Introduction to Coal Bed Methane

August 27, 2003
Coal Bed Methane:
What is it? Where is it?
Coal Basins and CBM In-place Reserves

- North Central Montana Basin: 3.7 Tcf
- Bighorn Basin: 3 Tcf
- Greater Green River Basin: 314 tcf
- Powder River Basin: 39 tcf
- Wind River Basin: 6 Tcf
- Hanna-Carbon Basin: 6 Tcf
- Denver Basin: 2 Tcf
- Piceance Basin: 99 Tcf
- Southwestern Utah Basin: 10 Tcf
- San Juan Basin: 84 tcf
- Uinta Basin: 10 tcf
- Raton Basin: 10 tcf
Outcrop
Geology and
Tertiary Coals
of the Powder
River Basin
Environments of Coal Deposition
Evolution of CBM
Methane in Coal

- Natural gas is held in contact with the coal through high water pressure.
- Water in cleats and fractures.

Coal Cleat Orientation

- Butt Cleat
- Face Cleat

Coalbed Matrix

Methane

Coal Maceral
Evolution of Expelled Fluids Related to Coal Rank

- **Peat**
- **Lignite**
- **Sub-Bituminous**
- **High Volatile Bituminous**
- **Med Volatile Bituminous**
- **Low Volatile Bituminous**
- **Semi-Anthracite**
- **Anthracite**

- **Ethane Plus ($C_2^+$)**
- **Biogenic Methane ($C_1$)**
- **Thermogenic Methane ($C_1$)**
- **Expelled Water**
- **CO$_2$**
- **Nitrogen**

- **Pore Water Salinity**

- **RO** values:
  - 0.40
  - 0.50
  - 1.10
  - 1.50
  - 2.0

- **Regions**:
  - **PRB**
  - **SJB**
  - **Arkoma**
Coal Fluids and Depth

- Frontier Formation - Lignite
- Lance Formation – Sub-Bituminous
- Mesa Verde Formation – High-Volatile Bituminous

Water, Nitrogen
Water, Methane
Methane, CO₂
Coal Bed Methane: How Do You Get it Out?
Typical Hard Coal Completions

Cherokee Basin (KS)  Arkoma Basin (OK)

Fort Scot FM.

Cherokee Group

MC Alester Formation

Hartshorne Coal

Hartshorne Sand
Typical CBM Completion

(Powder River Basin)
CBM Production Characteristics

Methane is held in place by reservoir water pressure.

To produce methane, water is drawn off.
CBM Drainage and Drainage Control

Tribal Minerals, No CBM Development

Fee Minerals, No CBM Development

Federal Minerals, CBM Development

Drainage Radius

Producing Wells

Injection Wells

Hydraulic Barrier

A

A'

B

B'
On-Lease and Off-Lease Drainage

- Claystone
- Claystone
- De-Pressurization and CBM Drainage
- Water Level
- Silty Claystone
- Productive Coal Seam
- Claystone
- Claystone
Hydraulic Barrier to Control Drainage

Injection Well

Lease Boundary

Production Well

B

B'

Claystone

Claystone

Claystone

Claystone

Claystone

Claystone

Productive Coal Seam

Sandy Claystone

Water Level
Water Management

CBM production can cause de-watering of nearby water wells or springs. These impacts will need to be remediated by the CBM operator.
Natural Gas Production Characteristics: Conventional Reservoir vs CBM
San Juan Basin: Vertical, horizontal, and multi-lateral wells; and multiple completions

Piceance Basin: Vertical and horizontal wells, single or multiple completions

Raton Basin: Vertical wells, multiple completions

Greater Green River Basin: Vertical wells

Uinta Basin: Vertical wells, single or multiple completions

Powder River Basin: Vertical wells, single completions
In the Powder River Basin, coals range in depths to below 2500’ but cleat reduces with depth and the majority of CBM is produced at shallower depths. At the same time, many coals outcrop at the surface but many shallow coals have undergone burning and most have expelled their methane.
CBM Basins and Maximum Producing Depth

Well Depth
- < 250
- 251 - 500
- 501 - 1000
- 1001 - 1500
- > 1500
<table>
<thead>
<tr>
<th>Comparison of Producing CBM Basins in the Rocky Mountain Region</th>
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<tbody>
<tr>
<td>Basin</td>
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<tr>
<td>State Location</td>
</tr>
<tr>
<td>Drilling Method</td>
</tr>
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<td>Completion Methods</td>
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<td>Producing Wells</td>
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<td>Primary Water Disposal Methods</td>
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<td>Water Lift Method</td>
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<td>Average water Production per well</td>
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<tr>
<td>Coal Rank</td>
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<tr>
<td>Well Depth (feet)</td>
</tr>
<tr>
<td>Net Coal Thickness</td>
</tr>
<tr>
<td>Gas Content</td>
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<tr>
<td>Well Spacing</td>
</tr>
<tr>
<td>Average Well Cost</td>
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<td>Average Well Reserves</td>
</tr>
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<td>Average Well Gas Production Rate</td>
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CBM Produced Water: Management Options
CBM Wells and Water Wells in the Powder River Basin
CBM and Water Management
EXHIBIT 22 - GROUNDWATER QUALITY FOR THE MONTANA PORTION OF THE POWDER RIVER BASIN

Selected groundwater quality data collected from water supply wells located throughout Montana PRB.

<table>
<thead>
<tr>
<th>County</th>
<th>Judith River Formation</th>
<th>Hell Creek / Fox Hills Formation</th>
<th>Fort Union Formation</th>
<th>Quaternary Alluvium</th>
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<tbody>
<tr>
<td></td>
<td>Avg. TDS (mg/L)</td>
<td>Avg. SAR</td>
<td>Avg. TDS (mg/L)</td>
<td>Avg. SAR</td>
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<tr>
<td>Big Horn</td>
<td>936</td>
<td>54</td>
<td>1440</td>
<td>14</td>
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<tr>
<td>Rosebud</td>
<td>2465</td>
<td>31</td>
<td>1376</td>
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<td>Powder River</td>
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<td>No data</td>
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<td>Custer</td>
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<td>No data</td>
<td>896</td>
<td>37</td>
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<td>Treasure</td>
<td>2312</td>
<td>64</td>
<td>1985</td>
<td>56</td>
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<tr>
<td>Weighted Average</td>
<td>2100</td>
<td>42</td>
<td>1148</td>
<td>37</td>
</tr>
</tbody>
</table>

Note: Avg. TDS = Average Total Dissolved Solids, Avg. SAR = Average Sodium Adsorption Ratio
<table>
<thead>
<tr>
<th>Analyte</th>
<th>National Drinking Water Standards (primary unless noted)</th>
<th>MT. Water Quality Stds. for Livestock PPM (MSU 2001)</th>
<th>CX Ranch Average (MDEQ, 2000)</th>
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</thead>
<tbody>
<tr>
<td>TDS mg/L</td>
<td>500 (secondary)</td>
<td>10,000</td>
<td>1,400</td>
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<tr>
<td>SAR</td>
<td></td>
<td></td>
<td>47</td>
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<tr>
<td>Sodium mg/L</td>
<td></td>
<td></td>
<td>558</td>
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<tr>
<td>Ammonia, Total mg/L</td>
<td></td>
<td></td>
<td>2.0</td>
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<tr>
<td>Chloride mg/L</td>
<td>250 (secondary)</td>
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<td>19</td>
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<tr>
<td>Fluoride mg/L</td>
<td>2.0 (secondary)</td>
<td>2</td>
<td>2.5</td>
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<tr>
<td>Sulfate mg/L</td>
<td>250 (secondary)</td>
<td>0.05 to 0.2 (secondary)</td>
<td>5</td>
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<td>Aluminum, total mg/L</td>
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<td>0.05 to 0.2 (secondary)</td>
<td>0.05</td>
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<td>Arsenic mg/L</td>
<td>0.05</td>
<td>0.2</td>
<td>0.001</td>
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<tr>
<td>Barium mg/L</td>
<td>2.0</td>
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<td>0.5</td>
</tr>
<tr>
<td>Beryllium mg/L</td>
<td>0.004</td>
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<td>0.0005</td>
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<td>Boron mg/L</td>
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<td>5</td>
<td>0.07</td>
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<td>Cadmium mg/L</td>
<td>0.005</td>
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<tr>
<td>Chromium mg/L</td>
<td>0.1</td>
<td>1</td>
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<tr>
<td>Copper mg/L</td>
<td>1.0 (secondary)</td>
<td>0.5</td>
<td>0.001</td>
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<td>Lead mg/L</td>
<td>0.015</td>
<td>0.3</td>
<td>0.002</td>
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<td>Iron, dissolved mg/L</td>
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<td>0.05</td>
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<td>Iron, total mg/L</td>
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<td>0.125</td>
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<td>Manganese mg/L</td>
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<td>0.01</td>
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<td>Mercury mg/L</td>
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<tr>
<td>Selenium mg/L</td>
<td>0.05</td>
<td>0.5</td>
<td>0.43</td>
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<td>Strontium mg/L</td>
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<tr>
<td>Radium mg/L</td>
<td>5 pCi/L</td>
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<td>0.2</td>
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<tr>
<td>Vanadium mg/L</td>
<td></td>
<td>0.1</td>
<td></td>
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<tr>
<td>Zinc mg/L</td>
<td>5 (secondary)</td>
<td>24</td>
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</tr>
</tbody>
</table>

CBM produced water from Montana shows some exceedances of drinking and livestock standards. Total Dissolved Solids (TDS) is exceeded for humans but is acceptable for livestock in the state of Montana. Fluoride is exceeded for both humans and livestock.

The Sodium Adsorption Ratio (SAR) is important as a limiting factor for soil condition and sodium is a limiting factor for plant growth. Both constituents limit the use of this particular water for irrigation although water management can mitigate deleterious effects.
CBM and Water Management

Production Rate Forecast For Area

MMCFD or MBWPD

Gas Rate
Water Rate
CBM Water Handling Options and Costs

- Hauling: $1.00/Bbl
- Deep Injection: $0.20/Bbl
- Surface Discharge: $0.02/Bbl
Treatment Processes

• Reverse Osmosis (RO)
• Electrodialysis Reversal (EDR)
• Ion Exchange
• Freeze Thaw Evaporation
• Artificial Wetlands
• Land-Based Wastewater Treatment
• Emerging Technologies
  – Capacitive Desalination (CDT or EWP)
  – Rapid Spray Distillation
CDT Technology: a New Solution

- “Capacitive Deionization Technology™”
  - Invented and patented by Lawrence Livermore National Laboratory
    - $40+ Million DOE investment
    - 10 years in development
  - Currently being developed commercially under license by CDT Systems, Inc.

- Operating Principle - Flow Through Capacitor
  - Liquid flows between high surface area electrode pairs having a potential difference of 1.3 vdc.
  - Ions and other charged particles are attracted to and held on the electrode of opposite charge for later release into a rinse stream.

Negative electrode attracts positively charged ions (cations)
- Calcium (Ca)
- Magnesium (Mg)
- Sodium (Na)

Positive electrode attracts negatively charged ions (anions)
- Chloride (Cl)
- Nitrate (NO$_3$)
- Silica (SiO$_2$)
CBM Development: An Attractive Component of America’s Energy Mix