[PS]Pennsylvania Coalbed Methane Update*

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Abstract

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Total CBM resource estimates were quantified by the following sources: (1) Geomega, Inc. (1983 unpublished report) — 2,654 Bcf for Pennsylvania anthracite and bituminous coal; (2) Gas Research Institute (1988) — 51 trillion cubic feet (Tcf) gas-in-place for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.

PENNSYLVANIA COALBED METHANE UPDATE

American Association of Petroleum Geologists Convention & Exhibition: May 19-23, 2013

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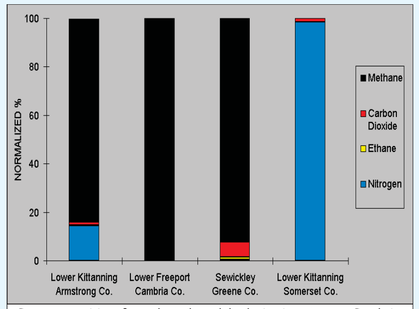
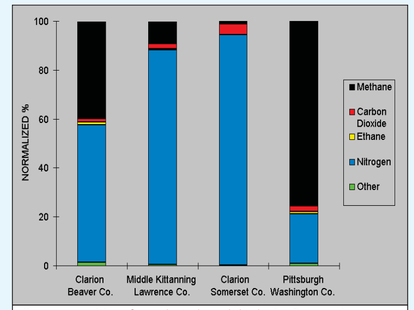


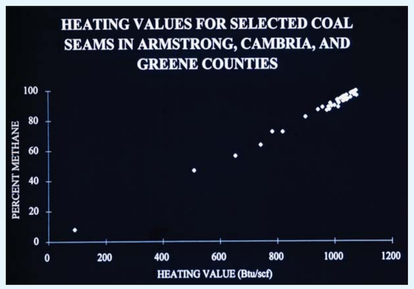
Gas composition for selected coal beds in Armstrong, Cambria, Greene, and Somerset Counties.

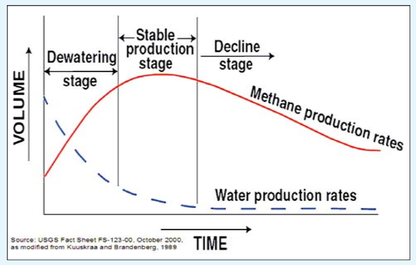
WHY COALBED CH_4?

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.

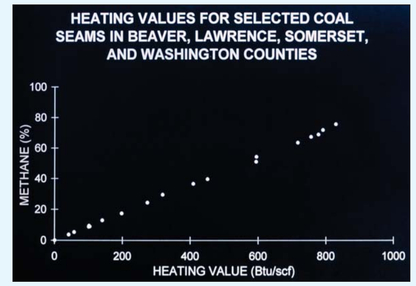


Gas composition for selected coal beds in Beaver, Lawrence, Somerset, and Washington Counties.





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 diluted 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).*

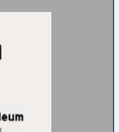


How Is CBM Used?

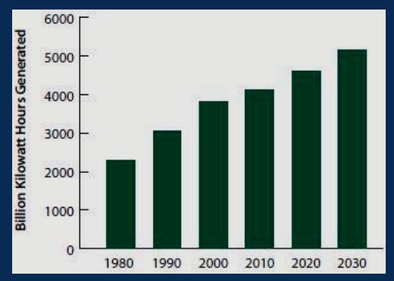
1. Pipeline fuel
2. Sales to power grid
3. Electrical generation (gas turbines, diesel generators, and internal-combustion engines)
4. Mine operations, other local uses
5. Boiler/coal dryers
6. Co-firing
7. Fuel cells
8. Submerged evaporators (treat wastewater)
9. Chemical feedstock (methanol, ammonia, etc.)
10. Raw material (LNG, gas products)

Acknowledgements

- John Gira and Deborah Kosmack (CNX Gas Co., LLC —subsidiary of CONSOL Energy, Inc.)
- Chris Shea (Keyrock Energy, LLC)
- Mark Leidecker (retired—Jesmar Energy, Inc.)
- Joanne Reilly (NACBM Forum, retired—Alpha Natural Resources, formerly Coal Gas Recovery, LP)
- U.S. Energy Information Administration
- U.S. Environmental Protection Agency



U.S. Electric Power Industry Net Generation By Fuel, 2008; Source: U.S. Energy Information Administration, Electric Power Annual, 2010



Source: U.S. Energy Information Administration, 2008

ABSTRACT

PENNSYLVANIA COALBED METHANE UPDATE

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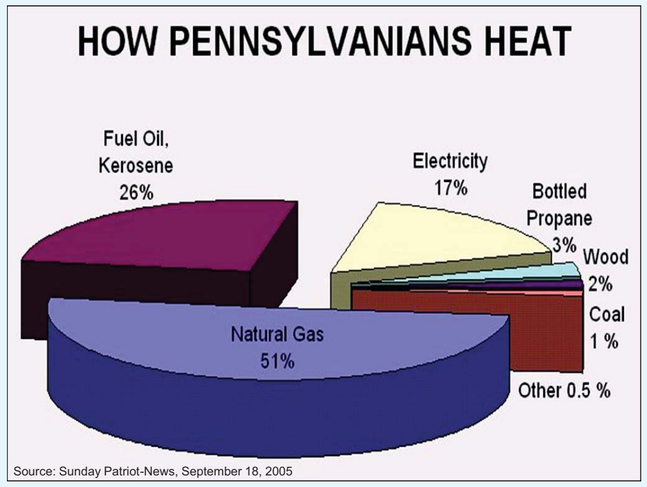
Interest in the economic value and development of natural gas from coal beds in Pennsylvania was stimulated by federal research during the late 1970s and early 1980s, resulting in a dramatic increase in production a decade later. Major growth in coalbed methane (CBM) as an unconventional source of natural 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 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.

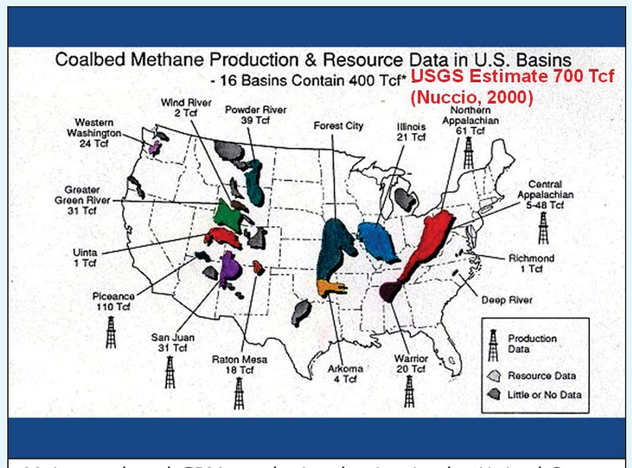
Total CBM resource estimates were quantified by the following sources: 1) Geomega, Inc. (1983 unpublished report)—2,654 Bcf (2.7 trillion cubic feet [Tcf]) for Pennsylvania anthracite and bituminous coal; 2) Gas Research Institute (1988)—51 Tcf gas-in-place for southwestern Pennsylvania and northwestern 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.

Outline

- *Overview*
- *Importance and impact of CBM resource*
- *Resource estimates*
- *Reservoir characteristics and production*
- *Previous studies*
- *Industry highlights*
- *Conclusions*



Source: Sunday Patriot-News, September 18, 2005



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

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 MBtu
- Stores 6 times more gas than equivalent volume of rock in conventional gas reservoir

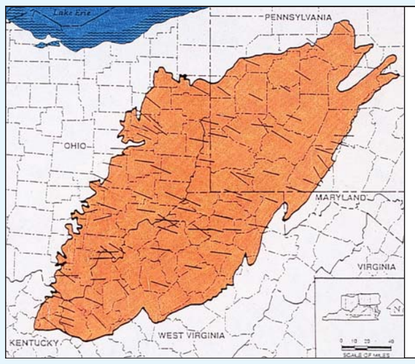
Why Is Methane Important?

- 23–25 times more effective than CO_2 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 *(Kelafant and others, 1988)*; 11.48 Tcf *(USGS Oil and Gas Resource Assessment, 1996)*
- Pennsylvania: 2,654 Bcf in anthracite and bituminous coals *(Geomega, 1983)*
- Pennsylvania: ~ 900 Bcf *(USDOE, EIA, PADEP)*
- Greene and Washington Counties: > 500 Bcf in Pittsburgh *(USBM, 1975)*

CLEAT AND PRODUCTION



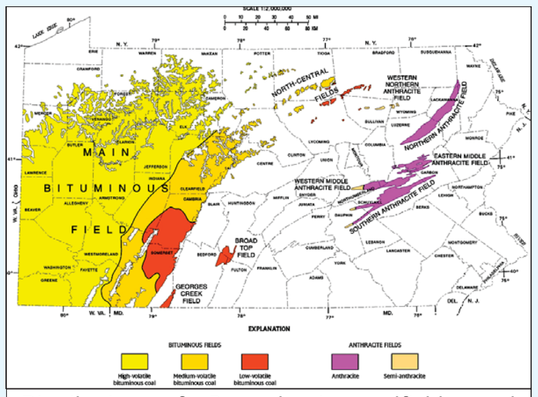
Dominant coal cleat orientations in the Northern Appalachian coal basin (*permission from the Gas Research Institute in Kelafant and others, 1988; modified from Colton and others, 1981; modified from Kulander and others, 1980).*

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).

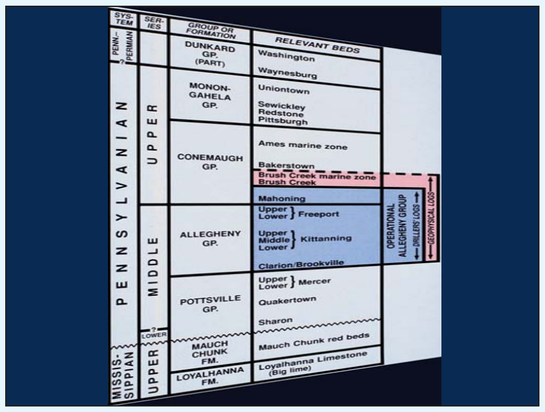
More importantly, the highest permeabilities (directional permeability) providing good gas flow are parallel to the face cleat orientation (Adams and others, 1984; Diamond, Elder, and Jeran, 1986). Maximum gas production can be achieved after the highly permeable reservoir has been drained. Degree of drainage radius, a function of fracture permeability, is also very critical to the commercial development of CBM.

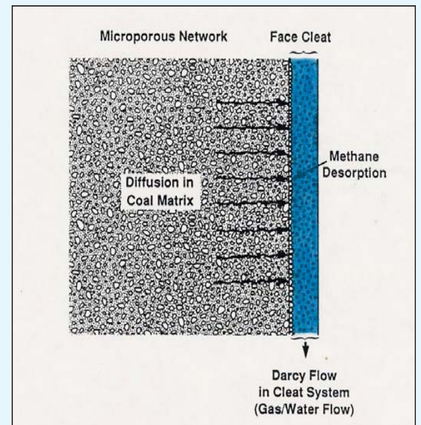
Face cleat is the major well-defined joint or cleavage plane in a coal bed (the dominant fracture plane facing the viewer). Butt cleat is the short, poorly defined joint or cleavage plane in a coal bed oriented at right angles to the face cleat and terminating against it.

Coal showing natural fractures, or face and butt cleats *(photo courtesy of James R. Shaulis, Pennsylvania Geological Survey).*

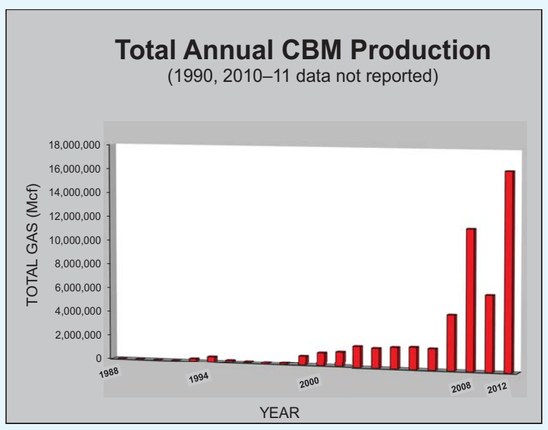


Distribution of Pennsylvania coalfields and associated coal ranks *(Pennsylvania Geological Survey, 1992, third edition).*





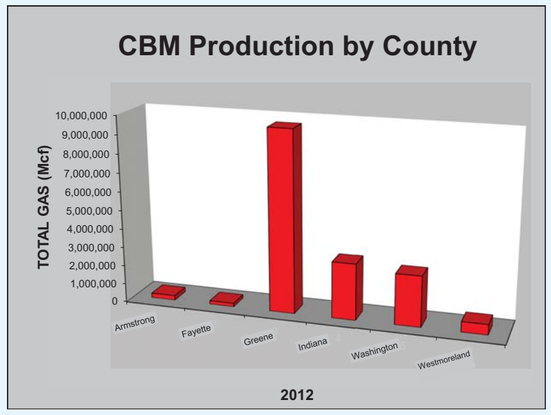
Cleat system and two-phase flow model of gas in a block of coal *(permission from ICF Resources, Incorporated, 1988).*



Northern Appalachian Coal Basin

Areal Extent, Drillable Area, and Gas-in-Place (GIP) For Target Coal Groups

Coal Group	Areal Extent (sq miles)	Drillable Area (sq miles)	GIP (Tcf)
Waynesburg	7,000	2,300	1.5
Sewickley	8,000	4,200	1.8
Pittsburgh	12,600	6,000	7.0
Freeport	22,800	18,200	15.5
Kittanning	28,000	21,000	24.1
Brookville/Clarion	30,300	23,000	10.8
		Total GIP	60.7



CBM Production by County
1988-2009 & 2012 (Mcf)

- Armstrong 263,896
- Cambria 313,480
- Fayette 853,284
- Greene 23,803,101
- Indiana 12,227,332
- Washington 6,430,521
- Westmoreland 1,739,397

TOTAL 45,631,011

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*

CBM Production by County
2012 (Mcf)

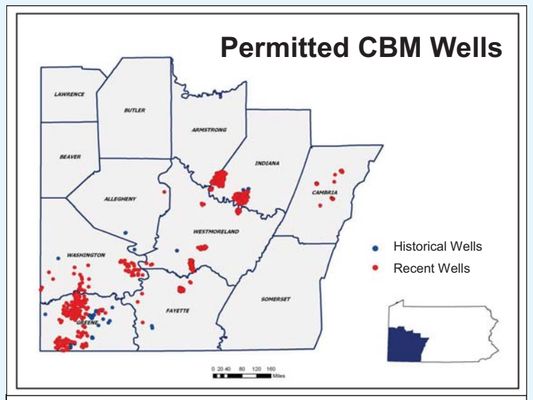
- Armstrong 245,011
- Fayette 181,469
- Greene 9,657,155
- Indiana 3,008,884
- Washington 2,711,303
- Westmoreland 553,878

TOTAL 16,357,700

INDUSTRY ACTIVITY

Types of CBM Wells

- Vertical (V) well producing from one or more coal seams
- V well drilled into one coal seam with series of horizontal (H) bores extending through coal, all single seam production
- 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 based on Department of Environmental Protection—Bureau of Oil and Gas Management and the Pennsylvania Wells Information System databases *(December 2012)*.

Major CBM Operators
(active and planned wells)

1. Alpha Natural Resources—formerly Coal Gas Recovery, LP (Greene County)
2. CNX Gas Co., LLC—subsidiary of Consol Energy, Inc. (Allegheny, Armstrong, Fayette, Greene, Indiana, Washington, and Westmoreland Counties)
3. Jesmar Energy, Inc. (Washington County) kept 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)

Allegheny, Armstrong, Fayette, Greene, Indiana, Washington, and Westmoreland Counties
(CNX Gas Co., LLC—CONSOL Energy, Inc.)

- ~ 300 producing wells in Pittsburgh to Brookville coals; DPDs ~ 75–2,000 ft
- Allegheny–3 Hs planned, Armstrong–22 Vs, Fayette–1 H planned, Greene–139 (most Hs), Indiana–100 (most Vs), Washington–28 (most Hs), and Westmoreland–7 Vs, Hs
- Gas quality: 70% CH_4 dried, treated for N_2, O_2, CO_2; 990 Btu/ft^3 to sales, no blending needed
- More pipeline built; processing plant expansion completed (from 5 MMcfd to now 10 MMcfd)

Washington County
(CNX Gas Co., LLC—CONSOL Energy, Inc.)

- Full scale ventilation air methane abatement project under development at Enlow Fork mine in partnership with Green Holdings America, LLC
- Successful deployment and operation of a 200 kilowatt Capstone microturbine generator to convert waste CBM from Fallowfield gas processing site to produce electricity

Information courtesy Deborah Kosmack (CONSOL Energy, Inc., February 27, 2013)

Greene County
(Alpha Natural Resources, Inc.—formerly Coal Gas Recovery, LP)

- ~ 45 directional wells in Sewickley, Pittsburgh, and Upper Freeport coals
- Received the Southwestern Virginia Technology Council's High Tech Excellence in Green Technology Award (2011):

  * *CMM recovery program uses surface directional wells to remove large volumes of methane.*

Cambria, Fayette, Indiana, and Westmoreland Counties
(Keyrock Energy, LLC)

- ~ 250 producing wells (most Vs, 1 H)
- Perforated intervals encase 250 ft total well bore in Lower Bakerstown to Mercer coals from ~ 400–1,500 ft deep; 3–6 coals at 6–15 ft net thickness; TDs ~ 800–1,650 ft
- Gas production 200–2,600 Mcfd; water production 24–4,900 barrels/day (2010); 6 NPDES sites—no treatment
- Gas quality 990–1,015 Btu/scf (saturated)
- Gas treatment—dehydration

Cambria, Fayette, Indiana, and Westmoreland Counties
(Vessels Coal Gas, Inc.—formerly LAHD Energy, Inc.)

- Cambria: 8 VCMMs in Upper Freeport to Lower Kittanning coals; DPDs 665–957 ft (Ebensburg, Nanty Glo quads)
- Fayette: 1 V nonproducing
- Indiana: 3 Vs in Upper Freeport, DPDs 475–575 ft
- Westmoreland: 2 Vs—1 active, 1 inactive

Washington County
(Jesmar Energy, Inc.)

- Five wells target Pittsburgh gob; TDs 391–883 ft
- Varner No. 1 producing for past 22 years; currently 150 Mcfd; TD 504 ft
  * *Gas Quality:* Mixing propane to achieve 1,015 Btu/ft^3
  * *Treatment:* Mole Gate Processor, dehydration at 5 lbs/Mcf
  * *Water Production:* 50 barrels in 3 months
- Other production sold to Robin Energy, Inc.
  * *2 of the wells:* 120–230 Mcfd

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

Domestic Energy Incentives

- PA Alternative Fuels Incentive Grant Program (created by Act 166 in 1992)
- PA Energy Harvest program (2003) $5 million/yr for clean, advanced energy projects (i.e., coal-to-diesel prototype, coal gasification, biodigesters, solar, micro-hydro, wind, other renewables; **CMM** eligible)
- PA Alternative Energy Portfolio Standards Act (Act 213 - 2004) Requires 18% of electricity sold be from renewable and advanced energy sources by 2019; **CMM** eligible)

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 CO_2 sequestration credit, and need for domestic energy

Ownership

- Coal owner (1983 PA Supreme Court)
- 1983 case challenged by surface landowners
- CBM Review Board: SB 275 (Sen. Don White) and HB 539 (Rep. Dave Reed) → HB 1847 amends Coal Refuse Disposal Control Act (1968)
- Other conflict? Attempt negotiation
- Sometimes civil litigation
- Unresolved? Setup escrow accounts until rights are resolved

CONCLUSIONS

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 various coal beds in Armstrong, Cambria, Greene, and Somerset Counties for their gas content. Supplementary data was acquired from industry in Fayette and Westmoreland Counties. Results from these tests were compiled with additional data from the MRCP, former USBM, and USDOE. Graphs were plotted for comparisons and trends. Analyses of coal bed depth and thickness versus total gas content revealed that there is a direct correlation between depth and gas content. Coal thickness, which is important in planning for commercial development, did not show a direct correlation with gas content in this study. It must be advised that depth alone is not the sole indicator of high gas content. For the new coal core samples tested, gas contents ranged from 10 cubic feet per ton (cf/t) for the Upper Kittanning coal in Armstrong County to 395 cf/t for the Lower Freeport coal in Cambria County. Additional graphs were generated for gas composition and heating values (British thermal unit/Btu values) of various coal beds.

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 or without 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 localized pockets that would be conducive to development.

Criteria for locating favorable drilling sites for CBM in Pennsylvania are: 1) numerous, relatively thick, 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 gas content within an individual coal bed, 125 to 150 cf/t; 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; permeabilities 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 in source rock identification for ownership purposes; and 7) target unmined coal seams or be within a significant distance from the outcrop or active mining to minimize loss of methane due to migration to the surface, unless using the lower Btu gob 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 known high emission rates, are attractive to the developer. The relatively high rank, total effective coal thickness, and deep burial of the coal suggests that this area has great potential for production. Based on current data, the Pottsville Formation will be insignificant in its contribution to the CBM resource in the basin, and perhaps in Pennsylvania. More exploration is needed to verify this.

Overall in-place estimates of CBM indicate there may be 61 Tcf in the Northern Appalachian coal basin (includes Pennsylvania, Ohio, West Virginia, and a small part of Maryland), 51 Tcf in Pennsylvania and West Virginia (Kelafant and others, 1988), and 2,654 Bcf (2.7 Tcf) in Pennsylvania (Geomega, Inc., 1983). According to the U.S. Geological Survey oil and gas resource assessment of 1995, the amount of recoverable CBM resources is projected at 11.48 Tcf. As of December 2012, Pennsylvania has about 985 wells classified as producing, active, and inactive. Productive depths range typically from 500 to 2,000 feet. A total of 45 Bcf of CBM was produced from 1988 to 2009 and 2012. The most recent and complete annual production figure compiled for 2012 reveals an all-time high of *16 Bcf*. This could heat about *240,000 households* for a year.

OWNERSHIP

When the severance 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 lessee 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.

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