Concepts Used for Conducting CMM Resource Assessment in Frontier Areas

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August 30 - 31, 2010

Methane to Markets Partnership - Mongolia

CMM Project Development Workshop

Ulaanbaatar, Mongolia
Presentation Outline

• Defining Terms: CMM Resources and Reserves
• Understanding the Occurrence of Gaseous Hydrocarbons in Coal
• Example CBM/CMM Resource Study: Texas Gulf Coast
• Hypothetical Resource Estimate for Mongolia Coal Deposit
Defining Terms: CMM Resources and Reserves
The Petroleum Resources Management System
Converting Resources to Reserves

Increases in Technically Recoverable Resources due to choices in technology

Increases in Reserves due to changes in sales price of production costs
Keys to Understanding Occurrence of Gaseous Hydrocarbons in Coal
Coal Rank and Hydrocarbon Generation

<table>
<thead>
<tr>
<th>Coal Rank</th>
<th>Hydrocarbon Products Generated From Coal Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peat</td>
<td>C</td>
</tr>
<tr>
<td>Lignite</td>
<td>B</td>
</tr>
<tr>
<td>Sub-bituminous C</td>
<td>A</td>
</tr>
<tr>
<td>High Volatile bituminous C</td>
<td>A</td>
</tr>
<tr>
<td>Medium Volatile bituminous A</td>
<td>B</td>
</tr>
<tr>
<td>Low Volatile bituminous A</td>
<td>B</td>
</tr>
<tr>
<td>Semi-anthracite A</td>
<td>B</td>
</tr>
<tr>
<td>Anthracite A</td>
<td>B</td>
</tr>
<tr>
<td>Meta-anthracite A</td>
<td>B</td>
</tr>
<tr>
<td>Meta-anthracite A</td>
<td>B</td>
</tr>
<tr>
<td>Meta-anthracite A</td>
<td>B</td>
</tr>
</tbody>
</table>

- **Range in Ro of Mongolian coal**

**Note:**
- High Ro is determined from 10 proximate analyses.
- Vitrinite reflectance measurement from one Witte coal sample.

**๋Powder River (subB):**
- **San Juan and Raton Basins (hvBb - m vb):**
Van Krevelen-type diagram for various coal types of south Texas and vicinity

Arrows represent mean maturation paths
Model of Methane Occurrence and Enrichment in Coal

Zone of Alteration
- Dry gas with isotopically light methane
- Gas composition controlled by (1) mixing of biogenic methane and/or (2) oxidation of heavy gases
- Located in margins and shallow central parts of basins.

Zone of Original Gas
- Wetter gas with isotopically heavier methane
- Gas composition controlled by rank and composition of associated coal
- Located in deep and central parts of basins

After Rice, 1993
Comparison of CBM Producing Basins in USA to Coal Basins in Mongolia

<table>
<thead>
<tr>
<th></th>
<th>San Juan</th>
<th>Raton</th>
<th>Powder River</th>
<th>Tavan-tolgoi</th>
<th>Nairn-sukhait</th>
<th>Nuurst-hotgor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coal Rank</strong></td>
<td>hvBb-mvb</td>
<td>hvBb-mvb</td>
<td>subB</td>
<td>hvBb-mvB</td>
<td>hvBb</td>
<td>hvBb-c</td>
</tr>
<tr>
<td><strong>Gas Content m³/tonne</strong></td>
<td>3-14</td>
<td>6-14</td>
<td>&lt;3</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td><strong>Max. Coal Thk.</strong></td>
<td>8-14m</td>
<td>&lt;3.5m</td>
<td>30-50m</td>
<td>1-73m</td>
<td>1-54m</td>
<td>1-38m</td>
</tr>
<tr>
<td><strong>Cum. Coal Thk.</strong></td>
<td>13-20m</td>
<td>13-22m</td>
<td>75-105m</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td><strong>Sorption Time</strong></td>
<td>&gt;52 days</td>
<td>&gt;8 days</td>
<td>&gt;7 days</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td><strong>Depth of Completion</strong></td>
<td>~800m</td>
<td>~650m</td>
<td>~150m</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>
Desorption Testing
Example Desorption Report
Example Adsorption Report

<table>
<thead>
<tr>
<th>Pressure (psia)</th>
<th>Gas Content (Raw Basis) (scf/ft³)</th>
<th>Gas Content (Raw Basis) (cc/gm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>19.2</td>
<td>0.60</td>
</tr>
<tr>
<td>64</td>
<td>41.1</td>
<td>1.28</td>
</tr>
<tr>
<td>108</td>
<td>63.8</td>
<td>1.99</td>
</tr>
<tr>
<td>202</td>
<td>100.4</td>
<td>3.13</td>
</tr>
<tr>
<td>350</td>
<td>142.9</td>
<td>4.46</td>
</tr>
<tr>
<td>507</td>
<td>177.5</td>
<td>5.54</td>
</tr>
<tr>
<td>807</td>
<td>222.5</td>
<td>6.95</td>
</tr>
<tr>
<td>1,226</td>
<td>262.4</td>
<td>8.19</td>
</tr>
<tr>
<td>1,916</td>
<td>301.0</td>
<td>9.40</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pressure (psia)</th>
<th>EL (Raw Basis) (scf/ft³)</th>
<th>VL (Raw Basis) (cc/gm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>591.7</td>
<td>4.08</td>
<td>12.2</td>
</tr>
</tbody>
</table>

Methane Adsorption Isotherm

- Raw Basis
- Temperature: 78.8°F (26.0°C)
- Ash Content: 11.96%
- EQ. Moisture Content: 7.47%
- V = 391.1 * P / (P + 591.7)

Adsorption Langmuir Plot

- Raw Basis
- Temperature: 78.8°F (26.0°C)
- Ash Content: 11.96%
- EQ. Moisture Content: 7.47%
- PV = 0.00256 * P + 1.51295

Sample Weight = 104.43 g
Ash Content = 11.96%
Particle Size = < 20 Mesh
EQ. Moisture Content = 7.47%
Temperature = 78.8°F (26.0°C)
Adsorption Laboratory
Data Required for CMM/CBM Resource Study:

Data-type and associated uncertainty

- Coal thickness data- continuous, variable with gaps caused by sparse data -- often modeled which may obscure uncertainty
- Coal Quality data- variability related to geologic setting and sampling density
- Depth and area of occurrence- function of geologic setting and sampling density
- Variation in data density- required for evaluation of resource class -- subjective to some extent
- Sorption data- desorbed gas content can be highly variable determined by coal type and geologic setting, may be necessary to model gas potential based on adsorption isotherm
CMM Resource Assessment Approaches

• Usually a volumetric calculation:
  – multiply mass of coal (tonnes) by gas content (cubic meters of methane per ton of coal) = volume of gas in place (equivalent to PIIP)

• Two accepted approaches to calculate estimate:
  – Use low, high, and mid range single values for all parameters; result is a resource estimate ranging from low to high forecasts
  – Stochastic estimate using probability functions developed for each parameter yielding a probabilistic forecast of resources
Example CBM/CMM Resource Study: Texas Gulf Coast
Location of Initial Study Area
Model for Methane Generation in Upper Texas Gulf Coast WilcoxD Coals

EXPLANATION
- Boundary of UPRC Leasehold
- Study Area
- County Line
- 190° = Equilibrium Temperature °F

Values greater than 60 ohms
Values 20-60 ohms
Values 10-20 ohms
Calvert Bluff
Simlaons
Hooper

D' Geopressed Geothermal Zone in Lower Wilcox

May 2001 www.ravenridge.com
Model for Methane Generation in Upper Texas Gulf Coast
Comparison of CBM Producing Basins

<table>
<thead>
<tr>
<th></th>
<th>San Juan</th>
<th>Raton</th>
<th>Powder River</th>
<th>Upper Texas Gulf Coast</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coal Rank</strong></td>
<td>hvBb-mvb</td>
<td>hvBb-mvb</td>
<td>subB</td>
<td>subB-hvAb</td>
</tr>
<tr>
<td><strong>Gas Content</strong></td>
<td>3-16</td>
<td>6-16</td>
<td>&lt; 4</td>
<td>3-15</td>
</tr>
<tr>
<td><strong>scm/ton</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Max. Coal Thk.</strong></td>
<td>7-12 m.</td>
<td>&lt; 3 m.</td>
<td>30-46 m.</td>
<td>6-12 m.</td>
</tr>
<tr>
<td><strong>Cum. Coal Thk.</strong></td>
<td>12-18 m.</td>
<td>12-21 m.</td>
<td>75-106 m.</td>
<td>3-33 m.*</td>
</tr>
<tr>
<td><strong>Sorption Time</strong></td>
<td>&gt;52 days</td>
<td>&gt;8 days</td>
<td>&gt;7 days</td>
<td>&lt;10 days*</td>
</tr>
<tr>
<td><strong>Depth of Completion</strong></td>
<td>~787 m.</td>
<td>~650 m.</td>
<td>~150 m.</td>
<td>~750 – 1800 m.</td>
</tr>
</tbody>
</table>
Type Log Showing Primary Objective

Upper Coal Package

Lower Coal Package

Type Log

Barracuda Seam
Gas Content Variation Within A Single Coal Seam

174.3 SCF/T

134.2 SCF/T

105.9 SCF/T
Resource Model: Barracuda Seam

Forecast: Gas-in-Place Barracuda Coal Seam

750 Trials

Frequency Chart

0 Outliers

Probability

0.000

0.007

0.013

0.020

0.027

0.033

0.040

0.047

0.053

0.060

0.063

30

20

10

0

40

30

20

10

0

0

1,125,000

2,250,000

3,375,000

4,500,000

Mean = 1,125,011

Certainty is 80.00% from 500,000 to 2,071,662 MCF

80% probability that GIP is between approximately 17,000 and 72,000m³

120,000m³

40,000m³

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CBM Resource Model for Barracuda Coal Seam and Cumulative Coal Thickness

• Developed Probability Frequency Distributions Based on Available Data for:
  – Gas Content of Coals (conservative)
  – Specific Gravity of Coal
  – Coal Thickness

• Assumed 64 hectare well spacing

• Forecasted Frequency of Occurrence of EUR’s of Proposed Wells by Size Class
Summary of Barracuda CBM Resource Base

- 28,283 Acres Mapped (11,466 hectares)
- Avg. Coal Thickness 15.3 Ft (4.6m)
- Avg. Gas Content 214.6 scf/ton (6.7 m³/ton)
- Maximum Gas Content of 470 scf/ton (14.7 m³/ton)
- 80% Probability of 0.5 to 2 BCF Gas in Place Per 160 Ac. Unit (14.16Mm³ to 56.63Mm³ per 64 hectares)
- Avg. Gas In Place 1,143,548 MCF Per 160 Ac. Unit (32.38 Mm³ per 64 hectares)
Hypothetical Resource Estimate for Mongolia Coal Deposit
Cross-section through part of Ovoot Tolgoi hvB-hvA Coal Deposit
## Thickness of Seams Ocurring in Ovoot Tolgoi Deposit

<table>
<thead>
<tr>
<th>Property</th>
<th>Series</th>
<th>No Seams</th>
<th>Minimum Thickness* (m)</th>
<th>Maximum Thickness* (m)</th>
<th>Mean Thickness* (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunrise Field</td>
<td>Upper Seams</td>
<td>11</td>
<td>0.6</td>
<td>74</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>5 Main</td>
<td>1</td>
<td>0.9</td>
<td>157</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>5 Lower</td>
<td>1</td>
<td>0.6</td>
<td>100</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>4 Main</td>
<td>1</td>
<td>1.0</td>
<td>30</td>
<td>8</td>
</tr>
<tr>
<td>Sunset Field</td>
<td>Upper Seams</td>
<td>60</td>
<td>0.6</td>
<td>31</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>5 Main &amp; Lower</td>
<td>2</td>
<td>0.6</td>
<td>142</td>
<td>39</td>
</tr>
</tbody>
</table>
In-Place Coal Resources Delineated by 430 Boreholes Drilled from 2006 through 2009

<table>
<thead>
<tr>
<th>Area</th>
<th>Type</th>
<th>Resource Limits Depth (m)</th>
<th>ASTM Group</th>
<th>In-Place Resources (Million Tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunrise Field</td>
<td>Surface</td>
<td>Surface to 250m</td>
<td>hwB to hwA</td>
<td>Measured: 53.8, Indicated: 15.7, Inferred: 4.9</td>
</tr>
<tr>
<td>Sunset Field</td>
<td>Surface</td>
<td>Surface to 250m</td>
<td>hwB to hwA</td>
<td>Measured: 82.1, Indicated: 19.4, Inferred: 8.1</td>
</tr>
<tr>
<td>Sub-Total</td>
<td></td>
<td></td>
<td></td>
<td>Measured: 135.9, Indicated: 35.1, Inferred: 13.0</td>
</tr>
<tr>
<td>Sunrise Field</td>
<td>Underground</td>
<td>250m to 600m</td>
<td>hwB to hwA</td>
<td>Measured: 11.2, Indicated: 5.2, Inferred: 11.2</td>
</tr>
<tr>
<td>Sunset Field</td>
<td>Underground</td>
<td>250m to 600m</td>
<td>mhB to hwA</td>
<td>Measured: 34.6, Indicated: 27.8, Inferred: 9.3</td>
</tr>
<tr>
<td>Sub-Total</td>
<td></td>
<td></td>
<td></td>
<td>Measured: 45.8, Indicated: 33.0, Inferred: 20.5</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>Measured: 181.7, Indicated: 68.1, Inferred: 33.5</td>
</tr>
</tbody>
</table>

Resources estimated using cross-section method
Hypothetical Isotherm for hvB-hvA Coal Rank

For illustration purposes only!
Hypothetical Gas Content Probability Distributions for Ovoot Tolgoi Coal Resources

For illustration purposes only!
Hypothetical CMM Resources of Ovoot Tolgoi Coal Deposit

Potential Surface Coal Mine
CMM Resource Estimate (million cubic meters)

<table>
<thead>
<tr>
<th>P90</th>
<th>P50</th>
<th>P10</th>
</tr>
</thead>
<tbody>
<tr>
<td>649</td>
<td>732</td>
<td>816</td>
</tr>
</tbody>
</table>

Potential Underground Coal Mine
CMM Resource Estimate (million cubic meters)

<table>
<thead>
<tr>
<th>P90</th>
<th>P50</th>
<th>P10</th>
</tr>
</thead>
<tbody>
<tr>
<td>562</td>
<td>630</td>
<td>696</td>
</tr>
</tbody>
</table>

For illustration purposes only!
The Petroleum Resources Management System (review)
Thanks!

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