Translating Lessons Learned From Unconventional Natural Gas R&D To Geologic Sequestration Technology

Vello A. Kuuskraa (vkuuskraa@adv-res.com; 703-528-8420)
Advanced Resources International, Inc.
1110 N. Glebe Road, Suite 600
Arlington, VA 22042

Hugh D. Guthrie (hugh.guthrie@netl.doe.gov; 304-285-4632)
United States Department of Energy
P.O. Box 880
Morgantown, WV 26507

Abstract. The gloomy, almost crisis-like outlook for the future of domestic natural gas in the late 1970s set in motion a set of national-level energy initiatives for adding new gas supplies. Two of the most valuable of these were: (1) the joint government/industry R&D programs in tight gas, gas shales and coalbed methane by the Department of Energy s Office of Fossil Energy (DOE/FE) that established the essential exploration and production technology for these resources; and, (2) the unconventional gas economic incentives (Section 29 tax credits) that buffered the economic risks faced by the early set of unconventional gas developers and helped attract scarce investment capital to this emerging resource.

Now, twenty years later, unconventional gas offers one of the impressive technology success stories. A poorly understood, high cost energy resource is now providing major volumes of annual gas supplies and helping meet the growing domestic demand for natural gas.

Unconventional natural gas provided 4,500 Bcf of supply in 1999, up threefold from about 1,600 Bcf twenty years ago.

Proved reserves of unconventional gas are 53 Tcf, up from less than 20 Tcf when the R&D and incentive programs started.

Assessed recoverable resources of unconventional gas are now estimated at 400 to 500 Tcf, providing confidence that with technology progress the contribution of unconventional gas will continue to grow.

Behind these spectacular numbers are a host of dedicated activities, occasional failures and many successes, all underlain by substantial investments in R&D and technology. Tight gas, the flagship of unconventional gas, is now pursued routinely by independents and majors alike in over a dozen major domestic basins. Gas shales development has expanded from the Appalachian Basin to new basins in Michigan (Antrim) and North Texas (Barnett). Coalbed methane, a resource once labeled moonbeam gas, has been converted from a mining hazard to an economic source of new gas reserves. Ironically, geopressured methane, the resource stated as

holding a 1,000 years of gas, came up short once the bright, hot light of serious scientific inquiring was turned on.

The look at the history of unconventional gas also provides a rich set of lessons learned. These lessons demonstrate that combining a well managed joint government/industry R&D technology program with performance-based incentives for early application of new technology can be highly successful, providing significant economic benefits to the U.S. economy.

Introduction. After decades of plentiful supplies, low costs and public indifference, in the 1970s natural gas finally moved to the center of national attention. The winter of 1975-76 saw worrisome curtailments in natural gas supplies leading to closing of schools and public facilities. In the following winter the problems of supply curtailments grew worse, leading to Congressional hearings and a scramble for explanations.

While numerous reasons were posed for the cause of the problem, the one set of answers that gained broad public and political acceptance was that the nation was rapidly running out of natural gas supplies. Prominent in the winning debate were two dominating figures, M. King Hubbert and the Federal Power Commission, both painting a pessimistic, depleting future:

> King Hubbert, who had gained considerable credibility among energy policy and Congressional staff by correctly forecasting the peak and subsequent decline in domestic oil production, applied his same forecasting methods to natural gas. In widely followed Congressional testimony, he set forth a future of limited natural gas resources and a pending crisis in gas supplies. Hubbert viewed a low domestic natural gas resource base of 1,050 Tcf of which nearly one-half had already been produced. He predicted that the peak in natural gas productions would occur shortly (in 1977) followed by a dramatic decline, Figure 1.
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> The Federal Power Commission, responsible for regulating the price and profitability of natural gas production, confirmed its stance for continued price controls defending it by stating -- why deregulate natural gas when there is so little left to find?

Search for New Resources. The bleak, uncertain outlook for natural gas set the stage for ground breaking legislation -- phased removal of wellhead price controls, incentives for new natural gas development, and restrictions on gas use for electric generation (NGPA, Public Law 95-621). The concern over future gas supplies also set in motion a search for new sources of natural gas, in settings that had been previously overlooked.

> A Federal Power Commission task force identified that 600 Tcf of gas in place existed in three large Western basins. These gas resources were held in geologically complex, extremely low permeability (tight) reservoirs where existing technologies were insufficient for ensuring economic production.
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> The Bureau of Mines identified that considerable volumes of methane (pure natural gas) were being vented for safety reasons from coal mines, wasting a valuable resource.

Gas bearing Devonian-age shales were judged to hold several thousand Tcf of gas in the Appalachian Basin, one of the least defined domestic gas producing regions.

And, public interest was stirred by major articles in Fortune and The Wall Street Journal that a new natural gas resource – geopressured aquifers -- could provide gas for a 1,000 years.

Numerous special purpose studies and narrowly focused R&D efforts were initiated to further understand and pursue these large, little-understood natural gas resources, Figure 2.

Foundation for a Coordinated R&D Program. Faced with a growing body of new, sometimes promotional information on unconventional natural gas, the Energy Research and Development Administration (ERDA) commissioned a comprehensive study of these resources. Advanced Resources International, then called Lewin and Associates, with Mr. Vello Kuuskraa as Study Director, was contracted to perform this broadly scoped, landmark study. The introductory page of this study, Enhanced Recovery of Unconventional Gas (Volumes I, II, and III), February 1978, pointedly set forth the challenge:

As conventional domestic natural gas supplies dwindle, the nation must seek ways to slow these trends and obtain new supplies. The choices faced are controversial, costly and risky. They entail difficult balancing among higher prices, accelerated development, reliance on imports and new technology. This study has been conducted to assist public decision-makers select among these many choices by addressing two questions:

How severe is the need for additional future supplies of natural gas?

What is the economic potential of providing a portion of future supply through enhanced recovery from unconventional natural gas resources?

As important, the study set forth the framework for an aggressive, coordinated program of research and development on unconventional natural gas the study serves to assist the Department of Energy (the successor to ERDA) design a cost-effective research and development program to stimulate industry to recover this unconventional gas and to produce it sooner.

Objectives, Design And Implementation Of The Program. The Department of Energy s unconventional gas R&D/incentives program has had many political twists and policy turns during its twenty years of existence. The outline and objectives of the original Enhanced Gas Recovery Program, that responded to the supply crisis atmosphere of the late 1970 s, was set forth in the FY 1978 Congressional Budget Request. Subsequent administrations, reflecting their own National priorities and energy strategies, shaped and modified this program continuously.

Original DOE R&D Program Objectives. The strategic policy goal was to develop and stimulate the deployment of advanced exploration, development and production technologies for recovering new gas supplies from the massive but complex unconventional gas resources -- tight gas, coalbed methane, gas shales and geopressured methane. The technical objectives were to increase per well gas recovery efficiencies and lower unit development costs while providing incentives (through tax credits) for prompt, orderly development of the nation s gas resources.

In addition, two quantitative, national-level natural gas supply goals were set forth for the Enhanced Gas Recovery Program:

> *Increase gas production by an incremental 3 billion cubic feet per day by 1986, and Add 10 Tcf of producible reserves by 1985.*

Changing Horses in Mid-Stream. Even before the results were in, the political winds and market conditions shifted. The Reagan administration, in 1980, first scaled back the R&D program and then pushed to eliminate government involvement in short-term gas supply R&D, citing that the private sector has the financial and technical resources to develop the technology needed for new unconventional gas resources. Congressional intervention maintained the program, although only at a life-support level.

In 1991/92, with the publication of the administration s National Energy Strategy and the growing R&D role of the Gas Research Institute in unconventional gas, much of the remaining DOE R&D program was eliminated, with only the low permeability (tight sands) area surviving. When, in 1994, the Gas Research Institute also shifted its priorities, terminating its focus on unconventional gas in favor of a more generic technology-based R&D program, for all practical purposes public R&D on unconventional gas came to an end. With subsequent loss of public support, the Gas Research Institute s R&D program on gas supply is now also being phased out.

Program Definition, Design and Implementation. The original DOE R&D program had its roots in Volume III of the study -- Enhanced Recovery of Unconventional Gas (1978) -- and was shaped considerably by industry and outside technical input. Unfortunately, in subsequent years the political process rather than science and analysis shaped much of program design. In contrast, the GRI R&D program on unconventional gas was able to stay, at least during its formative years, outside the political process. The two R&D programs complemented each other, with the DOE program often conducting the exploratory, fundamental science and the GRI program providing the applied science and technology transfer.

Each organization relied greatly on outside technical experts, research organizations and industry to perform and commercialize its R&D. This helped to bring valuable cost-efficiency and cost-sharing to the program, particularly during the field documentations stages, and to accelerate technology commercialization.

Supporting Policy Mechanisms. Two economic incentives were set forth in Congressional legislation to encourage the development of unconventional gas - - incentive pricing and tax credits.

Incentive Pricing Under NGPA. The first set of economic incentives for encouraging exploration and development of unconventional gas were set forth in the Natural Gas Policy Act of November, 1978. Section 107 of this act deregulated the well-head sales price of natural gas from Devonian-age gas shales, coal seams and geopressured brines. Section 102 of this Act enabled tight gas to become eligible for the highest ceiling price within the NGPA regulated categories, providing this resource with modest economic incentives.

Section 29 Tax Credit. A separate set of economic incentives for unconventional gas were placed into the Crude Oil Windfall Profits Tax Act of 1980. Section 29 of this act provided tax credits to qualified unconventional gas wells and formations. While producers initially needed to select which set of incentives to use, the deregulation of natural gas in 1981 made this choice moot. With amendments, the Section 29 tax credit qualifying period for new unconventional gas wells lasted until the end of 1992, with tax credits provided for gas produced through 2002.

The incentive provisions of the Section 29 tax credit were designed to reward efficient unconventional gas development and performance. During a time when national average wellhead natural gas prices were between $1.50 and $2.50 per Mcf, the tax credit for tight gas was about $0.50 per Mcf and for gas shales and was on the order of $1.00 per Mcf for coalbed methane, adding considerable economic value to the efficient production of these resources. The tax credits also helped justify the high investment needed for initial infrastructure.

Response to Incentives. Not surprisingly, industry s development and production of unconventional natural gas responded strongly to these incentives:

> The production of Section 29 legally eligible tight gas, a resource with many undeveloped basins and readily available technology, grew from 240 Bcf in 1980 to 1,180 Bcf in 1986, plateauing thereafter. Overall production from this resource, including legally and geo logically defined tight gas, was considerably higher as numerous low permeability areas and pre-existing tight gas production remained unapproved by FERC or a FERC-designated State agency.
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> Lacking a sufficient base of technology, coalbed methane had little opportunity to use the tax credits until the end of the 1980 s. Even with this late start, over 5,000 CBM wells were drilled and completed before the qualifying period for tax credits expired.
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> Drilling for gas shales increased substantially in the Appalachian Basin and with R&D opening up the Michigan Basin drilling boomed, averaging over 1,200 wells per year in the last six years of tax credits.

Post Tax Incentive Activity. A most significant outcome of the tax incentive program was that unconventional gas well drilling and completions stayed strong after the expiration of the tax credits:

> After a brief lull, tight gas well completions rebounded to 3,000 wells per year.
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> Coalbed methane well completions slumped somewhat in the mid-1990 s but now have reached new highs with the strong activity in the Powder River Basin.
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> Gas shale well drilling has averaged 900 wells per year for the six years since the expiration of the tax credits, only somewhat less than the 1,200 wells per year prior.

The reason for the strong post tax incentive activity was that unconventional gas exploration and development technology had progressed sufficiently and the infrastructure was in place such that the industry remained economic and could attract capital without the need for further incentives or subsidies.

Monitoring And Evaluation. The initial DOE and GRI unconventional gas R&D programs placed considerable emphasis on establishing reliable, efficient monitoring and evaluation systems. Explicit supply enhancement goals, detailed R&D program plans, and benefit to cost analyses were used in annual budget justifications. However, as the gas supply conditions moved from shortage to surplus and the political support for public R&D waned, the rules of the game and the measures of success changed.

The DOE R&D Program. The initial DOE R&D program s monitoring and evaluation process, involving independent outside technical experts, served the program well. As new information was collected and compared with expectations, a series of significant shifts in the program occurred. For example, the geopressured methane resource was found to be geologically flawed, the program was terminated. At the same time, other priorities and budget shifts occurred with increases for tight gas and coalbed methane and decreases for gas shales, bringing the individual technology area budgets into closer line with their resource potential.

However after a few years, as the gas shortage turned into a gas surplus, much of the national level evaluations and mid-course adjustments became politically driven rather than analytically founded. The coalbed methane R&D program was essentially shut down. The gas shale R&D program stayed on life support only due to Appalachian Basin political support. Subsequently the program was terminated in 1992. Tight gas R&D survived, but at a dramatically reduced level.

In recent years, DOE s R&D monitoring and evaluation process has again become much more analytical and rigorous. While no sense of urgency has yet emerged for using R&D or incentives to stimulate additional natural gas production (even though natural gas prices are at an all time high and concerns exist again about gas curtailments), several important management steps have been taken. A Strategic Center for Natural Gas has been established at the National Energy Technology Laboratory and a National Research Council/National Academy of Sciences evaluation of the accomplishments and benefits of each of the unconventional gas technology areas is underway.

The GRI R&D Program. From its inception, the Gas Research Institute was mandated by the Federal Energy Regulatory Administration (FERC) to perform extensive cost-benefit analyses, set forth rigorous budget justifications, and hold several levels of advisory board review. This process and a clear focus on unconventional gas served GRI and its R&D program well. In 1994, however, GRI switched from a resource-based program addressing unconventional gas to a generic E&P technology-based program. At that point, GRI began to look like any other industrial R&D shop, lost its national gas supply mandate, and found difficulties justifying its program costs and benefits to industry.

Discussion Of Results. Unconventional gas offers one of the great success stories of national benefits and progress in technology. A poorly-understood, high-cost energy resource, one that the U.S. Geological Survey had not even included in its national appraisals of future gas resources (until their most recent 1995 assessment), is now providing major volumes of annual gas supplies and helping meet growing domestic natural gas demand (Table 1):

Unconventional natural gas provided 4,500 Bcf of supply in 1999, up from 1,600 Bcf twenty years ago.

Proved reserves of unconventional gas are 52 Tcf, up from 20 Tcf twenty years ago; remaining recoverable resources of unconventional gas are estimated at 400 Tcf to 500 Tcf, Table 2.

Looking ahead, based on projections by DOE/EIA s National Energy Modeling System (in AEO 2001), considerable further development of this resource base is expected, assuming a continuing strong pace of technology progress. By 2010, annual unconventional gas production is expected to reach 6,700 Bcf. The recent NPC Natural Gas Study expects a similar contribution from unconventional gas, estimating 6,800 Bcf of supply in 2010 from these resources.

These lofty expectations for unconventional gas depend on continued strong technology progress. Recent cutbacks in industrial R&D, the small size of DOE s gas supply program, and the termination of the Gas Research Institute s public R&D on unconventional gas raise serious concerns on the future pace of technology progress. The NPC Study highlights its concerns by stating, However, recent (declining) trends in research and development spending raise concerns regarding this (aggressive pace of technology improvement) assumption.

1. Tight Gas Sands. By the mid-1970 s, industry knew that large quantities of natural gas resources existed in tight (low permeability) formations. However, the flow and production of gas from most of these tight formations were too low to support economic recovery. A handful of independents explored for areas where nature had sufficiently fractured this tight rock to make it productive, but generally with a poor record of success.

The combined DOE, GRI and industry R&D programs, plus a set of modest tax incentives, unlocked the gas resource held in these tight rocks. The gas play, born in the Appalachian and San Juan basins, expanded rapidly into the major Rocky Mountain gas basins and more recently into Texas and the Mid-continent. By 1999, annual tight gas production was 2,900 Bcf, up from 1,500 Bcf in the mid 1970 s. Proved tight gas reserves were 35 Tcf from over 50,000 producing wells (not including the numerous older low producing tight gas wells in the Appalachian Basin), with 50 Tcf of tight gas having been produced since the initiation of the R&D program.

2. Gas Shales. At the start of the DOE R&D Program, the Appalachian Basin gas shales were a small, declining resource providing 70 Bcf per year. Annual new well drilling averaged only 200 wells and proved reserves were below 1 Tcf. Wells were being completed open hole, with little definition of productive pay zones, and were being stimulated with nitroglycerine (a remnant of early 1900 s technology). Much of the activity was centered in the Big Sandy area of eastern Kentucky. Little understanding existed on key gas storage and production mechanisms nor about geologically similar gas shale plays in other parts of the country.

By 1999, annual gas shale production had reached 370 Bcf. Proved reserves were 5 Tcf, with another 4 Tcf having been produced in the twenty years from 1978 to 1998. Stimulated by Section 29 tax credits and the expansion into new gas shale basins in Michigan and North Texas, well drilling climbed sharply. Over 17,000 productive gas shales wells were drilled from 1978 to 1999 with a peak of 1,700 gas shale wells completed in 1992, the last year wells could qualify for tax credits.

3. Coalbed Methane. The combination of building a scientific base of knowledge, fostering appropriate technology and providing economic incentives launched the birth of a new natural gas industry -- coalbed methane -- now with nearly $10 billion of capital investment. Much of the early development was by independent production companies such as Devon Energy, Meridian Oil and Taurus Energy, who saw their gas production, reserve holdings and market capitalization rise sharply.

Coalbed methane production climbed from essentially zero at the start of the R&D program to 1,250 Bcf in 1999, from three significant basins. Proved reserves were 13 Tcf from over 7,000 producing wells, with another 8 Tcf having already been produced. The introduction and continuing adaptation of technology enabled the industry to remain profitable and vigorous, even after the 1992 expiration of Section 29 tax credits. Today, several new coalbed methane basins and plays are being actively developed, including the Powder River (Wyoming), Raton (Colorado), and Uinta (Utah), providing a base for continued growth.

4. Geopressured Methane. While considerable geologic and reservoir knowledge was gained, no commercial natural gas production was established for this resource. Still, the R&D program in geopressured methane helped bring a strong dose of reality and understanding on the viability, or lack of, for this gas resource and helped dispel the speculation that a 1,000 years of natural gas was at hand.

Lessons Learned.

Twenty years have passed since the DOE R&D and incentive programs were launched in unconventional natural gas. What lessons and insights might one be able to draw from this rich base of experience that would be relevant to other emerging DOE R&D programs such as Carbon Sequestration? Among the many lessons learned, ten stand out:

1. When rigorously planned and managed, government supported R&D can be highly successful, providing significant benefits to the domestic economy. The DOE and GRI R&D programs introduced knowledge and hardware that turned low productivity, high cost resources into a reliable source of new natural gas reserves and supply. Using a net profits value of $0.50 per Mcf of additional natural gas production and reserves due to advances in technology and economic incentives, the national economic benefits of unconventional gas are over $50 billion, not including future development.

2. Establishing a scientifically-based knowledge base the intellectual foundation, is an essential first step. The negative outlook for coalbed methane, that stemmed from an ill-advised and unsuccessful drill and hope field demonstration project, was overcome when a strong scientific foundation was established.

3. Joint industry/government partnerships and implementation help leverage R&D resources, bring practicality to the program, and accelerate commercial implementation. The GRI unconventional gas program regularly benefited from industry cost sharing and advice. DOE began to realize similar values when it increasingly turned to industry/government partnerships for implementing tight gas and gas shales R&D.

4. A critical mass of funding and sufficient time are essential for achieving success, particularly for ambitious, breakthrough efforts. The timely and efficient development of the coalbed methane resource had a major setback when the DOE R&D was prematurely terminated. Fortunately, GRI continued the R&D on this resource and made it one of its high priorities, enabling the technology to mature, to be rigorously field tested and to achieve success.

5. Economic and tax incentives can greatly accelerate industry s adoption of technology by helping justify capital, by lowering economic risk and by challenging the financial community s imagination. The tremendous boost in new investment and well drilling, seen by all three of the unconventional gas resources, is a testament to the power of properly structured economic and tax incentives.

6. Special purpose performance based rather than broadly structured or input based economic incentives are a key to success. The highly focused Section 29 tax had considerably larger impacts credits to the unconventional gas industry than the general purpose R&D tax credit available to all industry.

7. For maximum effectiveness, the incentives need to be sufficiently attractive and long lasting but also have a sunset provision. Section 29 tax credits significantly improved project economics during the initial risky phase of unconventional gas development. As the technology and resource understanding matured, these risk premiums became less, enabling the unconventional gas industry to compete for project approval and capital without the need for continued incentives.

8. Independent evaluation of fundamental assumptions, data and results, is essential for avoiding wasting scarce R&D resources. The independent review of the geology and science of geopressured methane helped close down a large R&D program targeting this geologically flawed and economically non-viable resource.

9. Cost reductions and efficiency improvements in geologically based technologies rely as much on adapting the technology to the geologic setting as on fundamental breakthroughs. Successful results in the various coalbed methane and gas shale basins required selectively adapting technology rather than blindly applying methods that worked in other geologic settings. Assembling detailed geologic and reservoir data on each of the high potential basins needs to be a priority for R&D.

10. Efficiently disseminating technology to industry requires a comprehensive program of technology transfer ranging from publications for the informed layman to high visibility flagship field demonstrations. GRI s publication of the Quarterly Review of Methane from Coal Seams Technology, the numerous articles prepared by its technical contractors and the major field laboratory at Rock Creek coupled with direct greatly reduced the time for technology penetration and implementation by industry.

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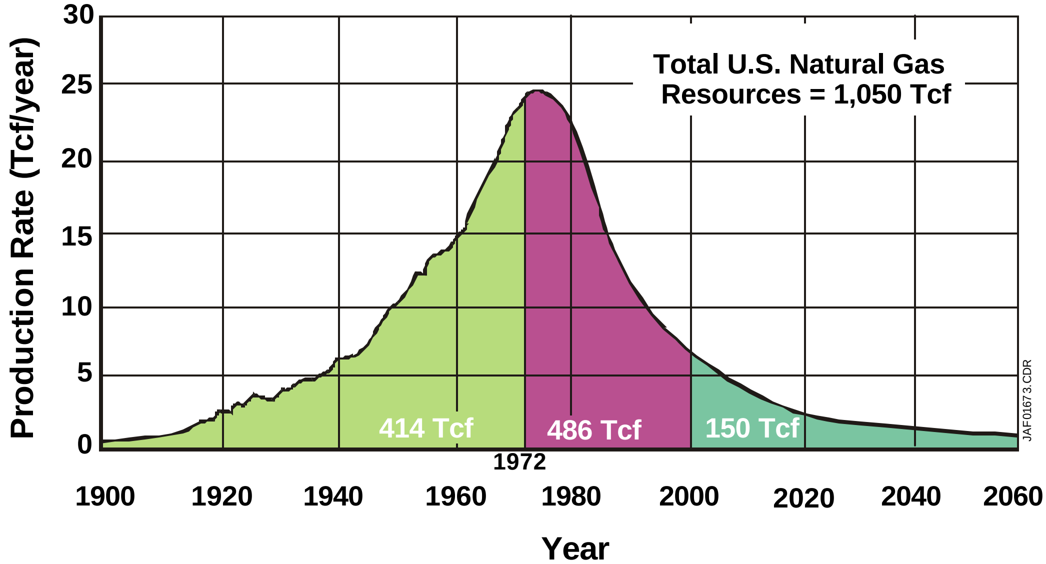
Figure 1. Past Outlook for U.S. Gas Production



(Modified from Hubbert, 1974)

Figure 2. Natural Gas Resource Pyramid Lower-48 States

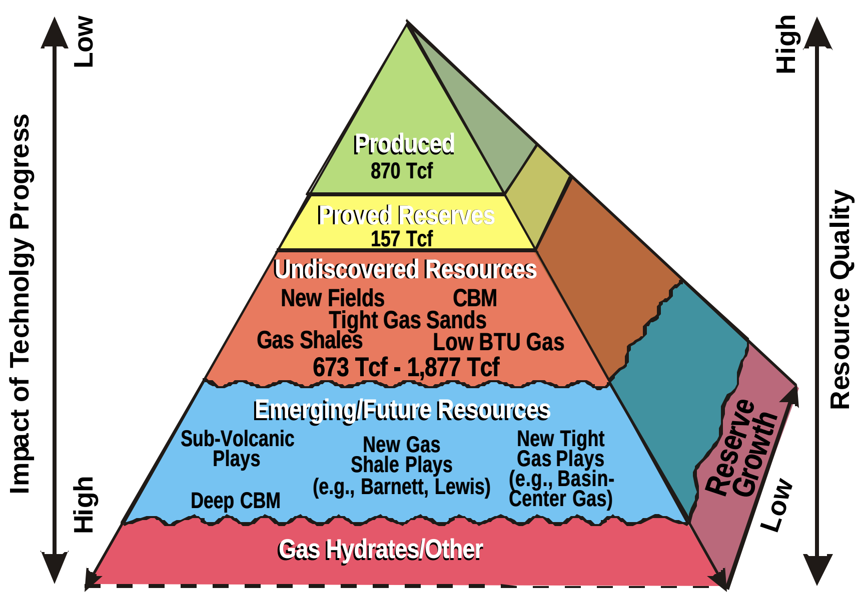


Table 1. Unconventional Gas: Past and Present

	1978	1999
Tight Gas Sands		
Production (Bcf)	1,560	2,900
Reserves (Tcf)	19	35
Gas Shales		
Production (Bcf)	70	370
Reserves (Tcf)	1	5
Coalbed Methane		
Production (Bcf)	-	1,250
Reserves (Tcf)	-	13
TOTAL		
Production (Bcf)	1,630	4,520
Reserves (Tcf)	20	53

Table 2. Status Of Natural Gas Resources (Lower-48) (Tcf)

	Proved Reserves	Additional Resources
Conventional Onshore	72	586
Unconventional	53	371
Federal Offshore	33	352
Deep Gas	7	*
TOTAL (L-48)	158	1,309

****Included in conventional onshore***