Interest in the economic value and development of natural gas from coalbeds in Pennsylvania grew during the late 1980s, resulting in a dramatic increase in production a decade later. Major growth in coalbed methane (CBM) as an unconventional source of natural gas continued from 1999 to 2008. This occurred in part because of increased knowledge of the CBM reservoir, improvement in drilling technology, higher gas prices, more favorable national economic conditions, and the need to expand our domestic energy resources. Since then, the number of new well permits decreased in 2009 owing to the global recession and focus on the Middle Devonian Marcellus shale gas play. However, commercial quantities of CBM are still being produced in seven counties of the southern and southwestern portions of the Main Bituminous field.

According to the Pennsylvania Department of Environmental Protection and the Pennsylvania Geological Survey Wells Information System, there are about 1,275 CBM wells in various stages of completion as of October 2012. The following coals of the Monongahela Group, Conemaugh Group, Allegheny Formation, and Pottsville Formation are among the principal CBM targets: Sewickley, Pittsburgh, Bakerstown (Upper and Lower), Brush Creek, Mahoning, Freeport (Upper and Lower), Kittanning (Upper, Middle, and Lower), Clarion, Brookville, and Mercer (Upper, Middle, and Lower). The most recent and complete annual production data compiled for 2008 reveals that CBM reached an all-time high of 11.6 billion cubic feet (Bcf). This could heat more than 168,100 households for a year. Currently, new production figures for 2009 through 2011 are being investigated to establish trends.

Total CBM resource estimates were quantified by the following sources: (1) Geomega, Inc. (1983 unpublished report) — 2,654 Bcf for Pennsylvania anthracite and bituminous coal; (2) Gas Research Institute (1988) — 51 trillion cubic feet (Tcf) gas-in-place for southwestern Pennsylvania and northwestern West Virginia; and (3) United States Geological Survey (1996) — 11.5 Tcf economically recoverable for the Northern Appalachian coal basin (Pennsylvania, Ohio, Maryland, and northern West Virginia). CBM, an energy source that rivals conventional natural gas in composition and heating value, continues to make a valuable contribution to our domestic energy mix on state and national levels.
Some of the reasons why Pennsylvania coalbed methane (CBM) should be used are: 1) a conservative estimate of natural gas recoverable from bituminous and anthracite coal beds totals 2,654 billion cubic feet (Bcf), of which well over half is classified probable and possible; 2) known coal bed locations yield low exploration costs; 3) proximity to pipeline infrastructure; 4) low capital investment due to relatively shallow depths versus conventional reservoir depths; and 5) the gas can be used for natural gas pipelines, electric power generation, cogeneration plants, and public utilities instead of wasteful venting to the atmosphere which contributes to the array of suspicious greenhouse gases.

Longwall mining method to extract coal underground in flat-lying strata; “gob” is the coal and surrounding strata above the coal that has collapsed during mining; “gob gas” is a dilute form of CBM emitted from the coal and surrounding strata above the coal during longwall mining owing to seepage of mine air into the gob area; heating values range from 300 to 800 Btu/cf (Bibler and others, 1997; photo courtesy of the Pennsylvania Coal Association).

Gas composition for selected coal beds in Armstrong, Cambria, Greene, and Somerset Counties.

Gas composition for selected coal beds in Beaver, Lawrence, Somerset, and Washington Counties.

How Is CBM Used?
1. Pipeline fuel
2. Sales to power grid
3. Electric generation (gas turbines, diesel generators, and internal combustion engines)
4. Mine operations, other local uses
5. Biocatalysts, other biofuel uses
6. Cogeneration
7. Fuel cells
8. Submerged evaporators (treat wastewater)
9. Chemical feedstock (methanol, ammonia, etc.)
10. Raw material (LNG, gas products)
ABSTRACT

PENNSYLVANIA COALBED METHANE UPDATE
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Interest in the economic value and development of natural gas from coal beds in Pennsylvania was stimulated by federal research during the late 1970s and early 1980s, resulting in a dramatic increase in production a decade later. Major growth in coaled methane (CBM) as an unconventional source of natural gas continued from 1999 to 2008. This occurred in part because of increased knowledge of the CBM reservoir, improvement in drilling technology, higher gas prices, more favorable national economic conditions, and the need to expand our domestic energy resources. Since then, the number of new well permits decreased in 2009 owing to the global recession and focus on the Middle Devonian Marcellus shale gas play. However, commercial quantities of CBM are still being produced in eight counties of the southern and southwestern portions of the Main Bituminous field. According to the Pennsylvania Department of Environmental Protection and the Pennsylvania Geological Survey Wells Information System, there are a total of 1,275 permitted CBM wells in various stages of completion and status as of December 2012. About 985 of these wells are classified as producing, active, and inactive. The following coals of the Monongahela Group, Conemaugh Group, Allegheny Formation, and Pottsville Formation are among the principal CBM targets: Sewickley, Pittsburgh, Bakerstown (Upper and Lower), Brush Creek, Mahoning, Freeport (Upper and Lower), Kittanning (Upper, Middle, and Lower), Clarion, Brookville, and Mercer (Upper, Middle, and Lower). The most recent and complete annual production data compiled for 2012 reveals an all-time high figure of 16 billion cubic feet (Bcf). This could heat about 240,000 households for a year.

Total CBM resource estimates were quantified by the following sources: 1) Geomega, Inc. (1983 unpublished report)—2,654 Bcf (2.7 trillion cubic feet [Tcf]) for Pennsylvania anthracite and bituminous coal; 2) Gas Research Institute (1988)—51 Tcf gas-in-place for southwestern Pennsylvania and northwestern West Virginia; and 3) U.S. Geological Survey (1996)—11.48 Tcf economically recoverable for the Northern Appalachian coal basin (Pennsylvania, Ohio, Maryland, and northern West Virginia). CBM, an energy source that rivals conventional natural gas in composition and heating value, continues to make a valuable contribution to our domestic energy stream on state and national levels.

Coal: A Dual Energy Source

- One ton of unmined bituminous coal
  * 45–86% carbon
  * 21–30 million Btu/ton (MMBtu/ton) or 10.5–15 thousand Btu/lb (MBtu/lb)
- Methane gas
  * ¼–½ thousand cubic feet/ton (Mcf/ton) or 250–500 MMBtu
- Stores 6 times more gas than equivalent volume of rock in conventional gas reservoir

Why Is Methane Important?

- 23–25 times more effective than CO2 in trapping heat in atmosphere
- Increases tropospheric ozone
- Atmospheric lifetime is about 10 years
- Reduction in emissions have quick effect
- Many cost-effective options for reducing emissions

Resource and Reserve Estimates

- Northern Appalachian Coal Basin: 61 Tcf (51 Tcf for WV and PA) total gas-in-place (Kellaffant and others, 1988); 11.48 Tcf (USGS Oil and Gas Resource Assessment, 1996)
- Pennsylvania: 2,654 Bcf in anthracite and bituminous coals (Geomega, 1989)
- Pennsylvania: ~ 900 Bcf (USDOE, EIA, PADEP)
- Greene and Washington Counties: > 500 Bcf in Pittsburgh (USBM, 1979)

HOW PENNSYLVANIANS HEAT

Major coal and CBM producing basins in the United States (U.S. Department of Energy, Federal Energy Technology Center, Morgantown, West Virginia).

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- Greene and Washington Counties: > 500 Bcf in Pittsburgh (USBM, 1979)
Results from horizontal drillholes show that drilling perpendicular to the direction having the highest concentration of face cleats will yield 2.5 to 10 times as much gas as holes drilled at right angles to the secondary or butt cleat (Diamond, Elder, and Jeran, 1986). More importantly, the highest permeabilities (directional permeability) providing good gas flow are parallel to the face cleat orientation (Adams and others, 1984; Diamond, Elder, and Jeran, 1986). Maximum gas production can be achieved after the highly permeable reservoir has been drained. Degree of drainage radius, a function of fracture permeability, is also very critical to the commercial development of CBM.

See Figure 16 for a distribution of Pennsylvania coalfields and associated coal ranks (Pennsylvania Geological Survey, 1992, third edition).

See Figure 17 for a photo of coal showing natural fractures, or face and butt cleats (photo courtesy of James R. Shaulis, Pennsylvania Geological Survey).

See Figure 18 for a cleat system and two-phase flow model of gas in a block of coal (permission from ICF Resources, Incorporated, 1988).

See Figure 19 for a map of the Northern Appalachian coal basin (permission from the Gas Research Institute in Kelafant and others, 1988; modified from Colton and others, 1981; modified from Kulander and others, 1980).

See Figure 20 for a map showing the areal extent, drillable area, and gas-in-place (GIP) for target coal groups.

Impact of U.S. CBM Resource
- Resource is throughout nation (37 states)
  - Compatible with gas infrastructure
  - Use of CBM can permit regional energy independence
  - Potential resource estimate 700 Tcf, 100 Tcf recoverable, projected to add ~12% to U.S. supply
  - Compared to conventional gas well drilling or production
    - Lower investment, gas cost
    - Less environmental impact
**INDUSTRY ACTIVITY**

**Types of CBM Wells**
- Vertical (V) well-producing from one or more coal seams
- V well-drilled into one coal seam withBrevis of several horizontal (H) bores extending through coal, all single well completions
- V well-drilled through multiple coal seams with laterals completed in and producing from all coals
- Former gob gas (coal mine methane/CMM) vents converted to CBM production

**Permitted CBM Wells**

- **Washington County**
  - Full scale ventilation air methane abatement project under development
  - Converted gob gas (coal mine methane/CMM) vents to CBM production

- **Cambria, Fayette, Indiana, and Westmoreland Counties**
  - ~ 300 producing wells in Pittsburgh to Brookville coals
  - Gas quality: 70% CH₄ dried, treated for N₂, O₂, CO₂; 990–1,015 Btu/scf (saturated)
  - Gas production: 200–2,600 Mcfd; wells bore in 24–4,900 barrels/day (2010)

**Regulatory Issues**
- Well Spacing: 10–320 acres, depth dependent
- Hydraulic Fracturing: Protection of fresh groundwater—surveys by EPA, GWPC, and IOGCC
- Water, Land Use/Urban Interface: Access roads, pipeline location, water loss, noise, and access to federal lands
- Surface Equipment: Compressors, tanks

**Summary**
- Western Pennsylvania continues CBM growth
- Environmental and energy benefits
- Economics favorable in areas at $3–4 gas price (recompleted/shallow wells)
- Near-term potential market
- Development depends on multiple completions, improved technology, increased gas price, increased CO₂ sequestration credit, and need for domestic energy

**Major CBM Operators**
- (active and planned wells)
  1. Alpha Natural Resources—formerly Coal Gas Recovery, LP (Fayette County)
  3. Jesmar Energy, Inc. (Washington County) and Varner No. 1, sold production from other five wells to Robin Energy, Inc.
  4. Keyrock Energy, LLC (Cambria, Fayette, Indiana, and Westmoreland Counties)
  5. Vessels Coal Gas, Inc. (Cambria County)

**Greene County**
- (Alpha Natural Resources, Inc.—formerly Coal Gas Recovery, LP)
  - ~ 45 directional wells in Sewickley, Pittsburgh, and Upper Freeport coals

**Domestic Energy Incentives**
- PA Alternative Fuels Incentive Grant Program (created by Act 166 in 1992)
  - Supports alternative & renewable energy sources; eligible
  - Requires 18% of electricity sold be from renewable and advanced energy sources by 2019; eligible
- PA Energy Harvest program (2003) $5 million/yr
- PA Coal to Diesel Program (2009)
  - Amends Coal Refuse Disposal Control Act (1968)
- PA Electric Power Authority
  - For clean, advanced energy projects (i.e., coal gasification, biodigesters, solar, micro-hydro, wind, other renewables; prototype, coal gasification, biodigesters, solar, micro-hydro, wind, other renewables)
  - * Gas Quality:
  - * Treatment:

**Ownership**
- Coal owner (1983 PA Supreme Court)
- 1983 case challenged by surface landowners
- CBM Review Board:
  - DOM 902 (Sewickley, Greene Co.)
  - DOM 903 (Sharon, Allegheny Co.)
  - HB 1847 (Cranberry Township, Allegheny Co.)
- Other conflict? Attempt negotiation
- Sometimes civil litigation
- Unresolved? Setup escrow accounts until rights are resolved
In the 1970’s, the Methane Recovery from Coalbeds Project (MRCP), former U.S. Bureau of Mines (USBM), and U.S. Department of Energy (USDOE) developed a series of pilot methane recovery projects in Pennsylvania whose success paved the way for future projects. Over the last thirty years, interest in the economic value of coal seam gas has attracted the oil and gas industry in the Commonwealth.

In a reconnaissance study of CBM, the Pennsylvania Geological Survey obtained cores from 240,000 households ranging from 1988 to 2009 and 2012. The most recent and complete annual resource assessment, typically from 500 to 2,000 feet. A total of 45 Bcf of CBM was produced from 1964-80 (Geomega, Inc., 1983). According to the U.S. Geological Survey oil and gas resources (Kelafant and others, 1988), and 2,654 Bcf (2.7 Tcf) in Pennsylvania

Northern Appalachian coal basin (includes Pennsylvania, Ohio, West Virginia, and Maryland), and north-central West Virginia. As revealed by a regional geologic mapping investigation with the West Virginia Geological Survey Digital Data Series DDS-30, CD-ROM, Denver, Colorado, 80 p.

Eureka! This stuff has new possibilities!!

CONCLUSIONS

Ownership

When the severity of mineral ownership rights among different owners exists, as it does in Pennsylvania, there is potential for conflict. Several options exist to address this issue. These include requiring the CBM lease to designate proposed wells and obtain the coal owner’s approval, as required by state law; or the CBM lease should specifically address the issue of conflicting uses and ownership on a case-by-case basis title search and analysis. Any successful development will depend on compromises between the oil and gas developer and landowner with the coal company.

All the indicators for successful gas production are present here. Cooperation between the gas producer and coal owner is necessary in cases of separate ownership and leases. Given the pros and cons, the developer must carefully evaluate the technical, economic, political, and legal aspects which are a critical part of planning a project in the Northern Appalachian coal basin.

Coal in general is an ideal reservoir rock. Its retention capacity is superior to that of a conventional natural gas sandstone or carbonate reservoir. Different ranks of coal have different capacities to store gas. In most cases, higher rank (and deeper) coals have a higher adsorptive or retention capacity for methane gas storage than lower rank coals. Methane contents for anthracite are known either to be anomalously high or low, but due to the lack of a good fracture system, production rates have been found to be low with minimal or no artificial stimulation. Steeply dipping and distorted coal beds complicate the scenario for favorable commercial development in the anthracite region. Based on the data available, economic potential in this area appears to be poor; however, more drilling should be done to determine if there are local pockets that would be conducive to development.

For locating favorable drilling sites for CBM in Pennsylvania are: 1) numerous coal formations, high rank coal beds (with a minimum of one foot in thickness if part of a multi-seam project); however, one or two seams may be just as economic as multiple seams depending on their gas content; 2) sufficient seam content within an individual coal bed, 125 to 150 ft./c; 3) sufficient depth or overburden thickness, at least 500 feet below the water table; in Pennsylvania, most identified coal beds between 500 and 2,000 feet deep are optimum targets; 4) favorable geologic structure, permeability, and porosity; fracture permeability preferably on the flanks of anticlines or synclines where the orientation and degree of jointing is more evident than on the structural axes; permeability ranging from 0.1 to 0.5 millidarcies; 5) sufficient reservoir pressure and gas saturation, 125 to 175 pounds per square inch of pressure; 6) stratigraphic traps to maintain reservoir integrity and minimize ambiguities, such as the rock identification for ownership purposes; and 7) target unmined coal seams or beds within a significant distance from the rate of active mining to minimize loss of methane due to migration to the surface, unless using the lower Btu gobs wells to intentionally drain the area within the active or abandoned mine and/or enrich or blend the gas for pipeline quality standards.

The target area for commercial development of CBM in Pennsylvania is roughly an elliptical-shaped region in the southwestern part of the state including most of Greene and parts of Washington, Fayette, Allegheny, Westmoreland, Armstrong, Indiana, and Cambria Counties. As revealed by a regional geologic mapping investigation with the West Virginia Geological and Economic Survey, the Pittsburgh, and the deepest coals that exist here, such as the Allegheny Formation coals and other coals near mines with Somerset Counties for their gas content. Supplementary data was acquired from industry in Fayette and Westmoreland Counties. Results from these tests demonstrated the presence of CBM, and USDOE. Graphs were plotted for comparisons and trends. Analyses of coal beds from 1995, the amount of recoverable CBM resources is needed to verify this.

REFERENCES


Pennsylvania Geological Survey (1992), Distribution of Pennsylvania coals, Map 11, color, 3rd ed., scale 1:2,000,000, 8.5” x 11”


U.S. Department of Energy, Federal Energy Technology Center, webmaster e-mail: webmaster.doe.gov, Morgantown, Wv.


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