SPE DISTINGUISHED LECTURER SERIES
is funded principally
through a grant of the

SPE FOUNDATION

The Society gratefully acknowledges
those companies that support the program
by allowing their professionals
to participate as Lecturers.

And special thanks to The American Institute of Mining, Metallurgical,
and Petroleum Engineers (AIME) and individual SPE sections
for their contribution to the program.
CHANGING PERCEPTIONS OF COALBED METHANE RESERVOIRS

Presented by:
David G. Hill

TICORA Geosciences, Inc.
19000 West Highway 72, Suite 100
Phone: 720/898-8200
Fax: 720/898-8222
Email: dave-hill@gti-ticora.com
U.S. Coalbed Gas Production

- Important Natural Gas Resource
  - Current Coalbed Gas production represents 7% of annual U.S. natural gas production
  - Over 13,000 producing coalbed methane wells in 12 states
Coalbed Reservoir Gas Production Characteristics

- Water production volume progressively declines with time. (Minimize well shut in time.)
- Development & in-fill wells often exhibit higher initial gas-water ratios.
- Maintain low bottom hole pressure to maximize gas production rates & recovery factors.
Gas Transport Mechanisms

1. Fluid production from Natural Fracture
   - To Wellbore

2. Gas Desorption from Coal Surface

3. Molecular Diffusion Through the Coal Matrix
Typical Methane Isotherm

- Methane Storage Capacity: 450 scf/ton
- Critical Desorption Pressure: 632 psia
- Initial Reservoir Pressure: 1,620 psia
- Initial Gas Content: 355 scf/ton
- Abandonment Gas Content: 125 scf/ton
- Abandonment Pressure: 100 psia
- Gas Recovery Factor: (230/355) X 100 = 64.8% scf/ton
Presentation Overview

- Early Coalbed Gas Industry Drivers
- Resource Base Perceptions
- Play Area & Gas Production Economics Perceptions
- Gas-In-Place Perception
- Recovery Factor Perception
- Play Area Perception
- Future Coalbed Gas Advances
- 2-5 Year Outlook for CBM
Early Coalbed Gas Industry Drivers

- Coal Mine Safety
- Energy Policy
- Oil & Gas Industry Technology
- Targeted Research & Development

Graph: CBM Industry 1981 - 1992

- Number of Annual CBM Completions
- Years: 1981 to 1992
U.S. Coalbed Gas Industry Investment and Revenues

Source: SPE 28581 “A Decade of Success: Coalbed Methane,” Schraufnagel, Hill, and McBane
Key Technology Advances In Coalbed Gas

- Understanding of Fundamental Production Mechanisms
- Improved Procedures for Isotherm and Gas Content Determination
- New Improved Well Testing to measure permeability
- Stimulation & Completion Practices to maximize deliverability / reduce costs
- Coalbed Specific Reservoir Simulators for property evaluation and projections
Post Tax Credit CBM Industry Drivers

- Natural Gas Prices
- Uneconomic Perceptions
- Off Shore Resource Focus
- Industry Consolidation

CBM Industry
1993 - 1996

Number of Annual CBM Completions

Year

0 200 400 600 800 1000 1200 1400 1600 1800 2000


Year

Number of Annual CBM Completions
1993 Projection of Future U.S. CBM Production

Source: GRI
Second Expansion Period

CBM Technology

New Basins

Play Specific Focus

Economics

CBM Industry
1996 - 2000

Number of Annual CBM Completions

0 500 1000 1500 2000 2500 3000 3500 4000


Year
U.S. Lower-48 Coalbed Gas Resources

- Western Washington Coal Region: 24 Tcf
- Greater Green River Basin: 314 Tcf
- Uinta Basin: 10 Tcf
- Piceance Basin: 99 Tcf
- San Juan Basin: 84 Tcf
- Raton Basin: 10 Tcf
- Wind River Basin: 6 Tcf
- Powder River Basin: 39 Tcf
- Illinois Basin: 21 Tcf
- Northern Appalachian Basin: 61 Tcf
- Central Appalachian Basin: 5 Tcf
- Black Warrior Basin: 20 Tcf
- Arkoma Basin: 4 Tcf
- Cherokee Basin: 6 Tcf

Sources: EIA, PGC, GRI, State Agencies, and Other Public Information Sources
U.S. Lower-48 Coalbed Gas Resources

Sources: EIA, PGC, GRI, State Agencies, and Other Public Information Sources
166.4 Tcf Total Producible Coalbed Methane Resource Base

Undiscovered 101.2 Tcf
Economic Recoverable 42.3 Tcf
Proved Reserves ~13.2 Tcf
Produced 9.7 Tcf

Increasing development costs, technology needs, and uncertainty.

Ref. GRI-99/0131

Wind River
Western Washington
Uinta
San Juan
Raton
Powder River
Piceance
Illinois
Greater Green River
Forest City
Cherokee
Cahaba
Black Warrior
C. Appalachian
N. Appalachian
Arkoma

U.S. Lower-48 CBM Resource Pyramid

Economic Recoverable CBM Resources
U.S. Lower-48 Coalbed Gas Resources

166.4 Tcf Total Producible Coalbed Methane Resource Base

- Undiscovered: 101.2 Tcf
- Economic Recoverable: 42.3 Tcf
- Proved Reserves: ~13.2 Tcf
- Produced: 9.7 Tcf

Increasing development costs, technology needs, and uncertainty.

Factor Influencing Change

1. New Information from Exploration and Recent Commercial Successes
2. Use of More Accurate Gas Content Analysis Methods
3. Greater Abundance and Spatial Coverage of Gas Content Data for the Rocky Mountain Region Basins

Ref. GRI-98/0003
U.S. Annual Coalbed Gas Completions

Year

Annual CBM Completions

Recent Industry Coalbed Activity

- New CBM Plays No Longer Driven By Section 29 Tax Credit
- Finding Costs are Very Attractive

Sources: GTI, State Agencies, and Other Public Information Sources
## Characteristics of Newest U.S. Rocky Mountain Region Coalbed Gas Plays

<table>
<thead>
<tr>
<th></th>
<th>Powder</th>
<th>Raton</th>
<th>Uinta</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Drilling</strong></td>
<td>Air - Water</td>
<td>Air - Percussion</td>
<td>Air - Percussion</td>
</tr>
<tr>
<td><strong>Completion</strong></td>
<td>Openhole</td>
<td>Cased Hole</td>
<td>Cased Hole</td>
</tr>
<tr>
<td></td>
<td>Underream</td>
<td>Perforate/Multi-stage</td>
<td>Perforate/Multi-stage</td>
</tr>
<tr>
<td></td>
<td>Water Frac</td>
<td>N₂ Foam/Sand</td>
<td>X-Link/Sand</td>
</tr>
<tr>
<td></td>
<td>Electric Water Pump</td>
<td>Progressive Cavity Pump</td>
<td>Conv. Rod Pump</td>
</tr>
<tr>
<td><strong>Well Spacing</strong></td>
<td>80 acres</td>
<td>160 acres</td>
<td>160 acres</td>
</tr>
<tr>
<td><strong>Avg. Well Cost</strong></td>
<td>$100,000</td>
<td>$360,000</td>
<td>$375,000</td>
</tr>
<tr>
<td><strong>Average Reserves</strong></td>
<td>0.4 Bcf</td>
<td>1.8 Bcf</td>
<td>1.5 BCF</td>
</tr>
<tr>
<td><strong>Average Finding Costs ($/Mcf)</strong></td>
<td>0.25</td>
<td>0.18</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Sources: GTI, State Agencies, and Other Public Information Sources
U.S. Average Daily Coalbed Gas Production (Mcfd)

Initial Coalbed Reservoir Gas-In-Place Perception

- In Many Established Coalbed Gas Plays, Cumulative Gas Production Volumes Have Exceeded the Initial GIP Volumes
- GIP is One of the Key Reservoir Parameters that Influences Production and Producible Reserves
  - Values are Method Dependent
  - Existing GIP Data May be Inaccurate

<table>
<thead>
<tr>
<th>Basin/Field</th>
<th>Initial GIP Estimate</th>
<th>Cumulative Production</th>
<th>δ GIP (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Warrior Basin Oak Grove Field (23 Wells)</td>
<td>1.55 Bcf</td>
<td>3.2 Bcf (10 Years)</td>
<td>206 %</td>
</tr>
<tr>
<td>San Juan Basin Cedar Hill Field (Cahn Well)</td>
<td>2.5 Bcf</td>
<td>2.4 Bcf (~10 Years)</td>
<td>96 %</td>
</tr>
<tr>
<td>Powder River Basin Marquiss Field (Lynde Trust 4-23 Well)</td>
<td>0.84 Bcf</td>
<td>1.130 Bcf (8/01/01)</td>
<td>135 %</td>
</tr>
<tr>
<td>Uinta Basin Drunkard’s Wash (Utah #35-1-9 Well)</td>
<td>3.2 Bcf</td>
<td>5.04 Bcf (12/01/01)</td>
<td>158 %</td>
</tr>
</tbody>
</table>
Lynde Trust 4-23 Well, Powder River Basin

Average Daily Production

- Gas (Mcf)
- Water (Bwpd)

Cumulative Production

- Cum Gas
- Cum Water

Oct-92 Mar-94 Jul-95 Dec-96 Apr-98 Aug-99 Jan-01 May-02

Oct-92 Nov-93 Apr-95 Aug-96 Jan-98 May-99 Oct-00 Feb-02
Utah 35-1-9 Well, Uinta Basin

Average Daily Production

Cumulative Production

Gas (Mcf)

Water (Bwpd)

Gas (McF)

Water (Bbl)

Jul-92  Nov-93  Apr-95  Aug-96  Jan-98  May-99  Oct-00  Feb-02
### Data Uncertainties For Coalbed Gas Resource And Reservoir Gas-In-Place Values

**GIP** = \( Ah\overline{\rho}_c \overline{G}_c \)

<table>
<thead>
<tr>
<th>UNCERTAINTY</th>
<th>DRAINAGE AREA</th>
<th>THICKNESS</th>
<th>IN-SITU DENSITY</th>
<th>IN-SITU GAS CONTENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIGH</td>
<td>![High DRA]</td>
<td>![High THI]</td>
<td>![High DSD]</td>
<td>![High GIS]</td>
</tr>
<tr>
<td>MEDIUM</td>
<td>![Medium DRA]</td>
<td>![Medium THI]</td>
<td>![Medium DSD]</td>
<td></td>
</tr>
<tr>
<td>LOW</td>
<td>![Low DRA]</td>
<td>![Low THI]</td>
<td>![Low DSD]</td>
<td>![Low GIS]</td>
</tr>
</tbody>
</table>

- **Commonly Used Methods**
- **Very High Sampling Density**
- **Best Practice Methods**

Ref. GRI-97/0263
Coalbed Reservoir Gross Thickness Error

Rule-of-thumb upper density limit: 1.75 g/cm³

Uinta
\[ y = -7.3705x + 697.24 \]
\[ R^2 = 0.9502 \]

Piceance
\[ y = -4.5427x + 415.99 \]
\[ R^2 = 0.8316 \]

San Juan
\[ y = -5.6368x + 532.64 \]
\[ R^2 = 0.9196 \]

Sources: GRI-97/0263, Lamarre and Pratt, Rocky Mountain Geologist, April 2002.
Coalbed Reservoir Gas-In-Place Distribution

San Juan Basin Fruitland Fm.
- 20% of gas is present at ρ > 1.76 g/cm³
- 80% is at ρ < 1.75 g/cm³

Uinta Basin Ferron Fm.
- 47% of gas is present at ρ > 1.76 g/cm³
- 53% is at ρ < 1.75 g/cm³
Coalbed Gas Reservoir Recovery Factor Perceptions

- Typical Recovery Factor Averages 50% to 60% with Conventional Technology
- New Enhanced CBM Recovery Technology
  - Injection of Nitrogen or Carbon Dioxide
  - Promotes the Desorption of Methane
  - Potential for Six-Fold Increase in Production Rate and Two-Fold Increase in Reserves
Play Area Perceptions - Coalbed Gas Producibility Model

Based on Comprehensive Geologic and Hydrologic Studies of the San Juan, Greater Green River, and Piceance Basins.

Exceptionally High Productivity is Governed by:
- Thick, Laterally Continuous Coals of High Thermal Maturity
- Adequate Permeability
- Basinward Flow of Ground Water Through Coals of High Rank and Gas Content Orthogonally Toward No-Flow Boundaries (regional hingelines, fault systems, facies changes, and/or, discharge areas)
- Generation of Secondary Biogenic Gases
- Conventional Trapping Along Those Boundaries to Provide Additional Gas Beyond that Generated During Coalification
The interplay of these critical geologic and hydrologic controls determines coalbed methane producibility.
Basin Property Comparisons

- Water Production
- Thickness
- Rank
- Gas Content

Basin
 Basin Property Comparisons

San Juan

Central Appalachian

Powder River

Arkoma

Water Production

Thickness

Gas Content

Perm

Rank
Basin Property Comparisons

Cambay Basin
India

Piceance

Jharia Basin
India

Raton
Play Type Comparison - Canada

Next Major Coalbed Gas Advances

- Extending the Producibility Model
  - New Areas/Basins (New Data)
  - Lower Maturity
  - Deep Coals
  - Infield Development

- New Players
  - Challenging Conventional Wisdom
  - International

- Environmental Drivers
  - Global Warming
    - Carbon Sequestration
    - Enhanced Coalbed Methane Recovery
  - Produced Water Management
Coalbed Gas: 2 – 5 Year Outlook

- Continued Exploration in Frontier Plays
  - Greater Green River Basin
  - Illinois Basin
  - Menefee – San Juan Basin
  - Wind River
  - Gulf Coast

- Growth In Mid-Continent Basins

- Extensive Infield Development in the San Juan Basin (outside the fairway)

- Commercial Production Begins in Canada

- Progress in Enhanced Coalbed Methane Recovery and CO₂ Sequestration
  - Science First
  - Financial Incentive Second