Resource Enterprises (REI, Inc.)

- Methane Drainage and Use
Methane Drainage Considerations

- **Mine Methane Emissions**
  - Emissions Distribution
  - Emissions Characteristics
    - Operating Coal Faces
    - Start of Longwall Panels

- **Location of Emissions**
  - Roof Fractures
  - Floor Fractures
  - Working Seam
  - Behind Shields
  - Gob/Bleeders
  - Belt/Transported Coal

- **Source of Methane Emissions**
  - Mining Seam
  - Gas Bearing Overlying Strata
  - Gas Bearing Underlying Strata
  - Charged Deep Underlying Gas Sources
Directional Drilling Approach

- Reservoir Conditions
  - > 600 m² of surface area for 2,000 m borehole

- Pressure Gradient Driven Flow
  - Gas Desorption from Microscopic Coal Surfaces
  - Gas and Water Flow through Natural Fractures in Coal to Borehole
  - Gas and Water Flow through Borehole to Wellhead for Water Separation
  - Gas Transported through Underground Network to Surface
In-Seam Drainage Considerations

### Impact of Reservoir Conditions

<table>
<thead>
<tr>
<th>Reservoir Properties</th>
<th>Pittsburgh</th>
<th>Pocahontas No. 3</th>
<th>Lower Hartshorne</th>
<th>Blue Creek</th>
<th>Double Seam</th>
<th>USCB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rank</td>
<td>High Volatile Bituminous</td>
<td>Medium Volatile Bituminous</td>
<td>Low-Medium Volatile Bituminous</td>
<td>Low-Medium Volatile Bituminous</td>
<td>Medium Volatile Bituminous</td>
<td>High-Medium Volatile Bituminous</td>
</tr>
<tr>
<td>Depth (m)</td>
<td>250 - 300</td>
<td>180 - 390</td>
<td>320 - 610</td>
<td>427 - 640</td>
<td>150 - 350</td>
<td>936</td>
</tr>
<tr>
<td>Reservoir Pressure Gradient (kPa/m)</td>
<td>9.48</td>
<td>5.39</td>
<td>9.73</td>
<td>3.39</td>
<td>6.79</td>
<td>7.78</td>
</tr>
<tr>
<td>Reservoir Pressure at Depth (kPa)</td>
<td>2,370 – 2,844</td>
<td>969 - 2,100</td>
<td>3,103 - 5,929</td>
<td>1,447 – 2,170</td>
<td>1,018 - 2,376</td>
<td>7,282</td>
</tr>
<tr>
<td>Permeability (md)</td>
<td>10 - 15</td>
<td>10 - 27</td>
<td>1.2 - 1.6</td>
<td>12-20</td>
<td>20 - 35</td>
<td>0.5 – 1.0</td>
</tr>
<tr>
<td>Thickness (m)</td>
<td>2.0</td>
<td>2.1 - 2.4</td>
<td>1.4 - 4.3</td>
<td>1.5 – 1.9</td>
<td>1.6 - 3.1</td>
<td>1.2 – 8.8</td>
</tr>
<tr>
<td>Gas Content (m³/t dmaf)</td>
<td>5.0 - 7.0</td>
<td>8.0 - 12.9</td>
<td>15.9 - 16.4</td>
<td>12.2 - 16.1</td>
<td>7.8 - 12.8</td>
<td>5 - 10</td>
</tr>
<tr>
<td>Langmuir Volume (m³/t)</td>
<td>22.9</td>
<td>22.4</td>
<td>20.9</td>
<td>20.8</td>
<td>27.16</td>
<td>26.3</td>
</tr>
<tr>
<td>Langmuir Pressure (kPa)</td>
<td>2,683</td>
<td>1,165</td>
<td>N/A</td>
<td>1,710</td>
<td>1,419</td>
<td>1,650</td>
</tr>
<tr>
<td>Sorption Time (hours)</td>
<td>741</td>
<td>168</td>
<td>37</td>
<td>72 - 96</td>
<td>56.6 - 66.7</td>
<td>360</td>
</tr>
</tbody>
</table>
Pre-Mining Methane Drainage Considerations

- **Reservoir Simulation**

  - **GC_{i} = 15 m^3/t, Spacing 20 m**

  ![Diagram](image1.png)

  ![Diagram](image2.png)

  ![Diagram](image3.png)

  **Fracture Locations**

  - **GC_{R} = 6 m^3/t, 2 Years**
Directional Drilling Approach

- Gob Degasification
  - Gob Degasification Techniques
  - Low Pressure Sink Created by Horizontal Gob Boreholes
Directional Drilling Engineering

- Torque and Drag Simulation
  - String Model of Drill Steel
  - Buckling Limits, Tension - Depth
  - Range Chart, Thrust - Depth

### 165 mm Directional Drilling with 89 mm Downhole Motor

<table>
<thead>
<tr>
<th></th>
<th>Sinusoidal Buckling Depth (m)</th>
<th>Helical Buckling Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Centralized Casing</td>
<td>137</td>
<td>198</td>
</tr>
<tr>
<td></td>
<td>427</td>
<td>488</td>
</tr>
<tr>
<td></td>
<td>396</td>
<td>472</td>
</tr>
<tr>
<td></td>
<td>792</td>
<td>884</td>
</tr>
<tr>
<td>178 mm Centralized Casing</td>
<td>808</td>
<td>838</td>
</tr>
<tr>
<td></td>
<td>792</td>
<td>884</td>
</tr>
</tbody>
</table>

- No Centralized Casing
- 178 mm Centralized Casing
- 70 mm CHD
- 73 mm MCHD
- 73 mm CHD, 114 mm stabilizers @ 15 m intervals
Developments in Directional Drilling

- Extended Reach Drills
  - Performance
    - 200 kN/4,000 NM
    - 1,500 m

- Extended Reach Drills
  - Performance
    - 555 kN/7,500 NM
    - > 2,000 m

- Permissible Equipment
  - Performance
    - 200 kN/4,000 NM
    - 1,500 m

- Multi-Purpose Drills
  - Underground
  - Highwall
  - Mine Appropriate SIS
Developments in Directional Drilling

- Extended Reach Downhole Tools and Pumps
Developments in Technology

- On-Board Focused Gamma Polygon Guidance
- On-Board Drill to Plan
- Data Management
- Drill Performance Monitoring

- Roof
- Coal
- Floor
Developments in Technology

- Well/Borehole Interception

- Magnetic Vector Technology

SIS Boreholes:
3,800 ft (1,158 m) total depth
2,560 ft (789 m) in-seam

Barrier

Surface to In-seam well setup location

Vertical Production Well

Intercept 150 mm Dia. Vertical Well
Directional Drilling Solutions

- Complementing Systems of Methane Drainage

- Complementary Pre-Mining Drainage in High Perm Conditions > 10 md
- > 1600 m Directionally Drilled Boreholes Navigated around Vertical Frac Wells
- In-Seam Borehole Average IP > 40 m³/min
- Significant Reservoir Pressure Reduction
- Increased Production from Frac Wells
- Record Coal Production Rates after 10 Yrs
- In Place GC Impedes Mains Development Inby of In-Seam Boreholes after 10 Yrs
Directional Drilling Solutions

- Applications in Tight Coals

- Applicable in Tight or Cemented Coals
- Where In-seam Gas Production Increases with Mining Related Stress Changes
- Intercept Fracs Orthogonally, both Mining and Adjacent Seams
- Vertical Wells Serve as Future Gob Wells
- CMM Recovered from Surface as Mining Advances
Directional Drilling Solutions

- Using Adjacent Seams
Directional Drilling Solutions

- Geo-Steering to Improve Connectivity
- Use Competent Coal Layer as a Bridge for Reach
- Navigate in Thin Competent Layer with LWD
- Develop Side-Tracks Down to Break Through Barriers to Vertical Permeability
- Carefully Contact Lower Friable Layers
## Directional Drilling Solutions

- **Implementing Stand-Alone Systems**

<table>
<thead>
<tr>
<th>Shutt In UGI Wellhead During Production</th>
<th>Vertical Well Equipped for Water/Gas Production:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mined Seam</td>
<td>- Well Intercept for Gas/Water Production</td>
</tr>
<tr>
<td>Sump Hole</td>
<td>- Vertical gob borehole</td>
</tr>
</tbody>
</table>

- **Gas Production Moved to Surface via Interception with Vertical Well (Post Use Gob Well)**
Directional Drilling Solutions

- Reducing Gas Contents of Underlying Seams
  - Pre-Mining Down-Dip Approach with Late Well Interception
  - Vertical Well used as a Gob Well once Undermined.

- Accumulated Water and CMM from Boreholes Drilled in Underlying Seam Produced from Vertical Well
Directional Drilling Solutions

- Reducing GC of Overlying Source Seams
- Dual Purpose and High Capacity Horizontal Gob Boreholes
- Adding Horizontal Legs to Vertical Gob Wells
Summary

- **Directional Drilling Solutions**

  - Developments in directional drilling technology provide for longer length, larger diameters, and more accurate placement of boreholes for improved methane drainage efficiency and longer drainage times.
  
  - Developments in reservoir simulation and torque and drag modeling aid in selecting appropriate directional drilling solutions and secondary stimulation or ECMM applications.

  - Geo-Steering technology provides the ability to maintain boreholes in-seam or in adjacent seams or strata, or specific coal layers, or hit specific targets, and combine underground and surface systems, particularly through vertical well interception.

  - Directional drilling solutions involving complementary surface and underground methane drainage systems can significantly improve gas content reduction and address mine timing and drainage time issues, particularly in tight coals.


  - Directional drilling applications include the ability to interpret geologic structure and characterize geologic anomalies including normal faults, intrusions (dikes, sand channels, karsts), and seam splits, exploration for abandoned workings, water drainage, water transfer, de-stressing, utility and monitoring.