CMM Resource Assessments and their Impact on Project Development

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Outline of Presentation

- CMM and CBM Resources Assessments and Coal Mine Development
- Elements of Resource Assessment
- Classification Schemes and Methods of Resource Estimation
- Example Resource Assessment: CMM/CBM Occurrences and the Potential for Development in Mongolia
- Coal Mine Development and the Impact on Resource Assessment
- Including the Economic and Social Dimensions in Resource Assessments
CMM and CBM Resources Assessments and Coal Mine Development
Types of Resources Assessments Discussed in this Presentation

- Coal
- Coalbed Methane (CBM)
- Coal Mine Methane (CMM)
  - Underground coal mines
  - Surface/Open cast mines
- Abandoned Mine Methane (AMM)
Gas Resources and the Coal Mining Life Cycle

Coal Mining Life Cycle

Mine Planning
Undeveloped Coal Reserves
Gas Resources Evaluated and Production Plan Adopted

Active Mining
Developed Coal Reserves
Gas Produced and Sold During Mining
Pre-mine and Gob Drainage

Mine Closed
Depleted Coal Reserves
Enhanced CH₄ Recovery and CO₂ Sequestration
Post-mining Gas Production

Gas Production Life Cycle
Pilcher, 2013
Elements of Resource Assessment
Input Considerations for Resource Assessments

- **Coal**: extensive drilling/coring, (or mining) and borehole logging.

- **CBM**: utilizes coal resource information, but needs additional testing to determine gas content, permeability, water saturation, and gas composition. Gas content data can come from core or cuttings.

- **CMM** integrates knowledge gained from coal resource exploration and coal mine development; generally requires experience in region to reliably forecast resource and producibility.
Input Considerations for Resource Assessments

- **CMM**
  - SMM integrates knowledge gained from coal resource exploration and coal mine development; generally requires experience in region to reliably forecast resource and producibility and is reliant on coal mine timing.
  - AMM utilizes historical information regarding size and extent of mining, methane emission during active mining, and time since closure to estimate potential resource. Forecasting is unreliable without AMM gas production reliability.
  - VAM resources largely determined by volume of ventilation air and exposure of coal in mine workings; safety considerations establish limits on methane and ventilation air.
Sources of Uncertainty Embedded in CMM/CBM Resource Estimates

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
Resources Classifications

- Resources classifications should:
  - Facilitate and organize exploration and development information and data so that the magnitude of a potentially valuable resource is reliably reported
  - Capture the uncertainty of the discovery and the potential for commercial development
  - May incorporate legally defined categories

- Resources classifications are used to assess the relative value of the resource base
- The basis on which resources are publicly reported may be strictly regulated
What External Factors Can/Should be Considered When Estimating and Reporting Resources and Reserves?

- economic
- environmental
- market
- legal
- political
- social
Classification Schemes and Methods of Resource Estimation
McKelvey (1972) Diagram Implies Relative Commercial Potential of Resources By Mapping Uncertainty

<table>
<thead>
<tr>
<th></th>
<th>IDENTIFIED RESOURCES</th>
<th>UNDISCOVERED RESOURCES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Demonstrated</td>
<td>Inferred</td>
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<tr>
<td></td>
<td>Measured</td>
<td>Indicated</td>
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<tr>
<td>ECONOMIC</td>
<td>Reserves</td>
<td>Inferred Reserves</td>
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<tr>
<td>MARGINALLY ECONOMIC</td>
<td>Marginal Reserves</td>
<td>Inferred Marginal Reserves</td>
</tr>
<tr>
<td>SUB-ECONOMIC</td>
<td>Demonstrated Subeconomic Resources</td>
<td>Inferred Subeconomic Resources</td>
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</tbody>
</table>

Other Occurrences: Includes nonconventional and low-grade materials
Converting Resources to Reserves — What Determines the Commercial Potential?

- Increases in Technically Recoverable Resources due to choices in technology
- Increases in Reserves due to changes in sales price of production costs
Joint Ore Reserves Committee
Mineral Resources Classification

- **DEMONSTRATED**
  - CURRENT JORC RESERVES
    - PROVED
    - PROBABLE

- **INFERRED**
  - CURRENT JORC RESOURCES
    - MEASURED
    - INDICATED
      - UNLESS ASSESSED BY GA AS SUBECONOMIC

- **ECONOMIC**
  - JORC MEASURED AND INDICATED RESOURCES ASSESSED BY GEOSCIENCE AUSTRALIA TO BE SUBECONOMIC (INCLUDES HISTORIC RESOURCES)

- **SUBECONOMIC**
  - PARAMARGINAL
  - SUBMARGINAL

- **JORC INFERRED RESOURCES (INCLUDES HISTORIC RESOURCE)**
The Petroleum Resources Management System (SPE, WPC, AAPG)
Approaches to Estimating (Assessing) CMM Resources

- Commonly 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 OGIP or 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 Resource Assessment:
CMM/CBM Occurrences and the Potential for Development in Mongolia
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
Rank of Mongolian Coal and Hydrocarbon Generation Potential

<table>
<thead>
<tr>
<th>Rank</th>
<th>Coal Type</th>
<th>% Volatiles in Coal</th>
<th>% Carbon in Coal</th>
<th>Vitrinite Reflectance (% R0)</th>
<th>Hydrocarbon Products Generated From Coal Source</th>
<th>Resultant Hydrocarbon Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Anthracite</td>
<td>4</td>
<td>200</td>
<td>-5.0</td>
<td>Low</td>
<td>Biogas</td>
</tr>
<tr>
<td>2</td>
<td>Semianthracite</td>
<td>13</td>
<td>200</td>
<td>-2.9</td>
<td>Methane and oil</td>
<td>Wet gas and oil</td>
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<tr>
<td>3</td>
<td>Low Volatile bituminous</td>
<td>25</td>
<td>170</td>
<td>-1.5</td>
<td>Metamorphosed methane</td>
<td>Condensate</td>
</tr>
<tr>
<td>4</td>
<td>Medium Volatile bituminous</td>
<td>33</td>
<td>80</td>
<td>-0.9</td>
<td>Other hydrocarbons</td>
<td>Dry gas</td>
</tr>
<tr>
<td>5</td>
<td>High Volatile bituminous</td>
<td>46</td>
<td>50</td>
<td>-0.3</td>
<td>Medium to high R0 products</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Sub-bituminous</td>
<td>80</td>
<td>50</td>
<td>-0.2</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Lights</td>
<td>80</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Peat</td>
<td>80</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- Powder River (subB)
- San Juan and Raton Basins (hvBb - mvb)
- Vitrinite reflectance measured from one Powder River sample.
- Range in R0 of Mongolian coal.
Kerogen Types of Known Coal Occurrences in Mongolian Coal Basins

![Graph showing Kerogen Types and Occurrences](image)
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>Narin-sukhait</th>
<th>Nuurstk-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>
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<tr>
<td><strong>Gas Content</strong></td>
<td>3-14</td>
<td>6-14</td>
<td>&lt;3</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td><strong>m³/tonne</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<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>
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<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>
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<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>
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<tr>
<td><strong>Depth of Completion</strong></td>
<td>~800m</td>
<td>~650m</td>
<td>~150m</td>
<td>?</td>
<td>?</td>
<td>?</td>
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**Desorption Test Results at Naryn Sukhait**

<table>
<thead>
<tr>
<th>Sample Name</th>
<th>Borehole Name</th>
<th>Analysis Date</th>
<th>Sample Depth (m)</th>
<th>S&amp;W (m³/t) (raw)</th>
<th>S&amp;W (m³/t) (DAF)</th>
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</thead>
<tbody>
<tr>
<td>CANISTER №1 29 October 2012</td>
<td>M12-714</td>
<td>11-Dec-12</td>
<td>83</td>
<td>0.184</td>
<td>0.193</td>
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<tr>
<td>CANISTER №2 09 November 2012</td>
<td>M12-715</td>
<td></td>
<td>379.7</td>
<td>3.758</td>
<td>3.758</td>
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<tr>
<td>CANISTER №3 15 November 2012</td>
<td>M12-713A</td>
<td>11-Dec-12</td>
<td>318.2</td>
<td>3.093</td>
<td>3.453</td>
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<tr>
<td>CANISTER №4 18 November 2012</td>
<td>M12-713A</td>
<td>11-Dec-12</td>
<td>331.2</td>
<td>1.185</td>
<td>1.573</td>
</tr>
<tr>
<td>CANISTER №5 22 November 2012</td>
<td>M12-713A</td>
<td>11-Dec-12</td>
<td>345.2</td>
<td>0.015</td>
<td>0.016</td>
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<tr>
<td>CANISTER №6 25 November 2012</td>
<td>M12-713A</td>
<td>11-Dec-12</td>
<td>376.2</td>
<td>1.231</td>
<td>1.334</td>
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<tr>
<td>CANISTER 1 - 524</td>
<td>M12-284B</td>
<td>17-Jun-12</td>
<td>203</td>
<td>0.09</td>
<td>0.168</td>
</tr>
<tr>
<td>CANISTER 2 - 525</td>
<td>M12-284B</td>
<td>17-Jun-12</td>
<td>217.4</td>
<td>0.172</td>
<td>0.0192</td>
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<tr>
<td>CANISTER 3 BTM - 526</td>
<td>M12-284B</td>
<td>17-Jun-12</td>
<td>245</td>
<td>0.941</td>
<td>1.753</td>
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</table>
Adsorption Testing Results
Calculated Coal Resources Shown by Depth, with Equilibrium Moisture Adsorption Isotherm

[Diagram showing coal resources at different depths with equilibrium moisture adsorption isotherm.

- Pressure (Mpa): 0, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5
- Gas Content (m³/t)
- Mining Depth (m): 0, 50, 100, 150, 200, 250, 300, 350, 400, 450, 500, 550
- Coal Resources (Mt)
  - *Coal S Resources
  - **Cumulative Coal S Resources

NOTE: Planned coal to be mined not calculated.]

Explanation:
- Isotherm Curve
- *Coal S Resources
- **Cumulative Coal S Resources

Global Methane Initiative
Probability Based Estimate of GIP by Depth Interval, Coal Seam 5 Naryn Sukhait
Gas and Water Production Forecast Based on p50 Decline Model
Methane Isotherms from Samples Collected at the Khotgor Deposit, Kharkhiraa Coal Basin
Methane Isotherms from Samples Collected at East and Central Gobi Coal Basins
Stochastic (probability based) Resource Estimate for the Central Gobi Coal Basin
Comparison of Methane Isotherms from Mongolia to p50 Isotherms from Database of US Isotherms
Hydrology of Mongolian Coal Basins
Hydrology Overlain with Annual Precipitation
Estimated Emissions Factors for Mongolian Coal Basins

CMM Emissions Factors by Coal Basin and Coal Rank

Explanation
- **Lignite**
- **Subbituminous**
- **Bituminous**

0.10 - 0.30
0.31 - 0.50
0.51 - 1.00
1.01 - 2.00
2.01 - 4.00
4.01 - 8.00

0 50 100 200 300 400 Kilometers
Estimated CMM Resources by Coal Basin In Mongolia
## Estimate of CMM Resources by Coal basin in Mongolia

<table>
<thead>
<tr>
<th>Coal Basin</th>
<th>p50 CMM Resources 0 – 300 m (billion m³)</th>
<th>p50 CMM Resources 300 – 600 m (billion m³)</th>
<th>p50 CMM Resources 600 – 900 m (billion m³)</th>
<th>p50 CMM Resources 900 – 1200 m (billion m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bayan-Ulgii</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Central Gobi</td>
<td>12.2</td>
<td>31.9</td>
<td>41.1</td>
<td>46.8</td>
</tr>
<tr>
<td>Choibalsan</td>
<td>11.8</td>
<td>26.9</td>
<td>35.5</td>
<td>41.0</td>
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<tr>
<td>Choir-Nyalga</td>
<td>14.1</td>
<td>36.7</td>
<td>48.4</td>
<td>55.8</td>
</tr>
<tr>
<td>East Gobi</td>
<td>15.7</td>
<td>42.5</td>
<td>56.0</td>
<td>64.6</td>
</tr>
<tr>
<td>Ikh Bogd</td>
<td>0.7</td>
<td>1.7</td>
<td>2.1</td>
<td>2.3</td>
</tr>
<tr>
<td>Kharkhiraa</td>
<td>30.8</td>
<td>63.7</td>
<td>77.8</td>
<td>85.8</td>
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<tr>
<td>Mongol-Altai</td>
<td>64.3</td>
<td>132.8</td>
<td>162.2</td>
<td>178.8</td>
</tr>
<tr>
<td>Ongi River</td>
<td>5.2</td>
<td>12.6</td>
<td>15.5</td>
<td>17.2</td>
</tr>
<tr>
<td>Orkhon-Selenge (North)</td>
<td>34.0</td>
<td>69.9</td>
<td>85.1</td>
<td>93.7</td>
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<tr>
<td>Orkhon-Selenge (South)</td>
<td>4.2</td>
<td>9.2</td>
<td>11.6</td>
<td>13.0</td>
</tr>
<tr>
<td>Southern Khangai</td>
<td>7.6</td>
<td>15.9</td>
<td>19.5</td>
<td>21.5</td>
</tr>
<tr>
<td>South Gobi</td>
<td>61.8</td>
<td>148.6</td>
<td>181.8</td>
<td>200.7</td>
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<tr>
<td>Sukhbaatar</td>
<td>2.9</td>
<td>7.8</td>
<td>10.2</td>
<td>11.8</td>
</tr>
<tr>
<td>Tamsag</td>
<td>52.5</td>
<td>113.8</td>
<td>143.3</td>
<td>160.8</td>
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<tr>
<td>Trans-Altai</td>
<td>20.9</td>
<td>50.5</td>
<td>61.6</td>
<td>68.0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>338.7</strong></td>
<td><strong>764.5</strong></td>
<td><strong>951.8</strong></td>
<td><strong>1,061.9</strong></td>
</tr>
</tbody>
</table>
Coal Mine Development and the Impact on Resource Assessment
Vertically Drilled Boreholes

Figure 1: Pre Mine Drainage

Direction of mining

Year 1 pit boundary
Year 2 pit boundary
Year 3 pit boundary

Coal to be mined

Figure 2: Post Mining

Mined through wells

Future direction of mining

Mined coal
Overburden Removal Increases Permeability

- Permeability increases exponentially with decreasing effective stress.
- Effective stress is diminished as overburden is removed during mining.
- Permeable pathways occurring in geologic structures such as breached folds or faults are enhanced as overburden is removed.
- Matrix and fracture permeability is enhanced as a function of the stiffness of the rock mass, density of fracturing and thickness of overburden removed.
Impact of Rock Stiffness on Increases in Permeability as Overburden is Removed

Medium-Volatile Bituminous Coal


Fracture compressibility for sub-bituminous coal, high volatile bituminous and equation for relationship between overburden removal and permeability increase from *Improvements in Measuring Sorption-Induced Strain and Permeability in Coal* by E.P. Robertson, SPE 116259, 2008 SPE Eastern Regional/AAPG Eastern Section Joint Meeting held in Pittsburgh, Pennsylvania.
Effects Caused by Relaxation of Stresses in Coal Bearing Strata

- Void spaces remain after coal removal that allows surrounding strata to relax and create zones of increased permeability
- Fluids can use these zones as pathways during migration from higher to lower pressure regimes
- Zones of increased permeability are gas drainage targets
- Voids and zones of increased permeability may also become productive targets for gas production after mine closure, they may also be the pathway for water influx
Impact of Mining on Gas Release
Method of Calculating Gas Resources at an Underground Coal Mine

- Monthly Liberated Methane from Coal Mine
- Frequency Distribution of Relative Emissions for Coal Mine
- Monthly Coal Production of Coal Mine
- Coal Production Forecasts
- Frequency Distribution Annual Volume Liberated from Coal Mine
Including the Economic and Social Dimensions in Resource Assessments
Understanding the Issues that Drive the Economics and Operation of a CMM Project

- Draining CMM for Mine Safety and Efficiency
- Certifying and Marketing GHG Emissions Reductions
- Selling Gas as Fuel & Feedstock

Global Methane Initiative
UNFC Resource Classification and the Socio-Economic Dimension
Muchas gracias!

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