Nature and Importance of Technology Progress for Unconventional Gas

Scott R. Reeves, George J. Koperna and Vello A. Kuuskraa
Advanced Resources International, Houston, TX and Arlington, VA

Introduction. At the core of every successful unconventional gas play are two common themes - - the continuous search for improvements in technology and the relentless pursuit of cost and operating efficiencies. It is these two themes that have transformed these previously overlooked uneconomic resources - - tight gas sands, coalbed methane and gas shales - - into today's largest single source of domestic natural gas production. The basic process, repeated over and over again, is that one or more new technology "concepts" lead to breakthroughs that transform the play from a technical curiosity to economic feasibility; subsequent cost and operating efficiencies then permit aggressive commercial development and the extension of the play to less-favorable reservoir environments.

This cycle of initial technology "breakthroughs" followed by aggressive cost reductions can be seen in the evolution of per-well recoveries for unconventional gas plays. At first, the per-well recoveries are relatively low. Then, they improve as a key technology concept is customized and applied to the particular reservoir properties of the gas play. In the later, more mature stages of the play, development of per-well recoveries decline as the less favorable reservoir environments of the play are developed. However, cost and operating efficiencies (gained over years of experience) allow the play to remain economic. An example of this technology and per-well performance cycle is presented in Table 1 for two significant tight sand plays in the San Juan Basin - - the Pictured Cliffs (with 8.7 Tcf of cumulative gas production) and the Dakota (with 6.7 Tcf of cumulative gas production).

Table 1. Trends in Technology and Well Performance for Two Tight Sand Plays, San Juan Basin

Time Period/ Technology Phase	Pictured Cliffs (Bcf/Well)	Dakota (Bcf/Well)
1980-1989 (Initial Efforts)	0.69	0.89
1990-1995 (Technology Progress)	0.99	1.03
1996-1999 (Step-Out Development)	0.83	0.73
2000-2005 (Operating Efficiencies)	0.51	0.58

In the fourth article in this six-part series on unconventional gas, this technology and performance cycle is examined further, focusing primarily on the importance of maintaining technology progress and further pursuing cost and operating efficiencies for unconventional gas development. This article also addresses the plays and types of technologies that will likely play a key role in future unconventional gas production and how maintaining technology progress may be achieved in the coming years.

Nature of Technology Progress. Figure 1 captures a number of key themes at the heart of technology progress in unconventional gas.

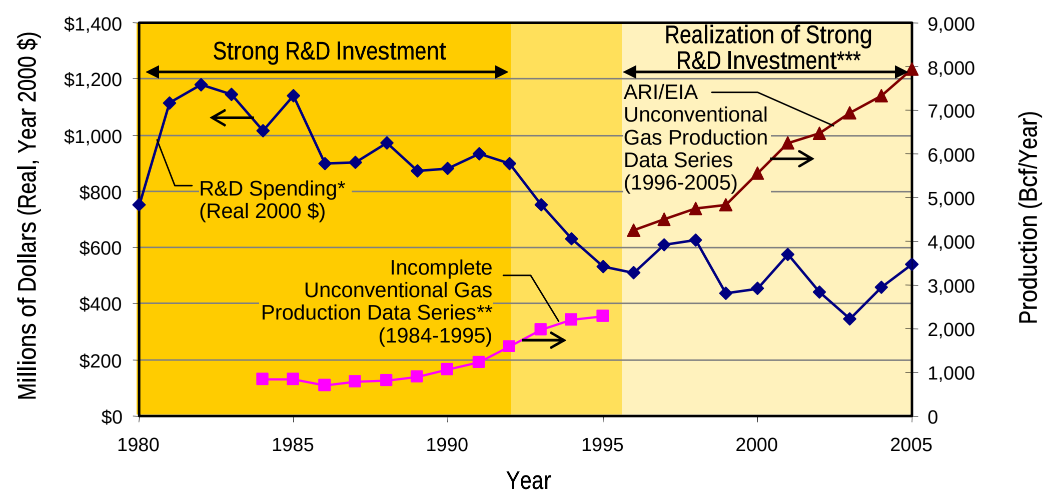
- First, we note the strong level of industry investment in oil and natural gas recovery R&D that occurred during the 1980s and early 1990s. (This figure is based on data from 29 major U.S.-based energy producing companies (EIA, 2006).) In looking at this data, it is important to recognize that, given a majority of these companies are multinational, the great bulk of this R&D investment was directed overseas to oil development and to deep water technologies. The recently issued NPC Global Oil and Gas Study (NPC, 2007)[1] puts this situation into clear perspective - - "R&D dollars, like capital expenditures, follow the most attractive opportunities, and these are increasingly found overseas". As such, "the percentage (of the R&D dollar) focused on U.S.-specific needs is relatively small". Even smaller is the percentage of these R&D dollars directed to domestic unconventional gas, a resource that was, in the past, considered "marginal" by the bulk of these major companies.

- Second, an important portion this post-R&D investment in unconventional gas was stimulated as "cost share" to key Gas Research Institute (GRI) and Department of Energy (DOE) projects. These included the Rock Creek Multiple Coal Seams Field Laboratory that established the scientific foundation for coalbed methane and the Multi-Well Experiment that subsequently provided the foundation for today's hydraulic fracture diagnostic technology. These field-based R&D efforts were instrumental in building the knowledge base and technology for economically producing coalbed methane and tight gas sands. Significant GRI and DOE R&D budgets in the 1980s and early 1990s helped define the technology needs and opportunities ("concepts") in unconventional gas and "bought down" the risks of early technology application.

- Third, we note the onset of increasing commercial-scale production of unconventional gas in the mid 1990s. The timing of this onset of increasing production very closely reflects a key technology finding set forth in the recent NPC's Global Oil and Gas Study (NPC, 2007) - - "Commercializing technology in the oil and gas market is costly and time-consuming; an average of 16 years passes from concept to widespread commercial adaption."

- Finally, we note the onset of higher domestic natural gas prices, starting in year 2000, when Henry Hub spot prices consistently exceeded $4 per Mcf. These higher prices along with earlier (1982 through 1992) Section 29 tax credits, provided the capital and economic support for applying advanced unconventional gas technology at significant commercial scale.

Figure 1: Investments in Oil and Gas Recovery R&D and Unconventional Gas Production



*Source (EIA, 2007)
**Does not include data from 6 major unconventional gas basins.
***Assumes 16 year lag from technology concept to widespread commercial adoption (based on NPC, 2007)
Source: Advanced Resources International, 2007

Noteworthy examples of such technology “breakthroughs” include the concepts of stimulation through cavitation for the Fruitland coals in the San Juan Basin Fairway, the application of slickwater-fracturing in the Fort Worth Basin Barnett Shale, and the pursuit of low-resistivity tight gas sand pay in the Jonah and Pinedale fields in the Greater Green River Basin.

There are also numerous examples that demonstrate how field-based R&D efforts can have an important impact on the pace of unconventional gas development. These examples include the Department of Energy’s (DOE) Multi-Well Experiment (MWX) site in the Williams Fork Formation of the Piceance Basin, the Gas Research Institute’s (GRI) Rock Creek Multiple Coal Seams Completion project in the Black Warrior Basin, GRI’s Western Cretaceous Coal Seams Project in the San Juan Basin, and GRI’s Antrim Shale R&D program in the Michigan Basin. While these field-based R&D efforts helped build the base of science, they were most valuable in accelerating the commercial development of these four unconventional gas plays (Figures 2 through 5).

Figure 2: Field R&D Activities and Williams Fork Tight Sand Production Growth, Piceance Basin

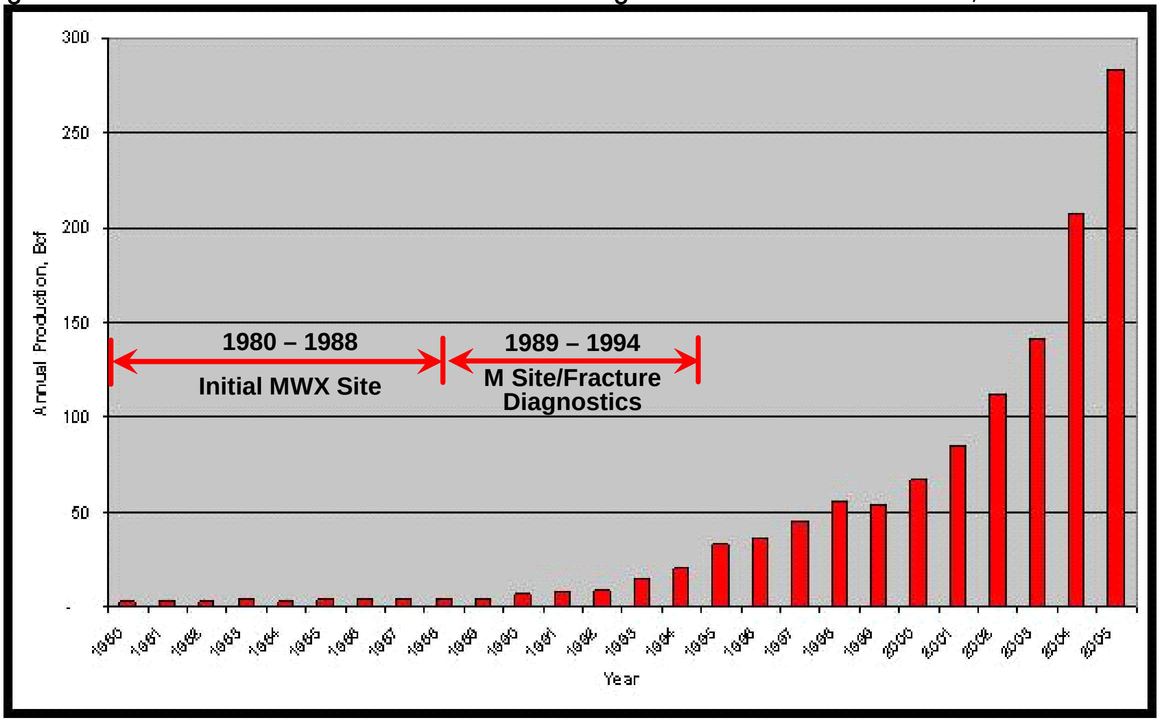


Figure 3: Field R&D Activities and Pottsville Coalbed Methane Production Growth, Black Warrior Basin

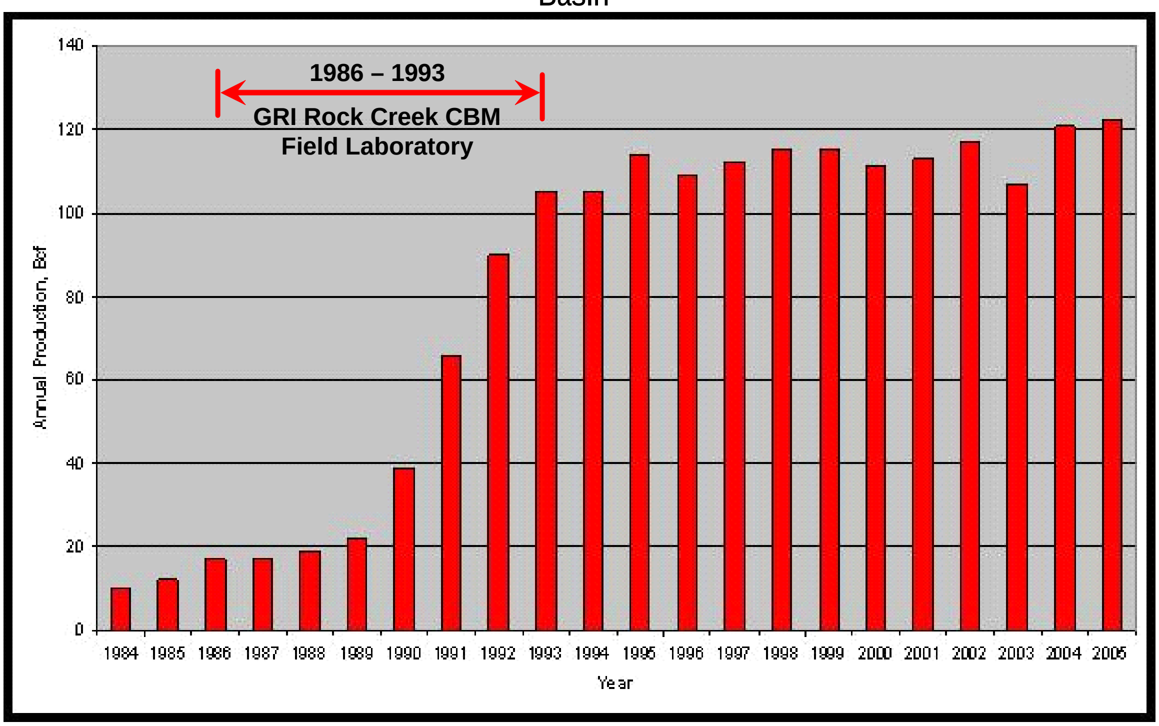


Figure 4: Field R&D Activities and Fruitland Coal Production Growth, San Juan Basin

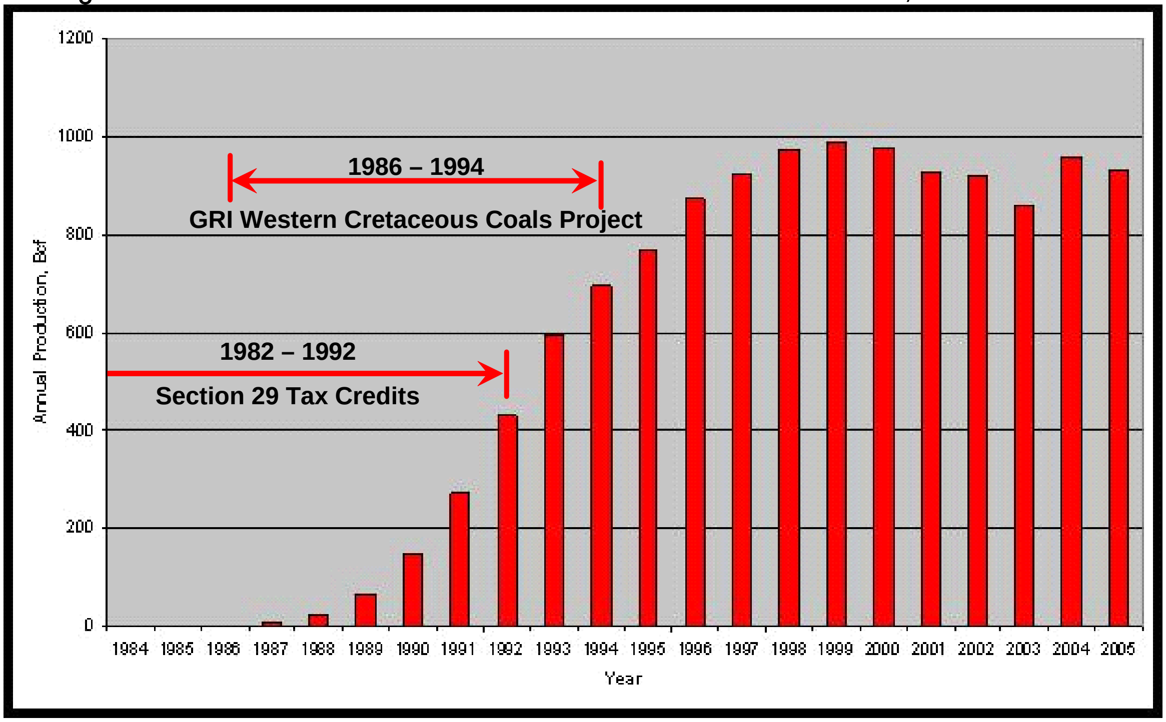
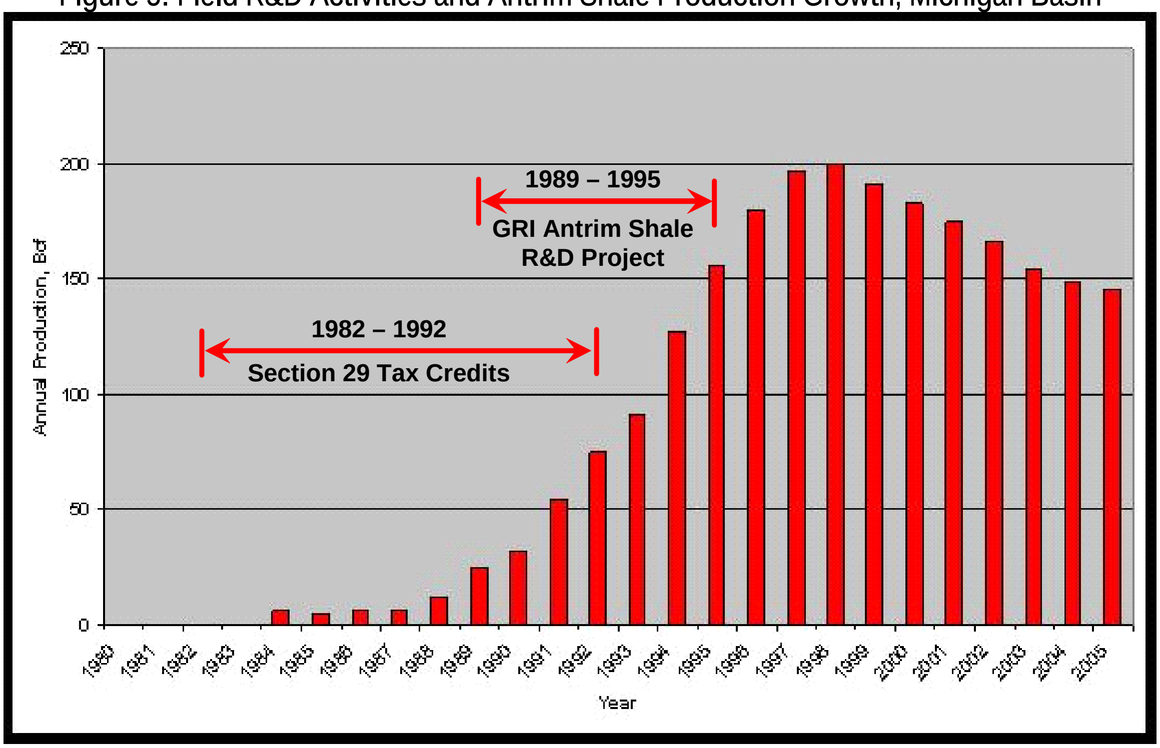


Figure 5: Field R&D Activities and Antrim Shale Production Growth, Michigan Basin



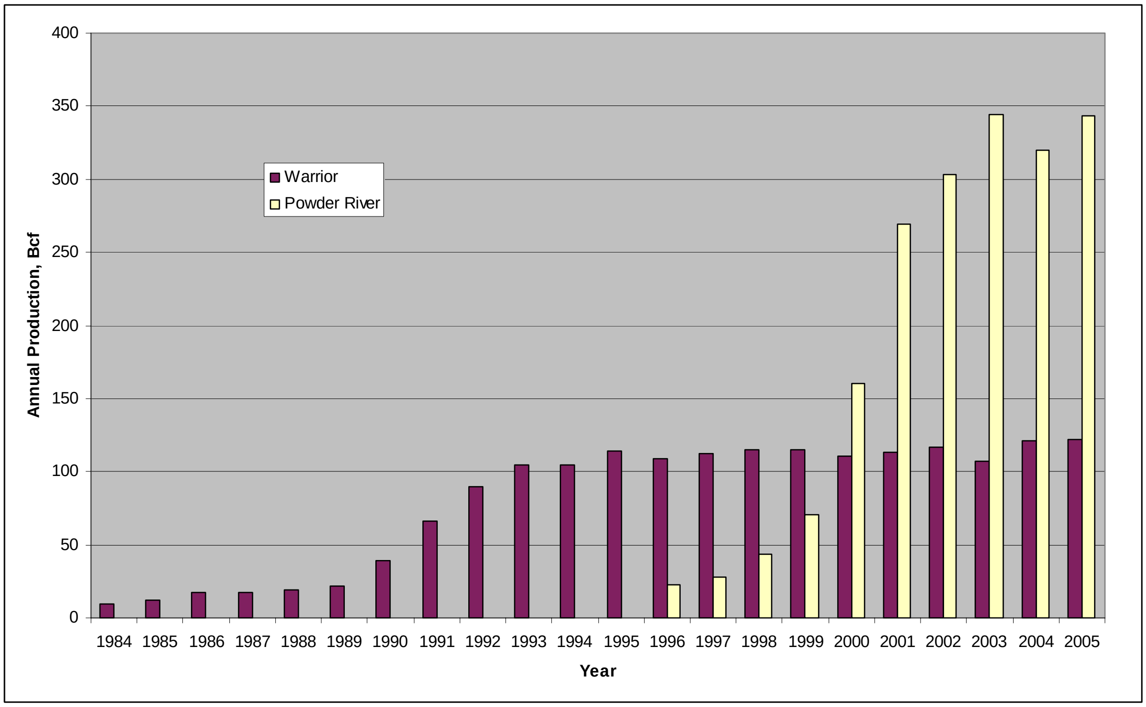
It is noteworthy that a common trait shared by each of these successful field R&D programs was the close partnership between an outside R&D team, a team with considerable independent financial resources and technical expertise, and one or more local operating companies to ensure that the R&D was focused on topics that had practical, value-adding impacts. Either party in isolation would not have achieved the same level of success in the same time frame. An R&D team, however well-funded, could not produce the same results without the active involvement of field operators. By the same token, an operator (with limited R&D resources) would likely not have taken the risks of independently pursuing and aggressively applying new, unproven technology concept.

This brings us to a final, yet important, realization with respect to technology development partnerships - - they both help **define** and **validate** a technology concept and then help ***accelerate*** the pace of technology adaptation and application to the site-specific needs of each unconventional gas play. Left to their own scientific interests and needs, operators would eventually define and validate the technologies required to unlock an unconventional play and then adapt this technology to their reservoir settings. The question is — *with benefit of an R&D partner and pooling of industrial expertise, how much more quickly would this process evolve?*

To examine this question, a comparison of the growth in two pairs of plays are examined – the Warrior and Powder River Basin coalbed methane plays (Figure 6), and the Antrim and Barnett gas shale plays (Figure 7). In both cases, the former, less-prolific play received considerable field R&D attention and as a result achieved accelerated commercial-scale gas production. The latter plays, despite ultimately proving to possess superior productive and commercial qualities, took much longer to achieve the same level of gas production. In the coalbed methane case, with the benefit of a strong GRI-sponsored field R&D program, the Warrior Basin achieved a production level of 50+ Bcf/year in 1991, whereas the more prolific Powder River Basin play, even with the benefit of previously developed CBM science but without the benefit of a strong field-based R&D program, did not achieve that level of production until 2000. Similarly, the

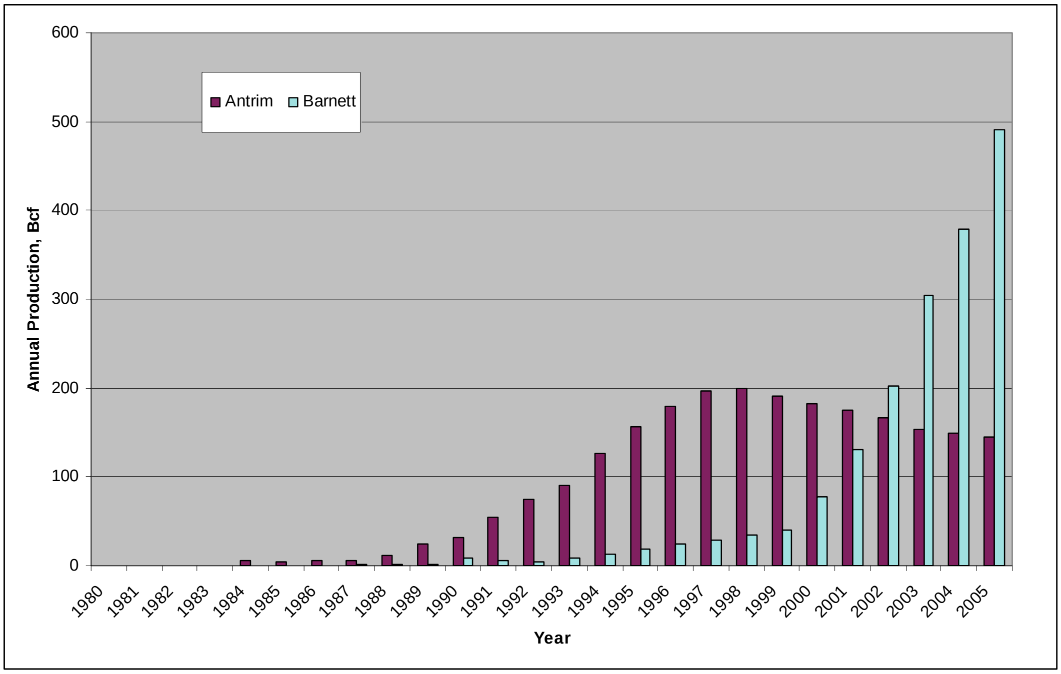
Antrim Shale achieved a production level of 50+ Bcf/year in 1991, but the more prolific Barnett Shale did not reach that level of production until 2000.

Figure 6: Comparison of Coalbed Methane Production Growth for the Warrior and Powder River Basins



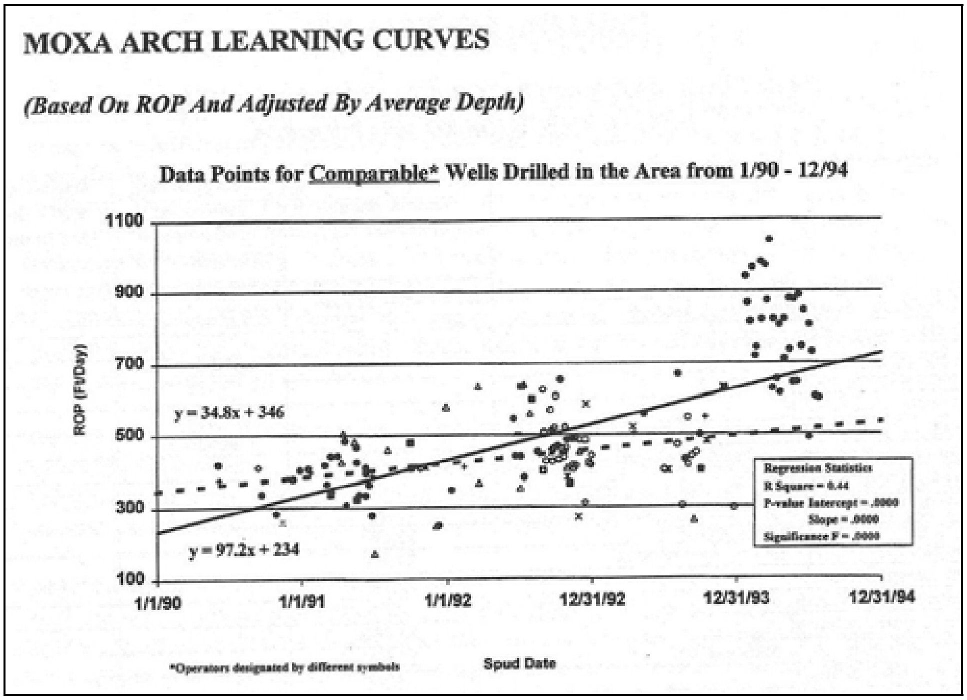
Thus based upon this somewhat anecdotal evidence, once a technology concept is shown to be valid, field-based R&D efforts may accelerate application of this technology to commercial levels by as much as a decade.

Figure 7: Comparison of Gas Shale Production Growth for the Antrim and Barnett Plays



Pursuing Operational Efficiencies. The concept of cost operating efficiency gains in unconventional gas is well established. Examples include the 24/7 "frac-factory" concept being implemented by Shell and Ultra Resources in some of the tight gas sand plays in the Rockies; Southwestern Energy's assembly of a customized drilling fleet for horizontal wells in the Fayetteville Shale; and, the "assembly-line" process being implemented for drilling and completing Powder River Basin coalbed methane wells.

Cost and operating efficiency gains are perhaps best illustrated by improvements in drilling penetration rates for a play over time. Figure 8 illustrates this trend for drilling wells to the Dakota Sand at the Moxa Arch of the Greater Green River Basin during 1990 to 1994. While documented evidence of similar trends of "learning" and cost reductions for other areas of unconventional gas development, such as hydraulic fracturing, are lacking in the public domain, their existence and importance nevertheless exist.



Source: (J. F. Brett, 1995)[2]

Figure 8: Improved Rates-of-Penetration over Time, Dakota Sand, Greater Green River Basin

In today's economic environment of rapidly rising service and supply costs, it may not be possible to achieve absolute cost reductions via operating efficiencies. However this does not mean that such gains are not being realized. It means that costs are increasing faster than gains in efficiency. This is an unsustainable situation. At some point operational efficiencies need to outpace increases in service and supply costs or a significant number of the unconventional gas plays will become prematurely uneconomic.

An important question is — *who are the R&D entities that will develop the new concepts and help facilitate technology progress in unconventional gas in the timeframe required to meet rising natural gas demand?* The two organizations that funded prior publicly-accessible R&D in unconventional gas — the U.S. DOE and the GRI — no longer do so due to a lack of funding. Private sector funding for supply related oil and gas recovery has declined by two-thirds (in real dollars) (EIA, 2006),[3] from its peak in the early 1980's to 2003, although an increase is noted in the past two years, Figure 1. Many of the companies that once had large R&D programs have either disbanded them, or they disappeared as a result of mergers and acquisitions. Many of those that remain have been retooled into technical service providers, primarily in support of large scale international operations (Gratton, 2005).[4]

Fortunately, the Energy Policy Act of 2005, establishes funding for unconventional gas R&D at $14 million per year for the next 10 years (out of an annual R&D allocation of $50 million). While a most valuable first step, given the host of technical issues to be addressed and the increasing contribution being made by unconventional gas (now providing nearly 24 Bcf per day) a more robust R&D program would deliver higher value. The organization selected to oversee and manage this R&D is the Research Partnership to Secure Energy for America (RPSEA), a non-profit corporation formed by a consortium of premier U.S. energy research universities, industry and independent research organizations. In the area of unconventional gas, RPSEA's goals are to:

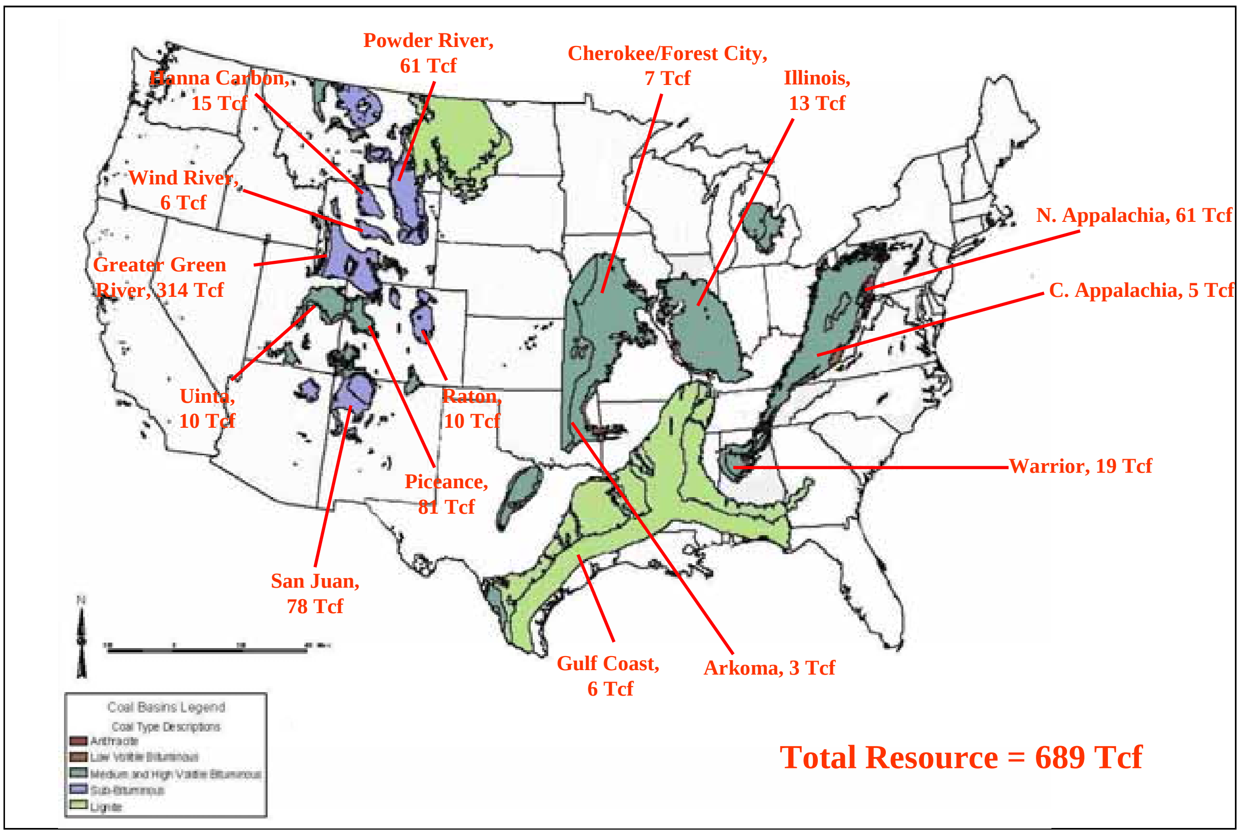
- Increase the size of the technically recoverable unconventional gas resource base by 30 Tcf.
- Convert 10 Tcf of technically recoverable unconventional gas to economically recoverable gas.
- Develop technologies for developing unconventional resources with minimum environmental impact.
- Emphasize science-building capacity and effective technology dissemination.

Basins/Technologies on the Horizon. As introduced in the third article in this series, the new and emerging unconventional gas plays that will require "next generation" technology development will likely include, among others:

- The deep poorly defined Upper Cretaceous (Mesaverde) tight gas sand plays in the Big Horn, Columbia and Unita basins.

- The deep coals of the Greater Green River and Piceance basins, containing an estimated 400+ Tcf of in-place resources; plus the Tertiary coals of the Gulf Coast (Figure 9).

- The Rocky Mountain gas shales along the Cretaceous-age seaway that stretches from the San Juan Basin in the south to the Big Horn Basin in the north, involving the Lewis, Mancos, Steele and Cody shales.



Source: (Reeves, 2003)[5]

Figure 9: Coalbed Methane Basins of the U.S.

The question is, *what types of technologies will be required to tap these currently undeveloped unconventional gas resources?* In our view, based on discussions with unconventional gas developers, this list includes:

- "Sweet-spot" detection methods – being able to identify in advance where the highly productive, naturally fractured "fairways" of a play exist.
- Reservoir characterization – being able to identify the entire productive pay interval.
- Advanced well stimulation methods – establishing the low-end of reservoir quality for using well stimulation to yield economic results?
- Enhanced recovery technology – using injection of nitrogen and/or CO_2 to accelerate and increase gas recovery from coals, shales and possibly tight sands.

With a vast untapped unconventional gas resource base, a strong demand for natural gas, a resourceful industry willing to explore and develop new unconventional plays, and an R&D organization willing to assist in technology development, many of the prerequisites of successful unconventional gas technology development are in-place. What is now required is an appropriate level of human and capital investment — to both create new unconventional gas technology concepts and then help accelerate their adaptation and widespread commercial application.

Authors

Scott R. Reeves is the Executive Vice President of Advanced Resources International, Inc., a research and consulting firm specializing in non-conventional gas, enhanced oil recovery and carbon sequestration. He provides technical consulting and advisory services to clientele throughout the world, and performs research on behalf of the U.S. Department of Energy, the Gas Technology Institute and others. Scott has published over 150 articles, papers and consulting reports and was a 2002/2003 SPE Distinguished Lecturer on Enhanced Coalbed Methane Recovery. Mr. Reeves received a BS in Petroleum Engineering from Texas A&M University and an MBA from Duke University.

George J. Koperna, Jr. is a Project Manager and Reservoir Engineer with Advanced Resources. He has over 10 years of experience on reservoir modeling and the injection of carbon dioxide for enhanced recovery and storage. Mr. Koperna is currently the technical co-leader for the DOE/SECARB's Mississippi saline reservoir CO_2 sequestration experiment and provides reservoir modeling for the two of DOE/SECARB's coalbed methane CO_2 storage pilots. Mr. Koperna's reservoir simulation expertise includes work on natural gas storage, CO_2 storage, and enhanced oil and coalbed methane recovery. He was the co-author of Advanced Resources recent CO_2-EOR "basin studies". Mr. Koperna holds B.S. and M.S. degrees in Petroleum and Natural Gas Engineering from West Virginia University.

Vello A. Kuuskraa is President of Advanced Resources International with over 30 years of experience in the oil and gas industry, particularly unconventional oil and gas resources, enhanced oil recovery and CO2 sequestration. He has a B.S. in Applied Mathematics from North Carolina State University and an MBA from the Wharton Graduate School, University of Pennsylvania. He serves on the Board of Directors of Southwestern Energy Company.

References:

1. National Petroleum Council; "Facing the Hard Truths about Energy", July 18, 2007.

2. J. F. Brett, M. K. Gregoli; "Successful Drilling Practices Study – Greater Green River Basin", Final Report, prepared for Gas Research Institute, GRI-95/0132.1, March, 1995.

[3] Energy Information Administration, *Performance Profiles of Major Energy Producers 2005*, DOE/EIA 0206(05), December 2006.

[4] Gratton, Patrick J.F., President of the American Association of Petroleum Geologists, Written Testimony Presented to the United States Senate Subcommittee on Energy and Water Appropriations, April 29, 2005

[5] Reeves, S.R., "Assessment of CO2 Sequestration and ECBM Potential of U.S. Coalbeds" Advanced Resources International, Inc., Topical Report, October 1, 2002 – March 31, 2003, U.S. Department of Energy, DE-FC26-00NT40924, February, 2003.