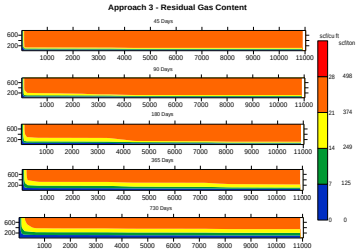
DIRECTIONAL DRILLING SOLUTIONS FOR METHANE DRAINAGE

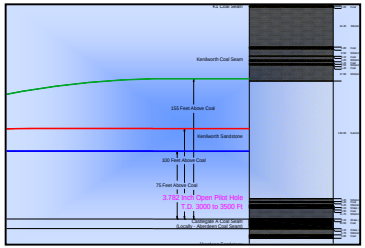
School of Underground Mining, Methane Session

Krakow, Poland, February 28, 2017

Resource Enterprises (REI, Inc.)

- Methane Drainage and Use

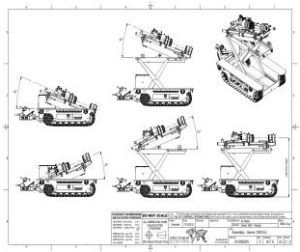
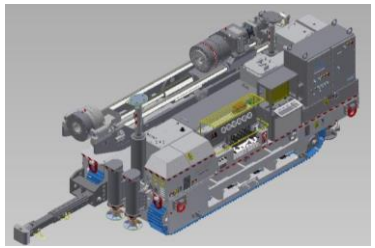









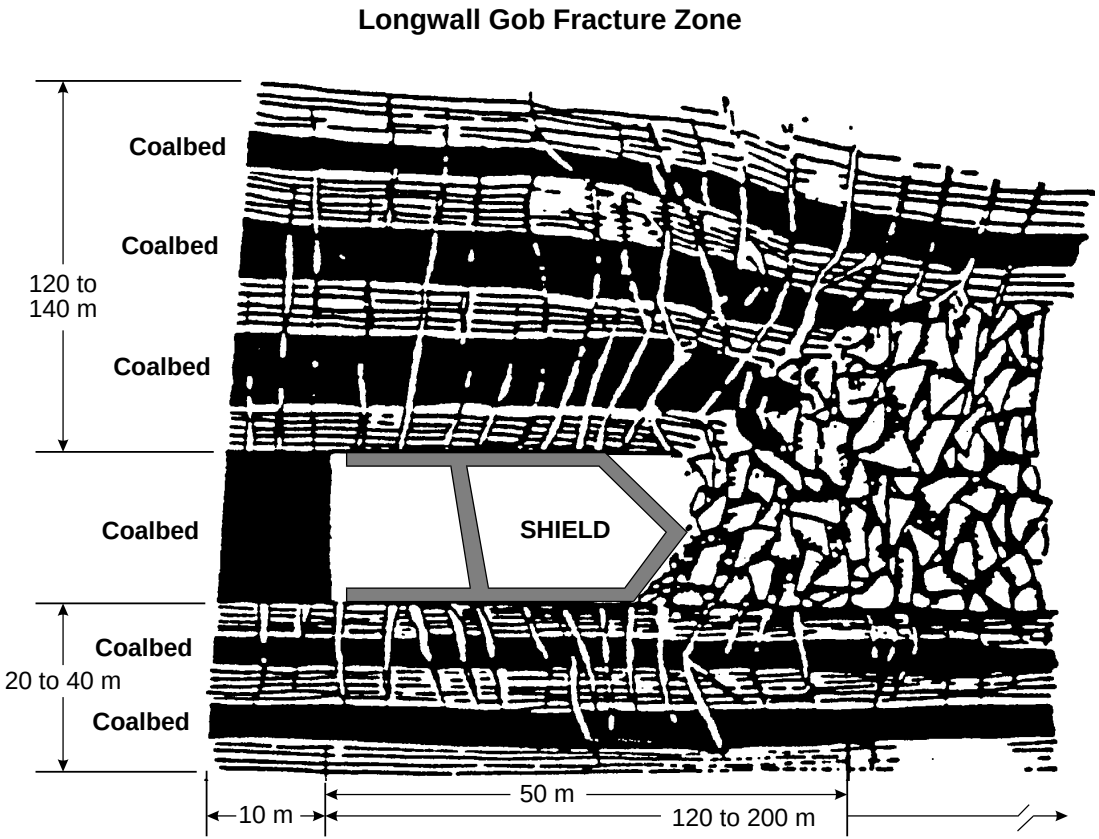



Methane Drainage Considerations

Characterizing Methane Emissions

- **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

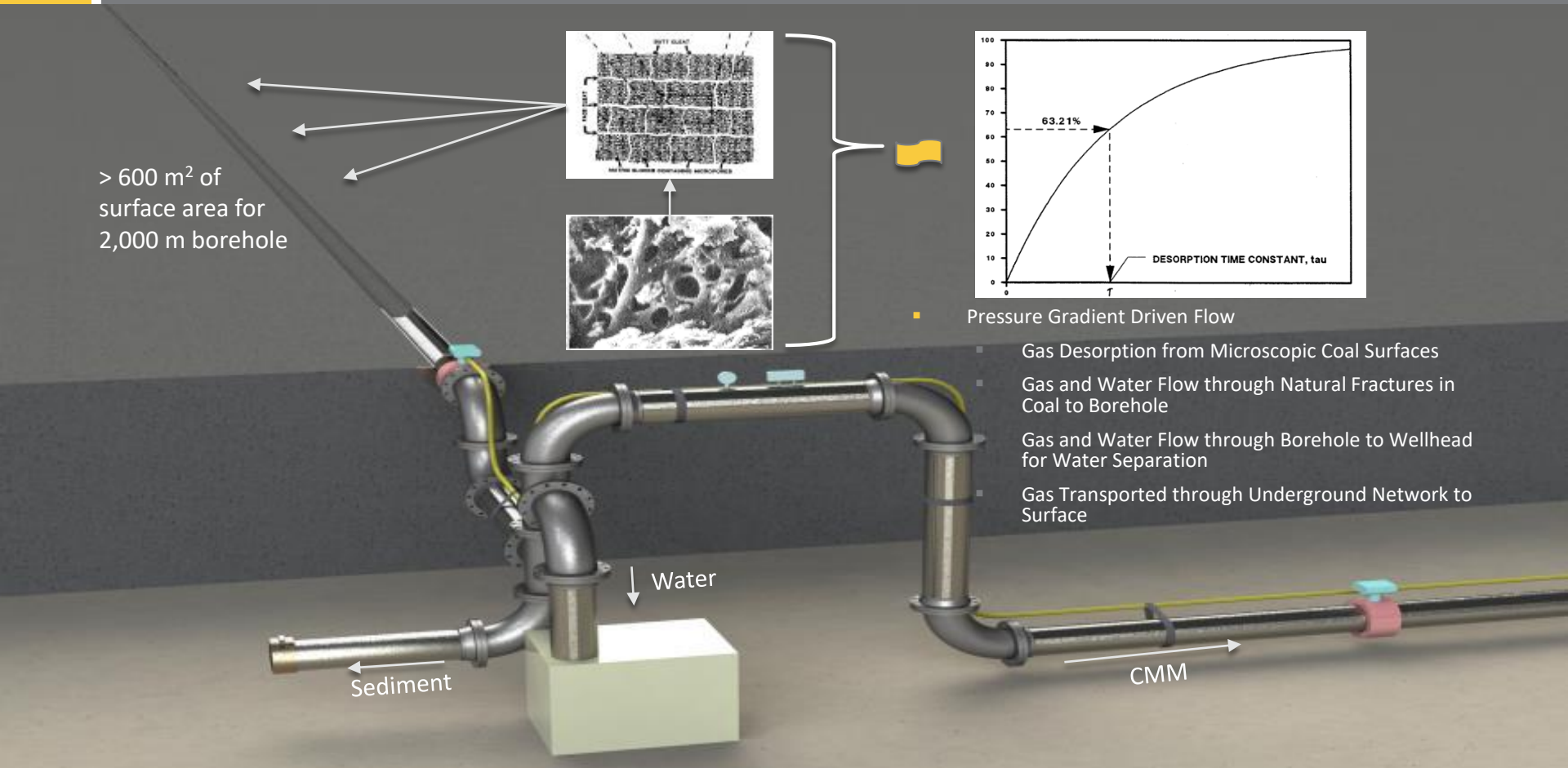


Directional Drilling Approach

- Reservoir Conditions

> 600 m^2 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



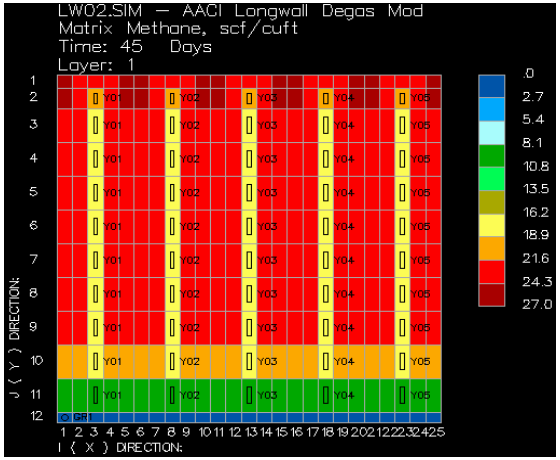
In-Seam Drainage Considerations

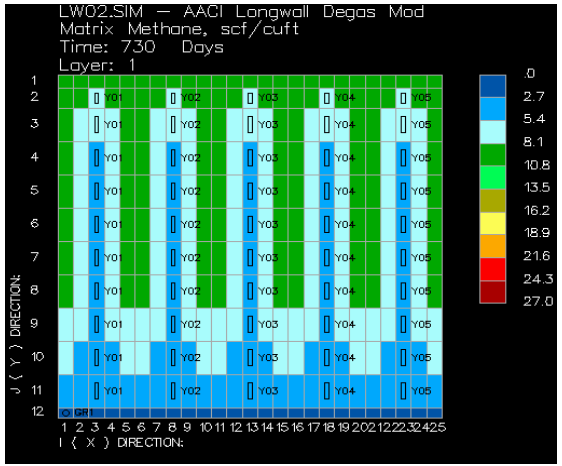
Impact of Reservoir Conditions

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

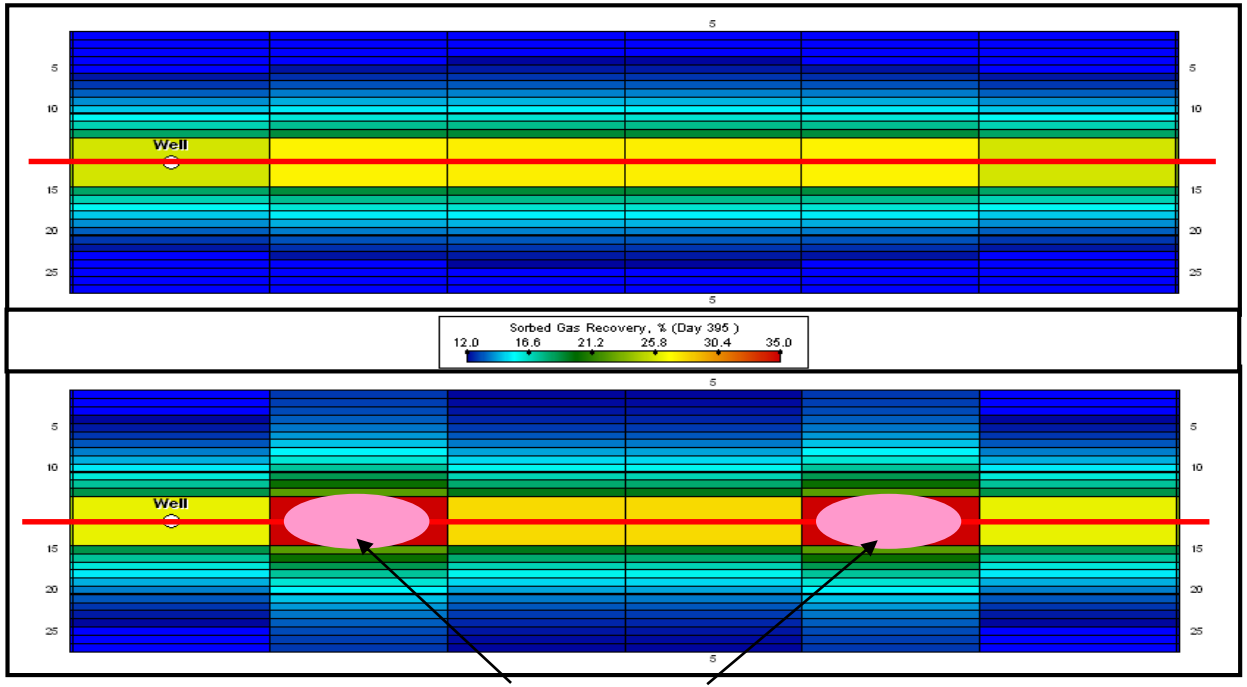
Pre-Mining Methane Drainage Considerations

Reservoir Simulation





- GC_I = 15 m^3/t, Spacing 20 m

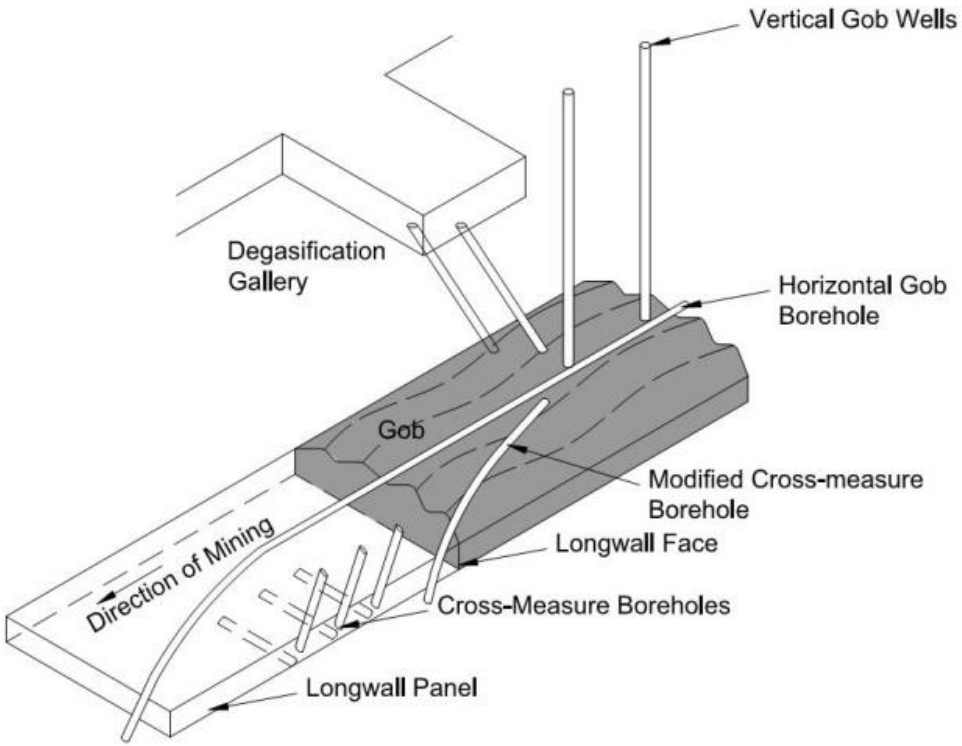


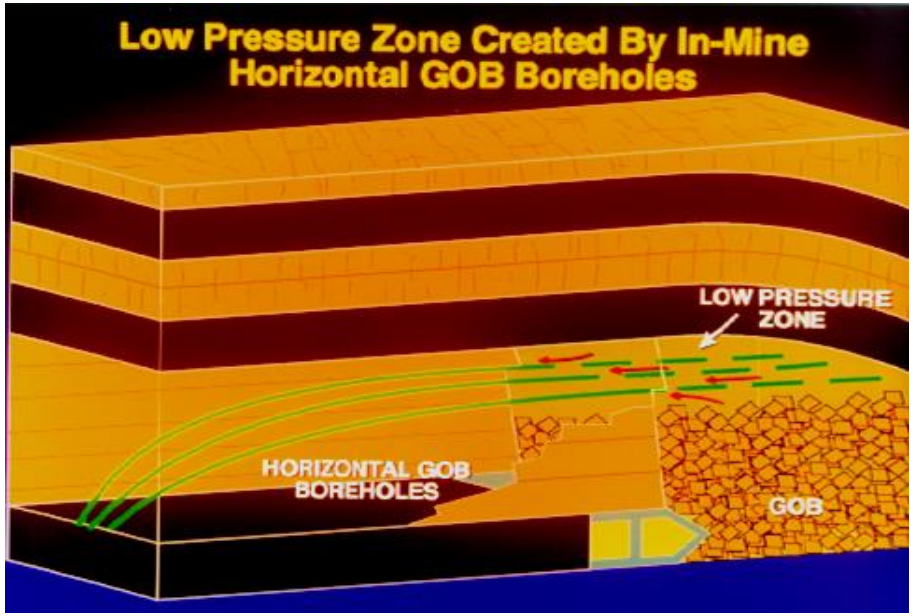
Fracture Locations

- GC_R = 6 m^3/t , 2 Years

Directional Drilling Approach

- Gob Degasification



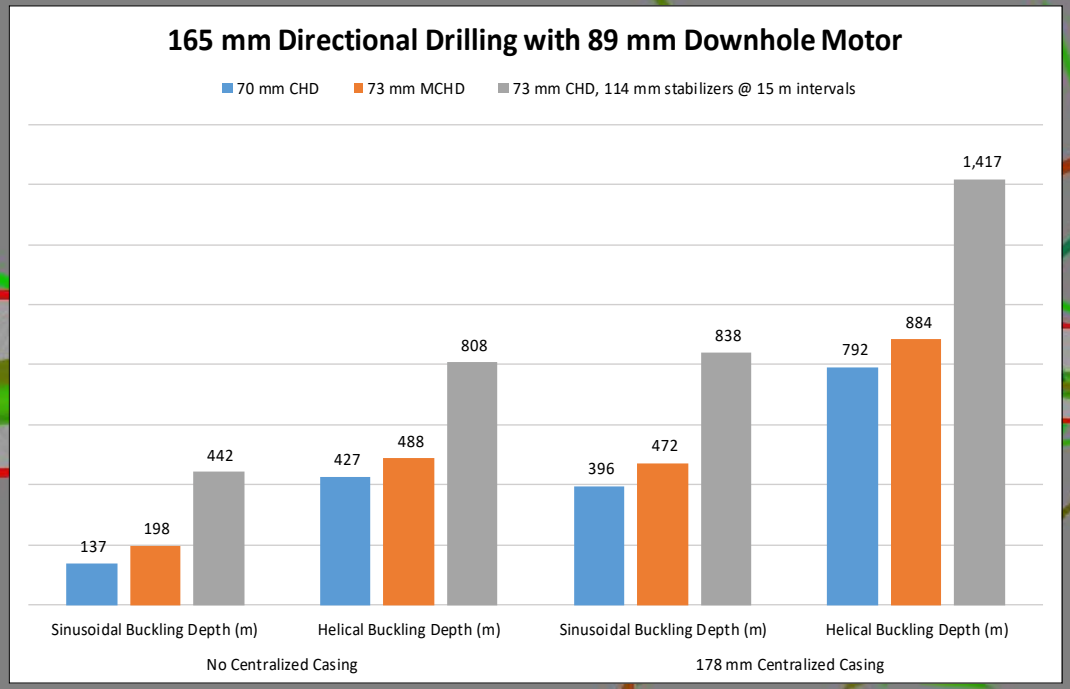


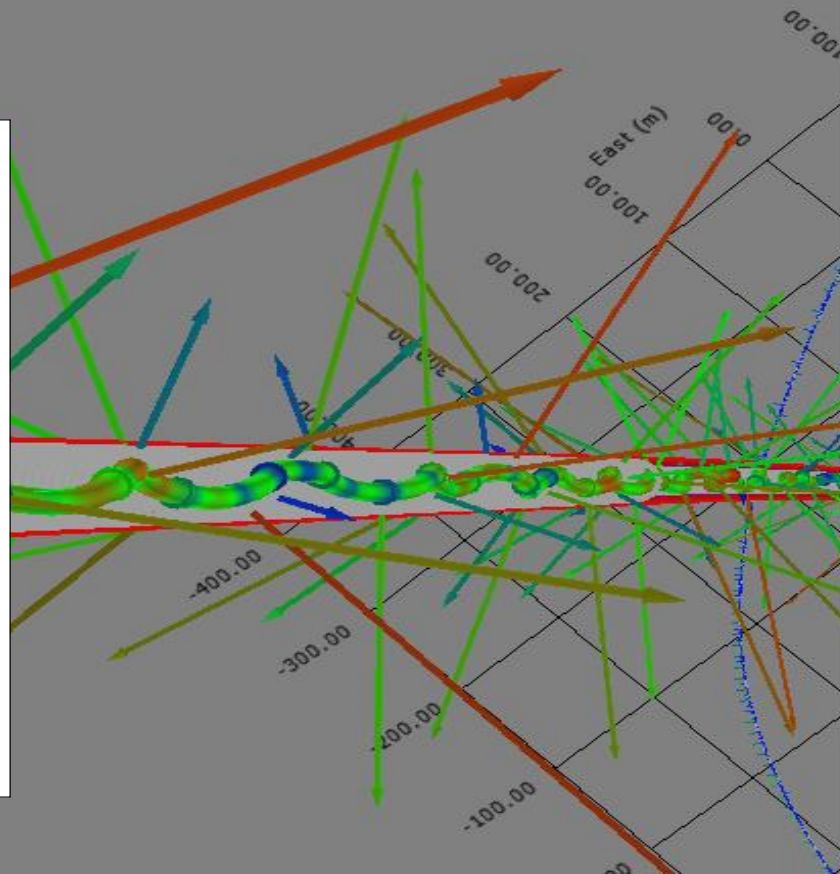
- **Gob Degasification Techniques**
- **Low Pressure Sink Created by Horizontal Gob Boreholes**

Directional Drilling Engineering

Torque and Drag Simulation

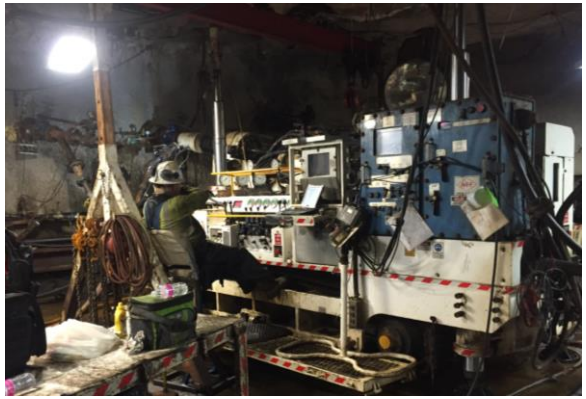
- **String Model of Drill Steel**
- **Buckling Limits, Tension - Depth**
- **Range Chart, Thrust - Depth**





Developments in Directional Drilling

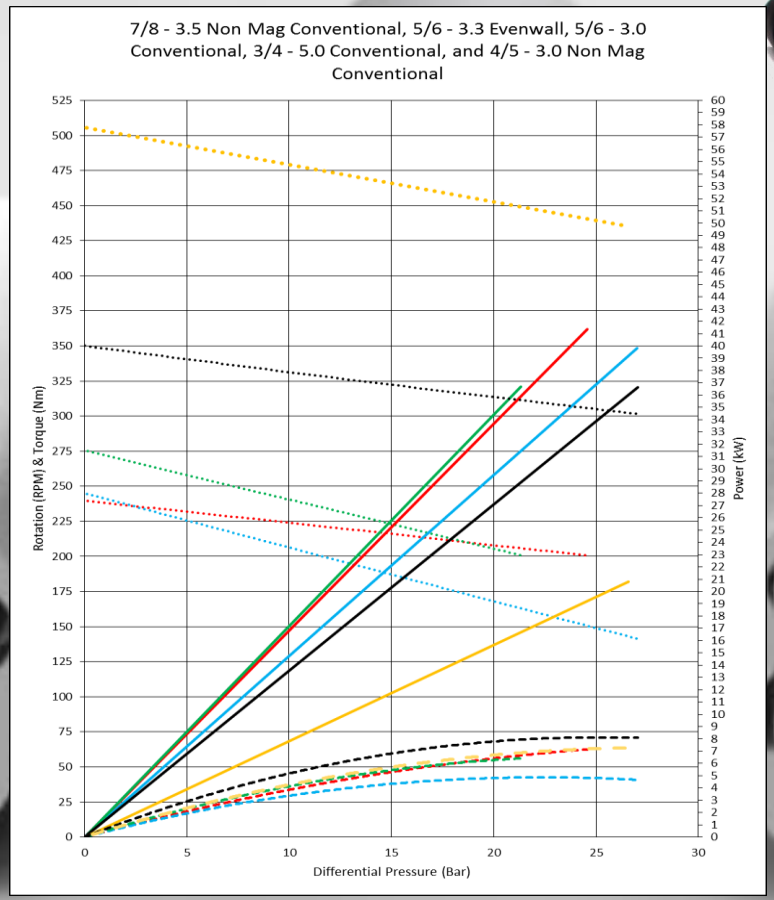
- Extended Reach Drills



- **Permissible Equipment**
  - Performance
    - 200 kN/4,000 NM
    - 1,500 m
- **Extended Reach Drills**
  - Performance
    - 555 kN/7,500 NM
    - > 2,000 m
- **Multi-Purpose Drills**
  - Underground
  - Highwall
  - Mine Appropriate SIS

Developments in Directional Drilling

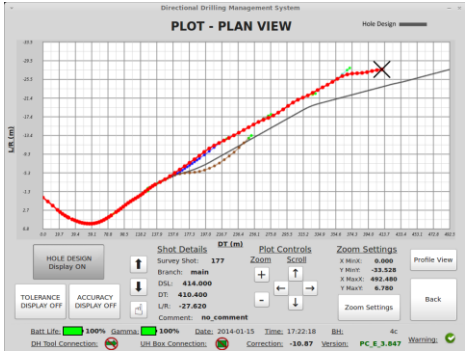
- Extended Reach Downhole Tools and Pumps

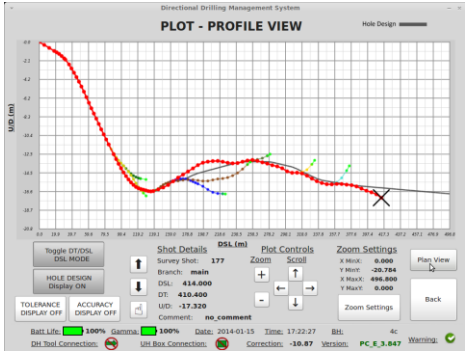


Developments in Technology

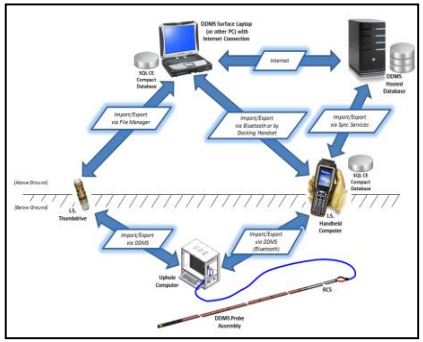
- On-Drill Navigation, Geo-Steering, and Rig Monitoring

- On-Board Drill to Plan

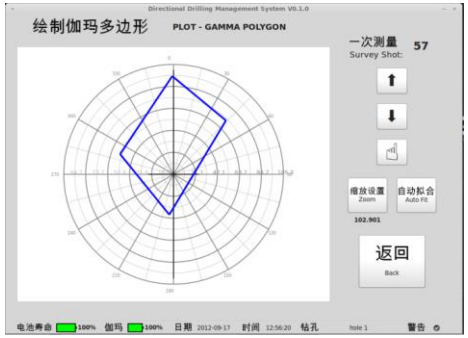


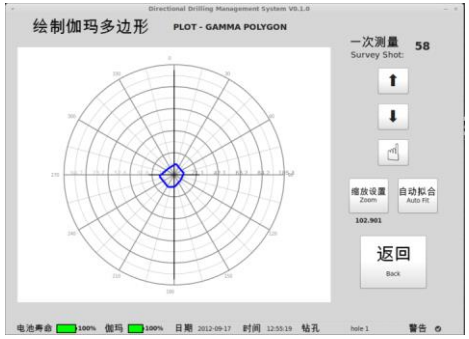


- Data Management

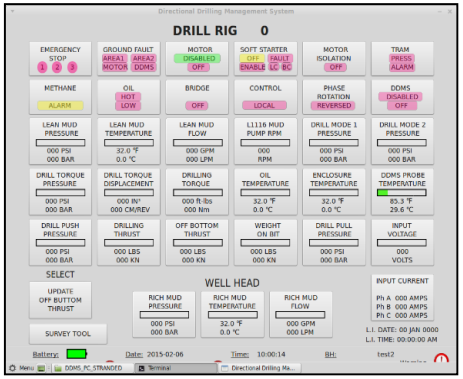


- On-Board Focused Gamma Polygon Guidance





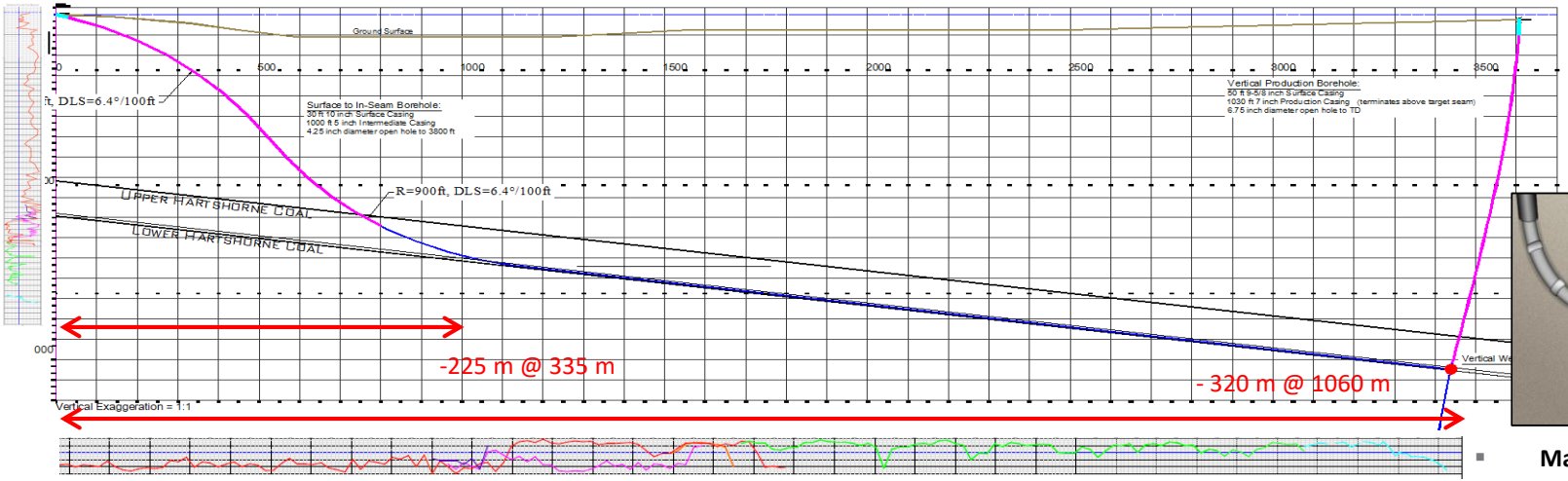
- Drill Performance Monitoring

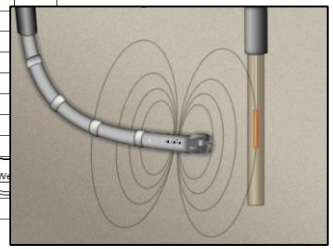


- Roof
- Coal
- Floor

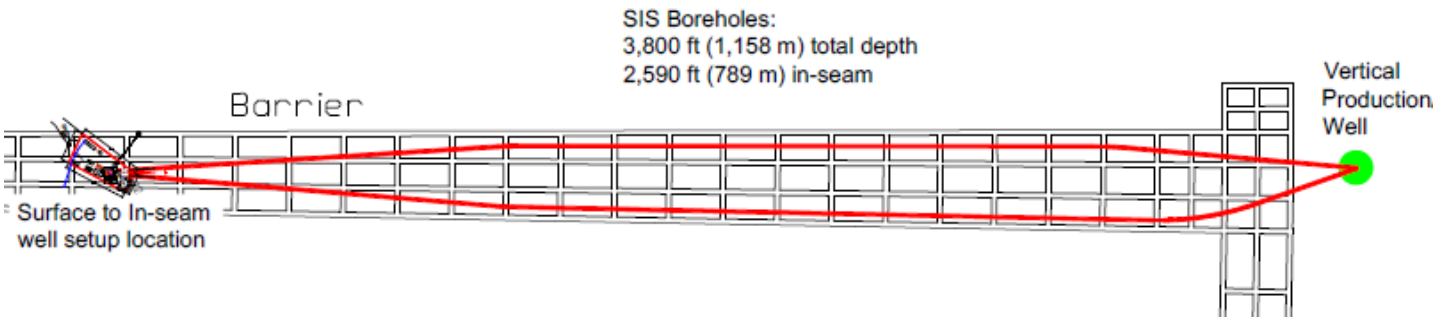
Developments in Technology

- Well/Borehole Interception





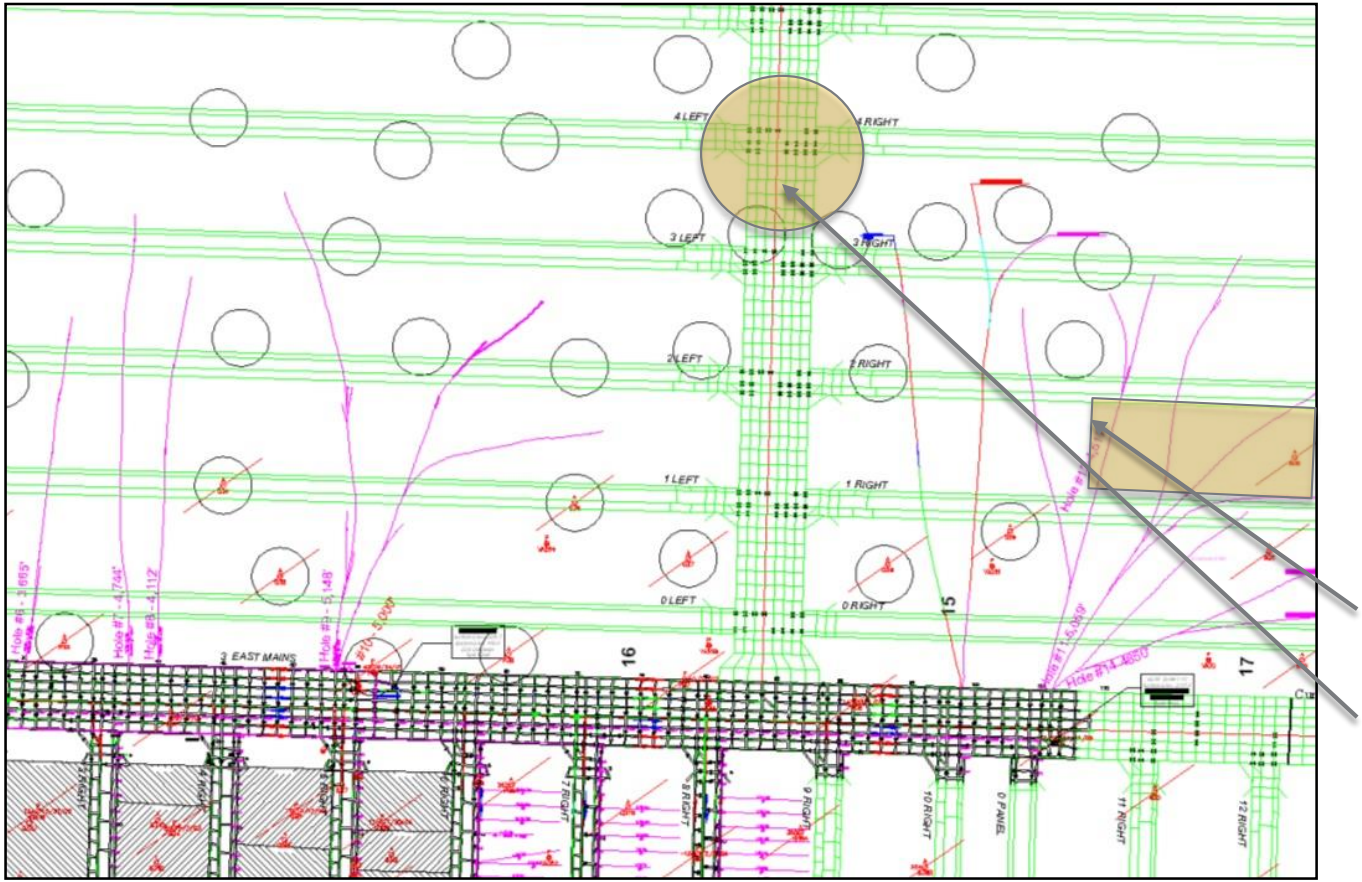
- Magnetic Vector Technology



- Intercept 150 mm Dia. Vertical Well

Directional Drilling Solutions

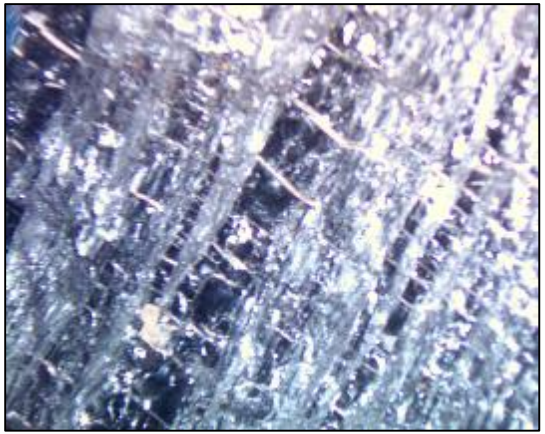
- Complementing Systems of Methane Drainage

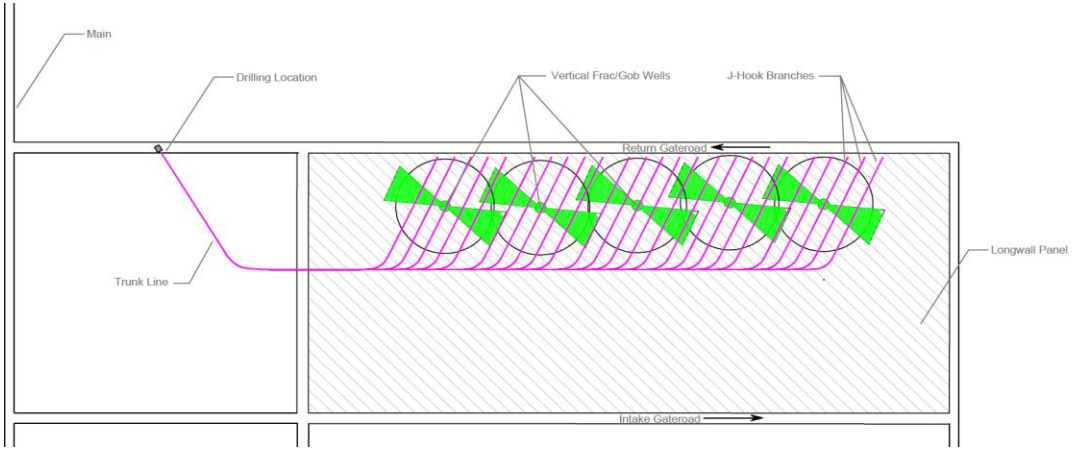


- **Complementary Pre-Mining Drainage in High Perm Conditions > 10 md**
- **> 1600 m Directionally Drilled Boreholes Navigated around Vertical Frac Wells**
- **In-Seam Borehole Average IP > 40 m^3/min**
- **Significant Reservoir Pressure Reduction**
- **Increased Production from Frac Wells**
- **Record Coal Production Rates after 10 Yrs**
- **In Place GC Impedes Mains Development Inby of In-Seam Boreholes after 10 Yrs**

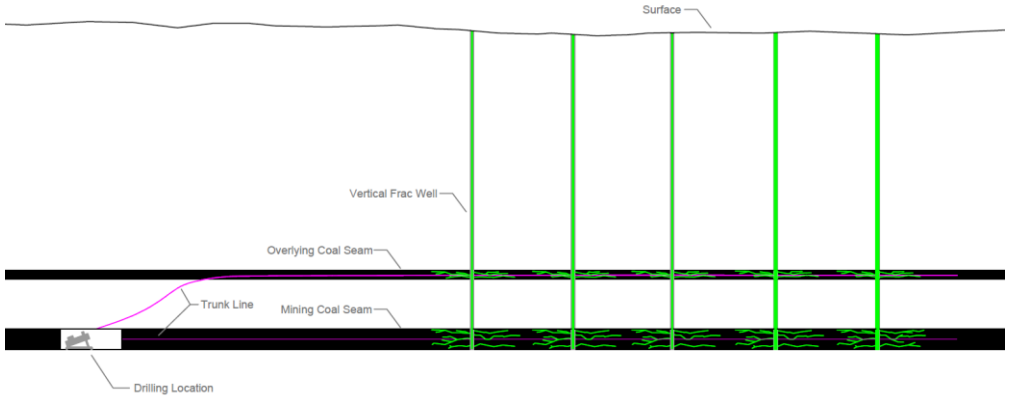
Directional Drilling Solutions

Applications in Tight Coals



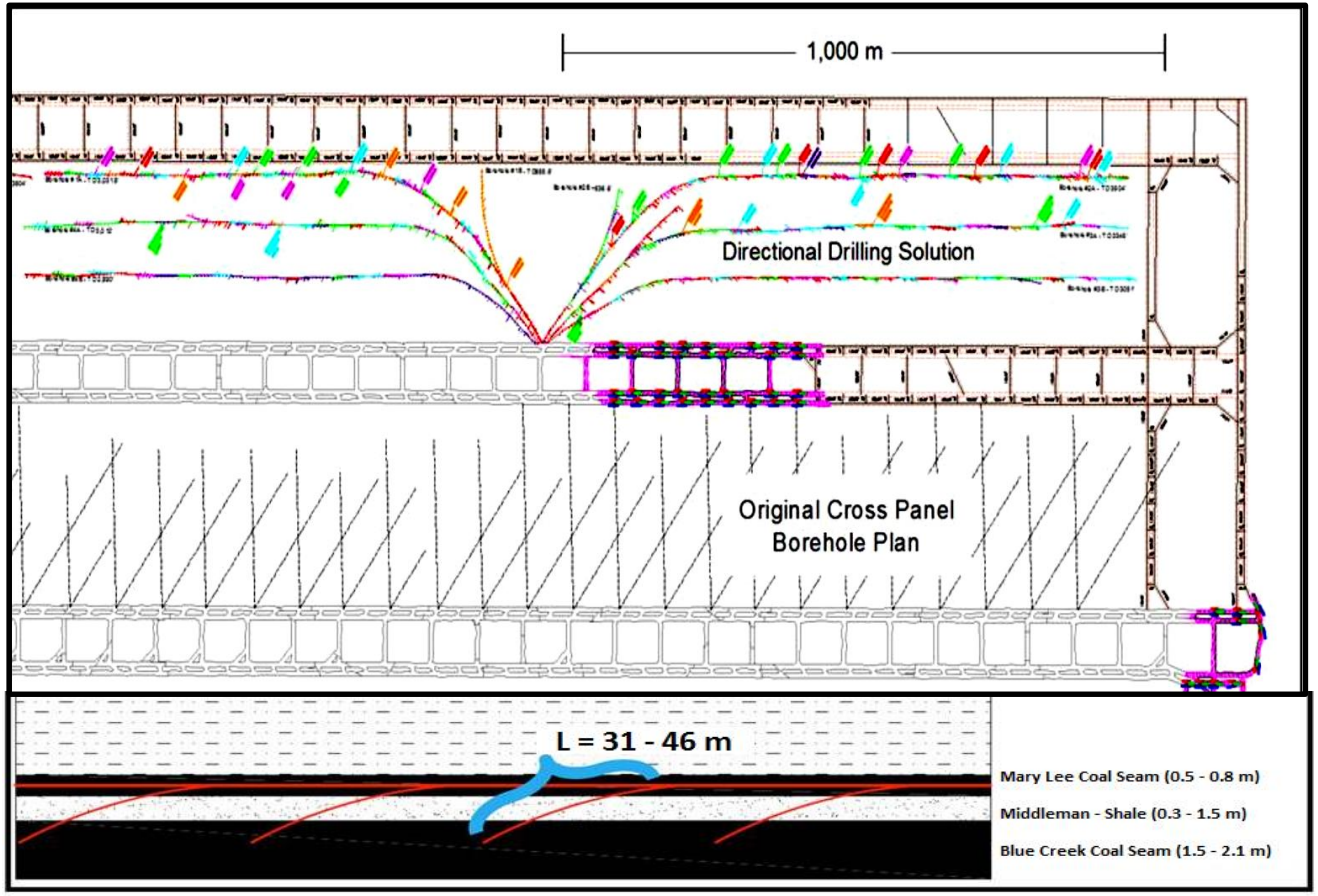


- **Applicable in Tight or Cemented Coals**
- **Where In-seam Gas Production Increases with Mining Related Stress Changes**
- **Intercept Fracs Orthogonally, both Mining and Adjacent Seams**
- **Vertical Wells Serve as Future Gob Wells**
- **CMM Recovered from Surface as Mining Advances**



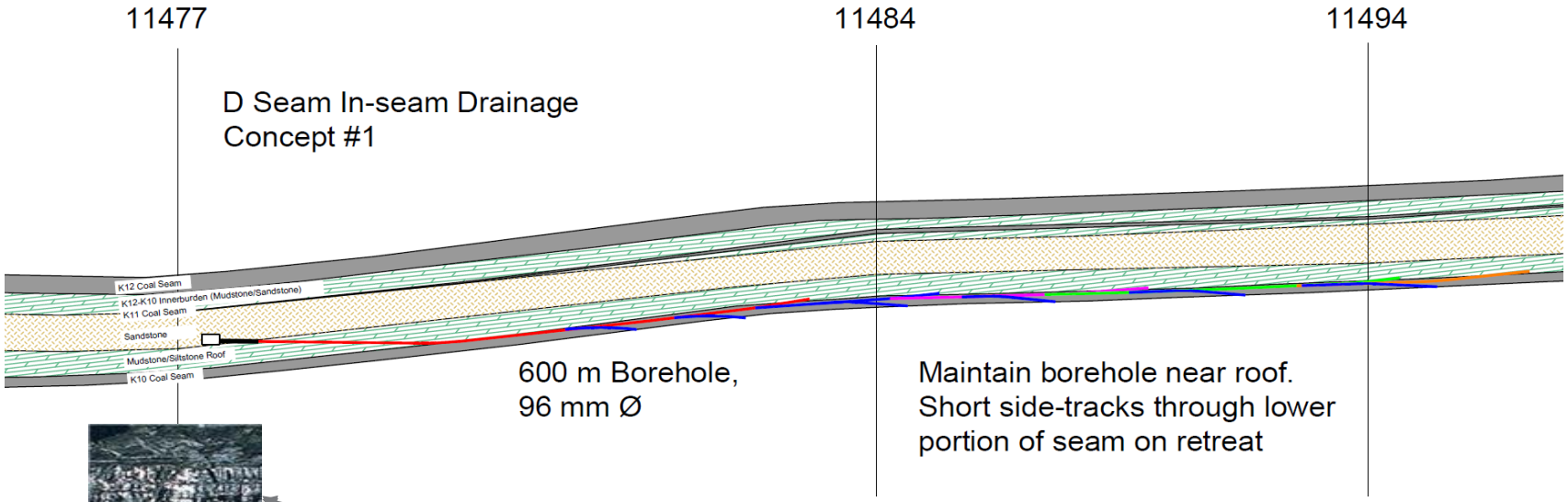
Directional Drilling Solutions

- Using Adjacent Seams



Directional Drilling Solutions

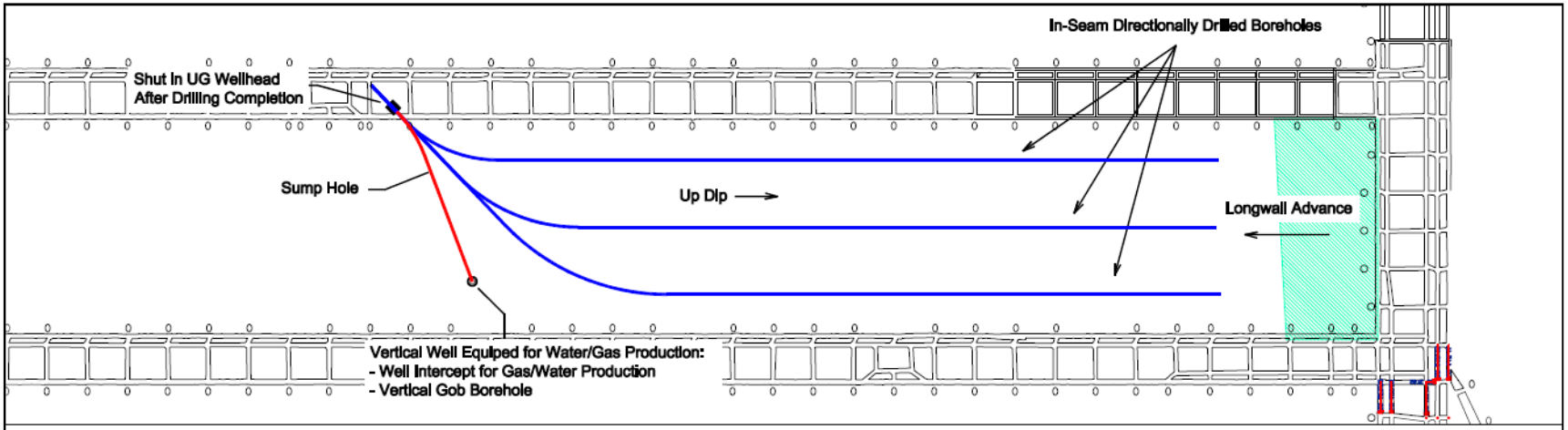
- Geo-Steering to Improve Connectivity

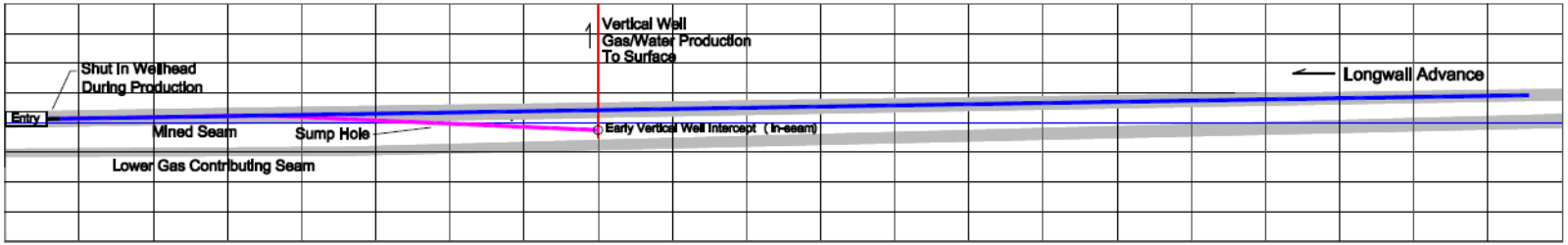


- **Use Competent Coal Layer as a Bridge for Reach**
- **Navigate in Thin Competent Layer with LWD**
- **Develop Side-Tracks Down to Break Through Barriers to Vertical Permeability**
- **Carefully Contact Lower Friable Layers**

Directional Drilling Solutions

- Implementing Stand-Alone Systems



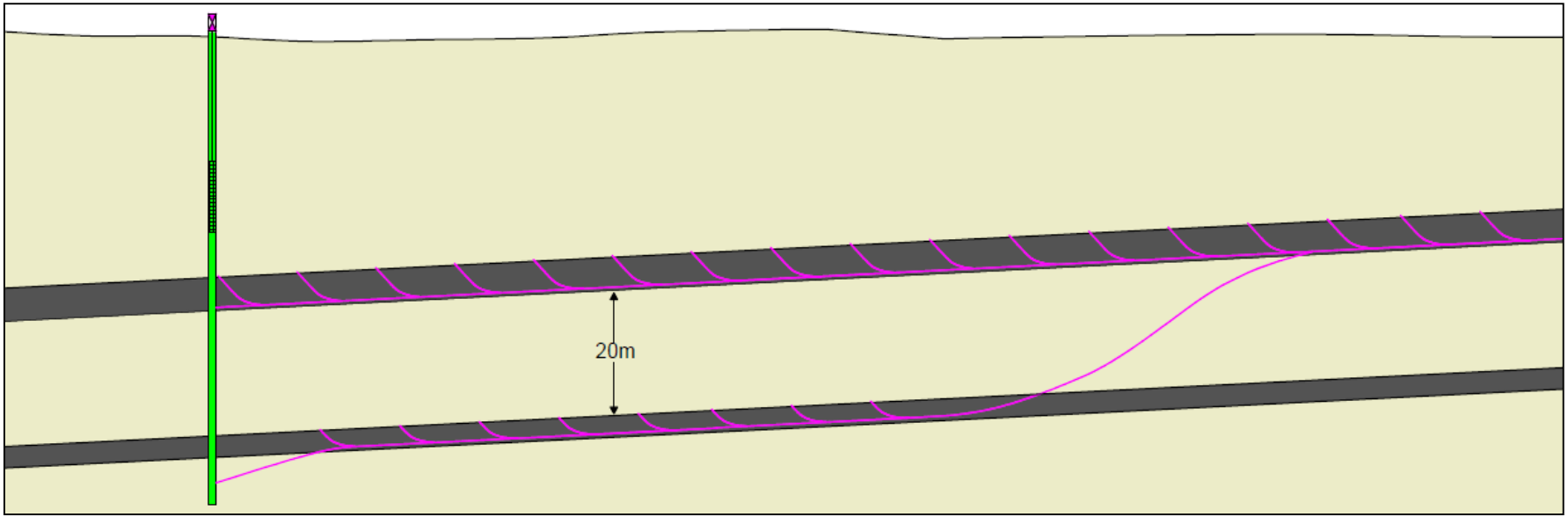


- Gas Production Moved to Surface via Interception with Vertical Well (Post Use Gob Well)

Directional Drilling Solutions

Reducing Gas Contents of Underlying Seams

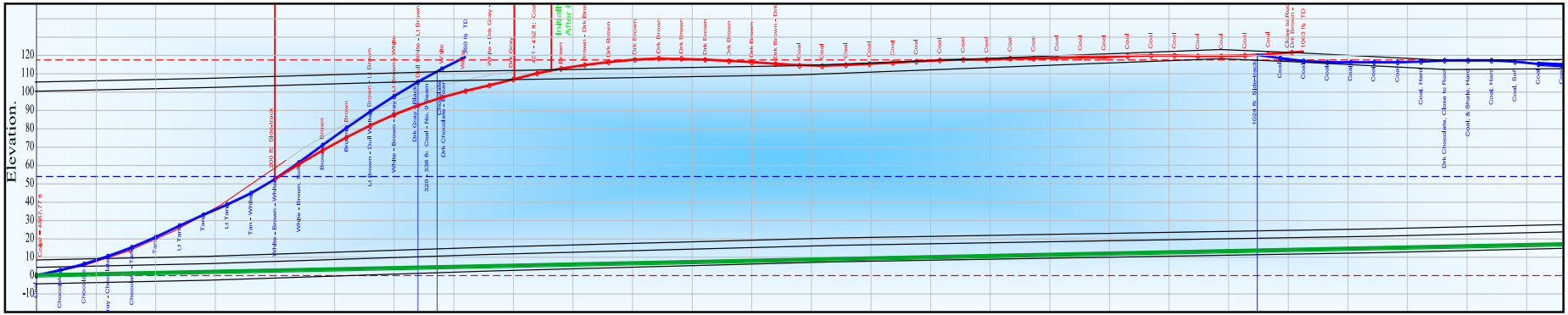
- **Pre-Mining Down-Dip Approach with Late Well Interception**
- **Vertical Well used as a Gob Well once Undermined.**



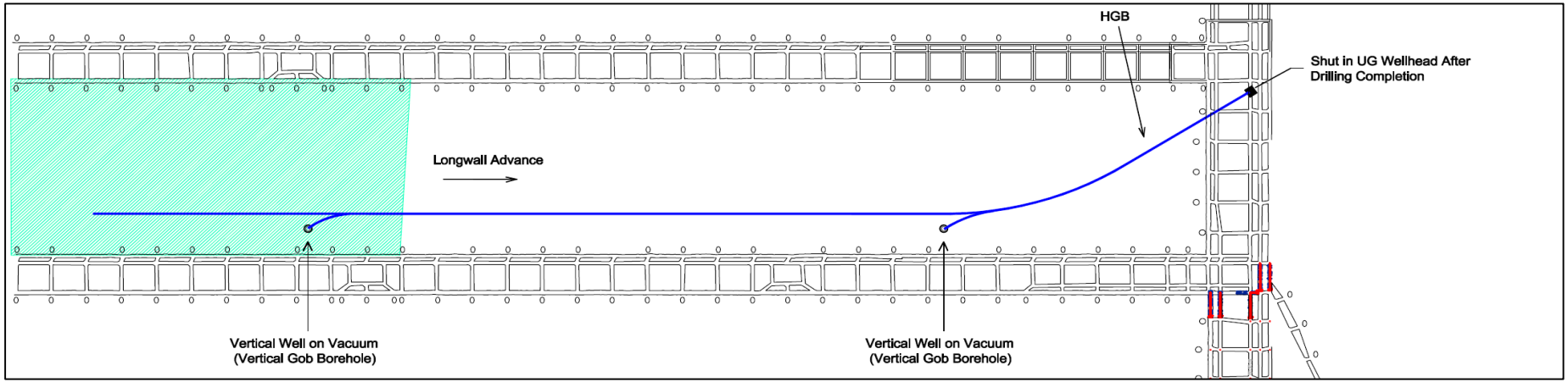
- **Accumulated Water and CMM from Boreholes Drilled in Underlying Seam Produced from Vertical Well**

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 provides 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.
- The Majority of Developments Methane Drainage Relate to Further Displacement of Conventional Methane Drainage Techniques with Advanced Directional Drilling Solutions.
- 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.