1995	6
Natural Gas Atlases of Major Reservoirs	1989	1997	5
Seismic Amplitude Variation with Offset Information	1990	1994	1
Drilling Waste and Produced Water Manuals	1990	1995	0.59
Fracture Information & Diagnostics	1991	1996	6
Emerging Resources in the Greater Green River Basin	1992	1995	8.1
Crosswell Seismic Imaging	1993	1998	2.2
Calcite Scale Handbook & ASTM Standards	1993	1998	2
Successful Drilling Practices Manual	1994	1998	1.6
Glycal Dehydrator Emission Calculation Program	1994	1998	0.4
Underbalanced Drilling Manuals	1995	1997	0.3
Drill String Safety Valves	1995	1999	0.1
Mesa Grip Seismic Survey Design Software	1996	1998	2
Freeze/Thaw for Production Water	1997	1998	1.2
Advanced Crosswell Seismic Source	1998	1999	0.77
Downhole Hydraulic Axial Vibrator for VSP's	1999	1999	1.7

(Data from Gas Research Institute, 2000b)

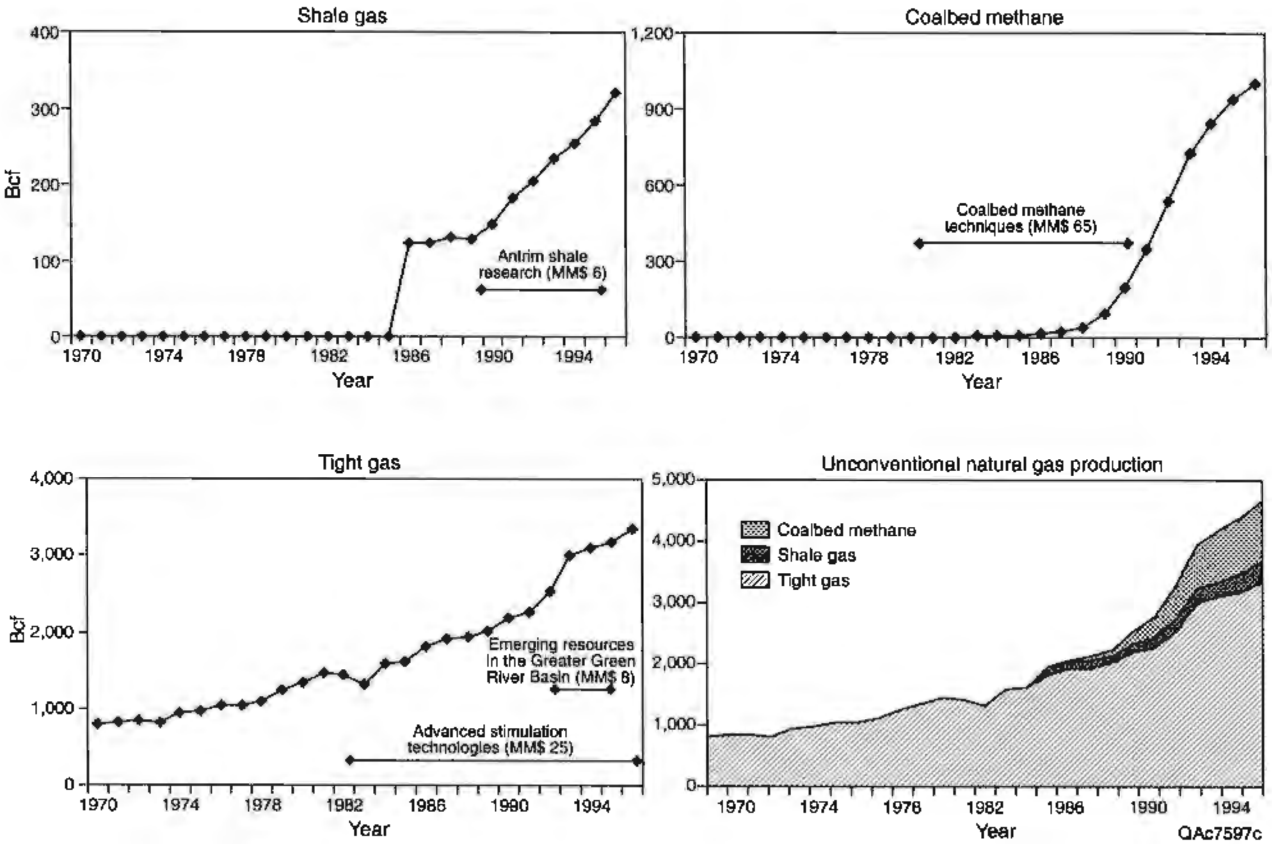

Figure 28. GRI's major historical programs and unconventional natural gas production. Data from Energy Information Administration (2000) and Gas Research Institute (2000b).

(1) The value of technology is determined in terms of incremental natural gas production from the deep-water/subsalt offshore and unconventional resource components over stable 1999 production levels forecast by the NPC reference case.
(2) Judging from past historical expenditures of total natural gas R&D expenditures, GRI's contribution of incremental production is assumed to be 15 percent.
(3) GRI's 15-percent contribution level to total natural gas R&D expenditures is assumed to be constant for the forecast analysis period.
(4) No significant lag time is assumed into the benefits of GRI's natural gas supply trust fund.
(5) Benefits achieved by the ongoing effect of GRI's past and current natural gas R&D programs are not incorporated into the analysis.
(6) High-, base-, and low-price cases are set at $4, $3, and $2/Mcf, respectively. For each case, prices are escalated by 1 percent/yr.
(7) A 3-yr-average royalty rate from 1997, 1998, and 1999 was utilized as the royalty rate for the forecast period because it was assumed to be the most recent level of royalty rates, and no programs or actions that should materially change this figure could be foreseen. Calculated 3-yr-average natural gas royalty rates for the Federal offshore, onshore, and American Indian lands were 15.72, 11.52, and 14.43 percent, respectively.
(8) A discount rate of 12 percent.

The cumulative value of technology for U.S. natural gas supply from 2000 through 2015 has been estimated to be 70 Tcf of incremental production, worth $230 billion. For Federal lands, the cumulative value of technology from 2000 through 2015 in terms of the difference in royalty revenue was estimated at $22 billion. GRI's average share of technology for U.S. natural gas supply was estimated at 15 percent, worth $3.3 billion.

Benefit/cost (BC) analysis of incremental U.S. and Federal lands natural gas production from technological advances attained through GRI's future gas supply research programs is shown in tables 15 and 16. GRI's share of incremental U.S. natural gas production from technological advances was assumed to be 15 percent on the basis of historical average-funding levels for natural gas supply R&D expenditures. The cost of GRI's natural gas supply fund was assumed to be 10 percent of Federal OCS royalty revenues attained from incremental production achieved through technological advancements. BC ratios at high-, base-, and low-price cases were positive for all forecast years.

Table 15. Value of GRI's Share (15%) of Technology Advancements to U.S. Natural Gas Supply

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Cumulative 2000-2015
Total Incremental Production (Bcf)	58	116	236	354	438	490	547	604	689	776	876	961	1,016	1,057	1,075	1,138	10,430
High Price Value (MM$)	$233	$468	$962	$1,458	$1,824	$2,058	$2,321	$2,588	$2,985	$3,396	$3,870	$4,290	$4,580	$4,811	$4,943	$5,287	$46,074
Base Price Value (MM$)	$174	$351	$721	$1,093	$1,368	$1,543	$1,740	$1,941	$2,239	$2,547	$2,902	$3,218	$3,435	$3,609	$3,707	$3,965	$34,555
Low Price Value (MM$)	$116	$234	$481	$729	$912	$1,029	$1,160	$1,294	$1,492	$1,698	$1,935	$2,145	$2,290	$2,406	$2,471	$2,643	$23,037
Cost = 10% Royalty Revenue (MM$)	$333	$351	$380	$407	$422	$432	$448	$455	$468	$480	$499	$508	$514	$516	$516	$518	$7,246
B/C Ratio at High Price Value	0.70	1.33	2.53	3.58	4.32	4.76	5.18	5.69	6.38	7.08	7.76	8.45	8.90	9.32	9.58	10.21	6.36
B/C Ratio at Base Price Value	0.52	1.00	1.90	2.69	3.24	3.57	3.88	4.27	4.78	5.31	5.82	6.34	6.68	6.99	7.19	7.66	4.77
B/C Ratio at Low Price Value	0.35	0.67	1.27	1.79	2.16	2.38	2.59	2.84	3.19	3.54	3.88	4.23	4.45	4.66	4.79	5.11	3.18

(High, base, and low price at $4, $3, and $2 per Mcf, respectively, escalating at 1% annually. Discount rate of 12%, assuming GRI's share of total incremental production 15%.)

Table 16. Value of GRI's share (15%) of Technology Advancements to Federal Lands Natural Gas Supply

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Cumulative 2000-2015
Total Incremental Production (Bcf)	52	108	181	254	310	355	406	442	484	521	558	591	608	613	609	609	6,701
High Price Value (MM$)	$214	$444	$755	$1,067	$1,316	$1,521	$1,760	$1,933	$2,138	$2,323	$2,466	$2,639	$2,742	$2,792	$2,800	$2,827	$29,737
Base Price Value (MM$)	$161	$333	$566	$800	$987	$1,141	$1,320	$1,450	$1,604	$1,742	$1,849	$1,980	$2,056	$2,094	$2,100	$2,120	$22,303
Low Price Value (MM$)	$107	$222	$377	$533	$658	$761	$880	$967	$1,009	$1,161	$1,233	$1,320	$1,371	$1,396	$1,400	$1,413	$14,868
Cost = 10% Royalty Revenue (MM$)	$333	$351	$380	$407	$422	$432	$446	$455	$468	$480	$499	$508	$514	$516	$516	$518	$7,246
B/C Ratio at High Price Value	0.64	1.27	1.99	2.62	3.12	3.52	3.93	4.25	4.57	4.84	4.94	5.20	5.33	5.41	5.43	5.46	4.10
B/C Ratio at Base Price Value	0.48	0.95	1.49	1.97	2.34	2.64	2.94	3.19	3.43	3.63	3.71	3.90	4.00	4.06	4.07	4.10	3.08
B/C Ratio at Low Price Value	0.32	0.63	0.99	1.31	1.56	1.76	1.96	2.12	2.28	2.42	2.47	2.60	2.67	2.70	2.71	2.73	2.05

(High, base, and low price at $4, $3, and $2 per Mcf, respectively, escalating at 1% annually. Discount rate of 12%, assuming GRI's share of total incremental production 15%.)

In the base-price case, cumulative BC ratios for 2000 through 2015 were 4.77 and 3.08 for U.S. and Federal lands, respectively.

Project economics of GRI's proposed natural gas supply fund were performed for U.S. and Federal natural gas incremental production through technological advancements by using internal rate of return (IRR) and net present value (NPV). Both U.S. and Federal lands project economics of GRI's natural gas supply fund revealed positive outcomes, assuming GRI's average share of technology of 15 percent (tables 17, 18). High-, base-, and low-price cases, along with a discount rate of 12 percent, were assumed. For the base-price case, IRR and NPV were 143 percent and $8 billion, respectively, for U.S. natural gas incremental production. For Federal lands, IRR and NPV were 101 percent and $5 billion, respectively. GRI's natural gas supply fund proved to be an economically sound R&D investment objective under the economic analysis performed and assumptions made.

CONCLUSIONS

The U.S. natural gas resource base is vast, although still largely undefined, and will meet demand with continued technological advancements. If U.S. demands cannot be met by domestic production, it will not be because of an inadequate resource base. Rather, it will be because of a lack of investment in natural gas supply R&D. Given the lead time required for natural gas supply R&D to be transformed into natural gas production, it is essential to maintain the research investments of today to realize the technological benefits of tomorrow (Kuuskraa, 1998).

In the 1999 NPC study, natural gas demand was forecast to increase from 22 Tcf in 1998 to 31 Tcf in 2015. Projected to meet this demand was U.S. Lower-48 natural gas production that was forecast to increase from 19 Tcf in 1998 to 26 Tcf in 2015. However, the goal of 31 Tcf of supply by 2015 can be achieved at reasonable prices only if exploration and production technological advancements continue in the future. Major increases in natural gas supply are attributable to successes in technologically difficult areas such as deep water, deep conventional formations, and unconventional formations. These natural gas resource areas are very dependent on continued technological advancements for their production growth and economic recovery.

In the past, GRI's multiyear, high-risk, high-cost gas supply research programs such as coalbed methane, advanced stimulation technologies, Antrim shales, and

Table 17. Project Economics of GRI's Natural Gas Supply Fund for U.S. Natural Gas Supply

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Cumulative 2000-2015		
Total Incremental Production (Bcf)	58	116	236	354	438	490	547	604	689	776	876	961	1,016	1,057	1,075	1,138	10,430		
High Price Value (MM$)	$233	$468	$962	$1,458	$1,824	$2,058	$2,321	$2,588	$2,985	$3,396	$3,870	$4,290	$4,580	$4,811	$4,943	$5,287	$46,074		
Base Price Value (MM$)	$174	$351	$721	$1,093	$1,368	$1,543	$1,740	$1,941	$2,239	$2,547	$2,902	$3,218	$3,435	$3,609	$3,707	$3,965	$34,555		
Low Price Value (MM$)	$116	$234	$481	$729	$912	$1,029	$1.160	$1.294	$1.492	$1.698	$1,935	$2,145	$2,290	$2,406	$2,471	$2,643	$23,037		
Cost = 10% Royalty Revenue (MM$)	-$333	-$351	-$380	-$407	-$422	-$432	-$448	-$455	-$468	-$480	-$499	-$508	-$514	-$516	-$516	-$518	-$7,246	IRR	NPV (12%)
High Price Net Cash Flow (MM$)	-100	117	582	1,051	1,402	1,626	1,872	2,133	2,517	2,916	3,371	3,783	4,066	4,295	4,427	4,769	38,827	280%	$11,598
Base Price Net Cash Flow (MM$)	-158	0	341	687	946	1,111	1,292	1,486	1,770	2,067	2,404	2,710	2,921	3,092	3,191	3,447	27,309	143%	$7,961
Low Price Net Cash Flow (MM$)	-216	-117	101	322	490	597	712	839	1,024	1,218	1,436	1,638	1,776	1,889	1,956	2,126	15,790	71%	$4,324

(High, base, and low price at $4, $3, and $2 per Mcf, respectively, escalating at 1% annually. Discount rate of 12%, assuming GRI's share of total incremental production 15%)

Table 18. Project Economics of GRI's Natural Gas Supply Fund for Federal Lands Natural Gas Supply

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Cumulative 2000-2015	IRR	NPV (12%)
Total Incremental Production (Bcf)	52	108	181	254	310	355	406	442	484	521	558	591	608	613	609	609	6,701		
High Price Value (MM$)	$214	$444	$755	$1,067	$1,316	$1,521	$1,760	$1,933	$2,138	$2,323	$2,466	$2,639	$2,742	$2,792	$2,800	$2,827	$29,737		
Base Price Value (MM$)	$161	$333	$566	$800	$987	$1,141	$1,320	$1,450	$1,604	$1,742	$1,849	$1,980	$2,056	$2,094	$2,100	$2,120	$22,303		
Low Price Value (MM$)	$107	$222	$377	$533	$658	$761	$880	$967	$1,069	$1.161	$1.233	$1.320	$1.371	$1,396	$1,400	$1,413	$14,868		
Cost = 10% Royalty Revenue (MM$)	-$333	-$351	-$380	-$407	-$422	-$432	-$448	-$455	-$468	-$480	-$499	-$508	-$514	-$516	-$516	-$518	-$7,246	IRR	NPV (12%)
High Price Net Cash Flow (MM$)	-119	93	375	660	894	1,089	1,312	1,478	1,670	1,843	1,967	2,132	2,227	2,276	2,284	2,309	22,490	197%	$6,982
Base Price Net Cash Flow (MM$)	-172	-18	166	393	565	709	872	995	1,135	1,262	1,351	1,472	1,542	1,578	1,584	1,603	15,056	101%	$4,499
Low Price Net Cash Flow (MM$)	-226	-129	-3	127	236	328	432	511	601	682	734	812	856	880	884	896	7,622	47%	$2,016

(High, base, and low price at $4, $3, and $2 per Mcf, respectively, escalating at 1% annually. Discount rate of 12%, assuming GRI's share of total incremental production 15%.)

emerging resources in the greater Green River Basin resulted in significant economic increases in natural gas. These natural gas production increases have contributed greatly to increased Federal royalty revenue, and in fact have provided an excellent rate of return on the Federal investment.

U.S. natural gas production growth was forecast by the 1999 NPC study to be largely from the deep-water/subsalt offshore and unconventional resources. Through this study, the cumulative value of technology in terms of U.S. incremental natural gas production from 2000 through 2015 has been estimated to be 70 Tcf, worth $230 billion under a base-case price. For Federal lands only, the cumulative value of technology from 2000 through 2015 in terms of the increase in Federal royalty revenue is estimated at $22 billion. Through analysis of historical natural gas supply R&D expenditures, GRI's average share of technology is estimated at 15 percent, or $3.3 billion. A much higher percentage can be assumed for unconventional resources only.

The value of establishing a natural gas supply research trust fund built by nominations of 10 percent of royalty payments from natural gas production on the Federal OCS was examined through BC analysis and project economics. For the base-case price, cumulative BC ratios for 2000 through 2015 are 4.77 and 3.08 for U.S. and Federal lands, respectively. Project economics of GRI's natural gas supply research trust fund revealed positive outcomes, assuming GRI's average share of technology of 15 percent. For the base-case price, IRR and NPV were 143 percent and $8 billion, respectively, for U.S. natural gas incremental production. For Federal lands, IRR and NPV were 101 percent and $5 billion, respectively.

GRI's natural gas supply research trust fund is a critically important and economically viable R&D investment. GRI's natural gas supply trust fund accomplishes the recommendations of the 1999 NPC study in meeting the challenges of the nation's growing natural gas demand by enabling government and industry to take a leadership position in establishing, at the highest level, a strategy for natural gas in the nation's energy portfolio. Moreover, it establishes a balanced, long-term approach for responsibly developing the nation's natural gas resource base by driving research and technology development at a rapid rate.

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