Overview of Surface-Based Methods for Methane Drainage

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Overview

Surface-based boreholes can be used to drain gas either prior to mining or for recovering gob gas from mined-out areas:

1. Pre-drainage techniques include:
   - Vertical wells (various simulation techniques);
   - Surface to in-seam wells drilled directionally from the surface.
2. Post-mining surface techniques include:
   - Vertical gob wells;
   - Surface drilled horizontal gob lateral wells.

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Pre-Drainage Techniques

- Vertical fracture stimulated wells
- Vertical open-hole/under-reamed wells
- Surface to in-seam wells

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Vertical Stimulated Wells

- Hydraulically fractured wells have been shown to drain up to 73% of the original gas in-place based on studies by the U.S. Bureau of Mines;
- Wells are typically cased, cemented and then stimulated by hydraulic fracturing.

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Open-Hole/Under-Reamed Wells

- In open-hole/under-reamed wells, no casing is set across the targeted coals seams;
- Formation damage induced by drilling is mitigated by either mechanically under-reaming or by pressuring up the well and then quickly flowing it back to allow the coal to spall into the wellbore;
- Generally less expensive than vertical stimulation wells.

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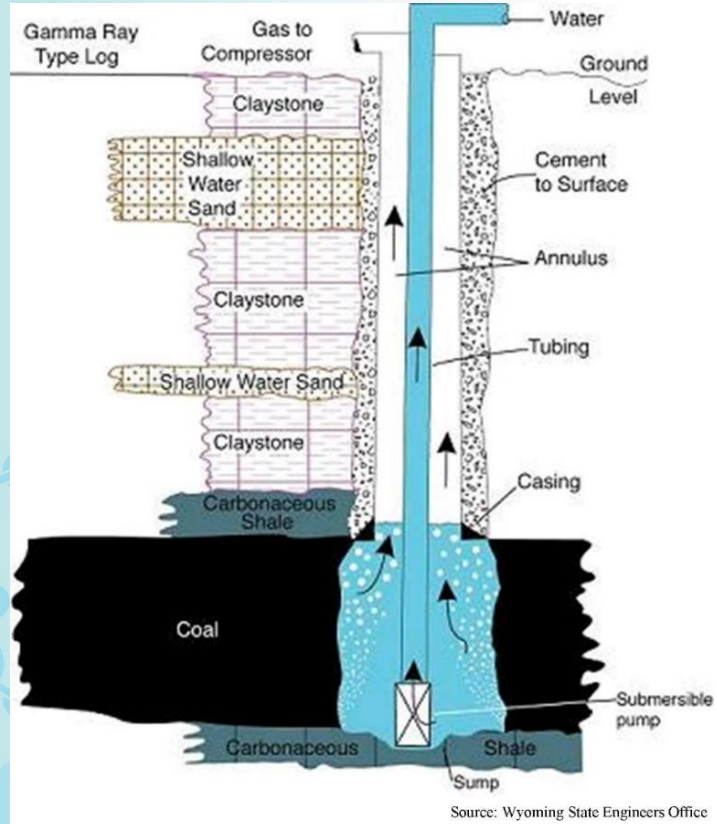
Open-Hole/Under-Reamed Completion

Advantages

- Eliminates the need for hydraulic fracturing (operations and costs)
- No casing across the coal seam

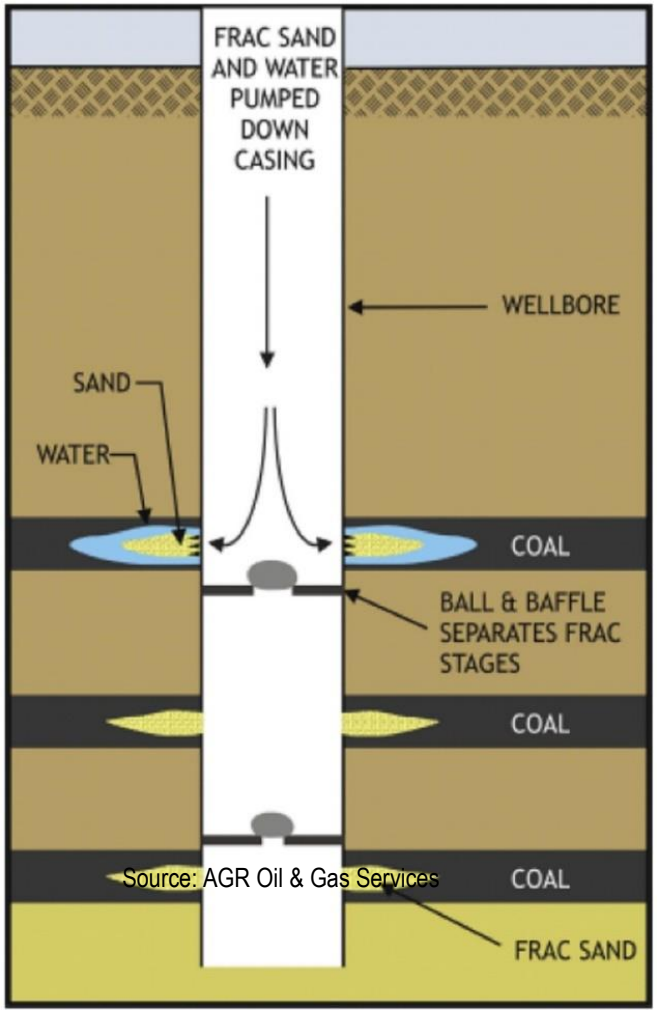
Disadvantages

- Not good for multiple seam settings



Source: Wyoming State Engineers Office

Hydraulically Fractured Well



Source: AGR Oil & Gas Services

Advantages

- Proven to increase production from low permeability coal seams
- Provides good wellbore control
- Ideal for multiple seams

Disadvantages

- Leaves casing across the coal seam; can mill out, or use fiberglass casing
- Higher cost than open/under-reamed

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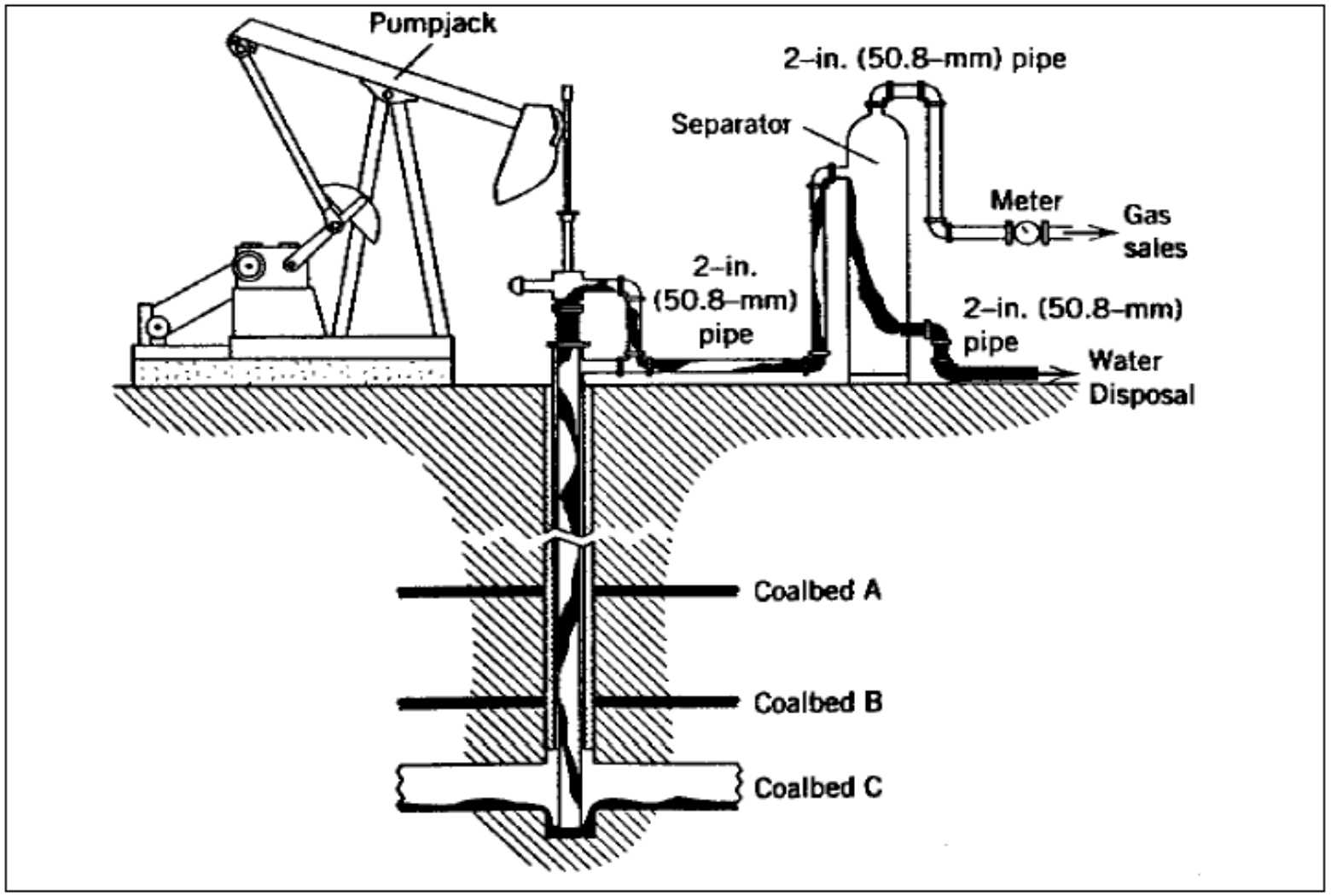
Typical Vertical Well Setup After Completion (Both Hydraulically Fractured Wells and Open-Hole Well)



Source: Hartman et al., 1997. Copyright 1997, John Wiley & Sons, Inc. Reprinted with permission of John Wiley & Sons, Inc.

Surface to In-Seam Techniques

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Surface-drilled directional oil & gas well types defined by radius size

Radius Type	Radius (m/ft)	Achievable Lateral Length (m/ft)	Drilling Method
Zero	0	3 / 10	Telescopic probe with hydraulic jet
Ultra-short	0.3-0.6 / 1-2	60 / 200	Coiled tubing with hydraulic jet
Short	1-12 / 3-40	460 / 1,500	Curved drilling guide with flexible drill pipe; entire drill string rotated from the surface
Medium	60-300 / 200-1000	460-1,525+ / 1,500-5,000+	Steerable mud motor used with compressive drill pipe; conventional drilling technology can also be used
Long	300-850+ / 1000-2,500+	600+ / 2,000+ (Record is over 12,000 m/ 40,000 ft)	Conventional directional drilling equipment used; very long curve length of 850-1,350 m (2,800-4,400 ft) needed to be drilled before achieving horizontal

Source: USDOE, 1993

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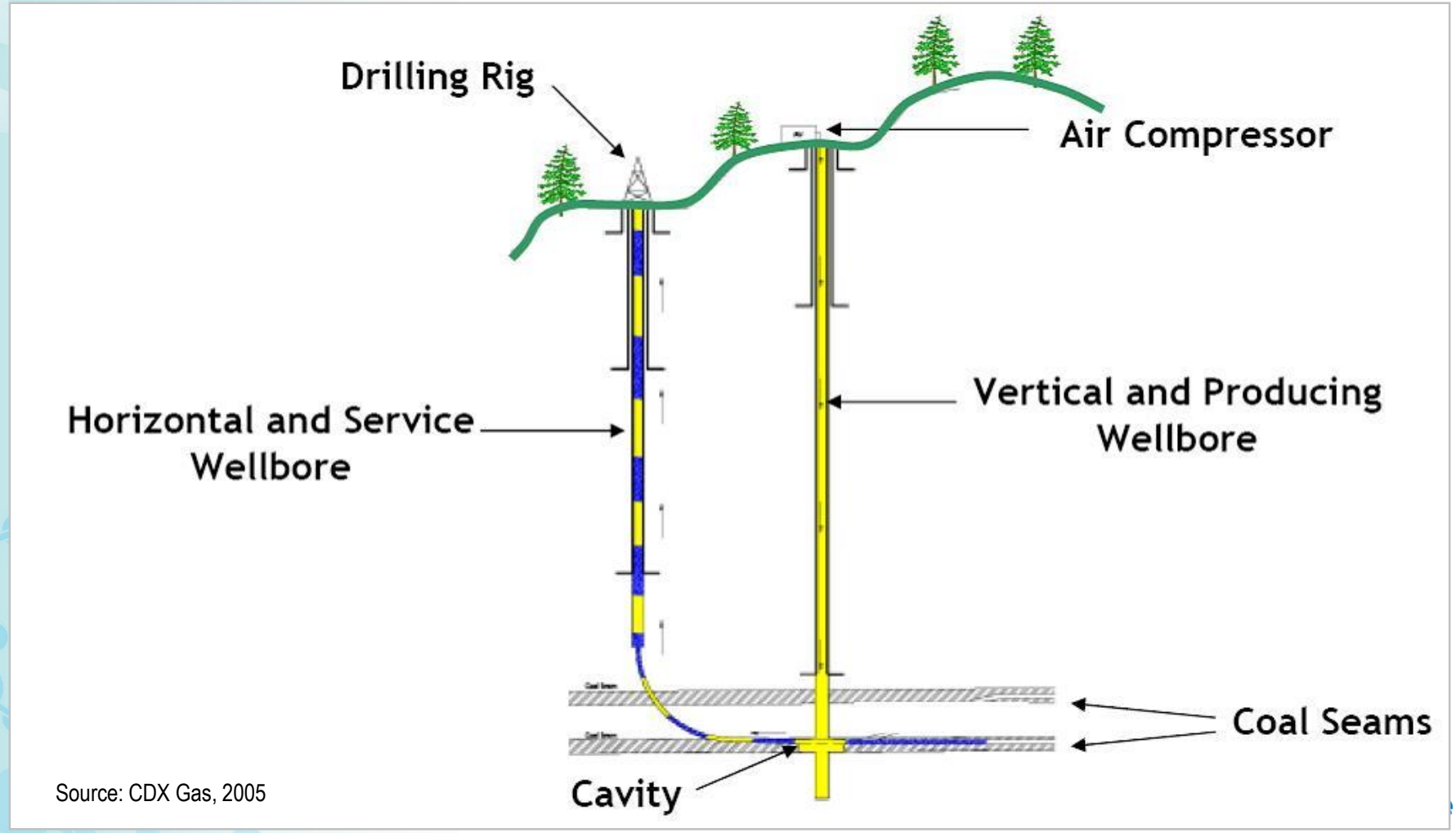
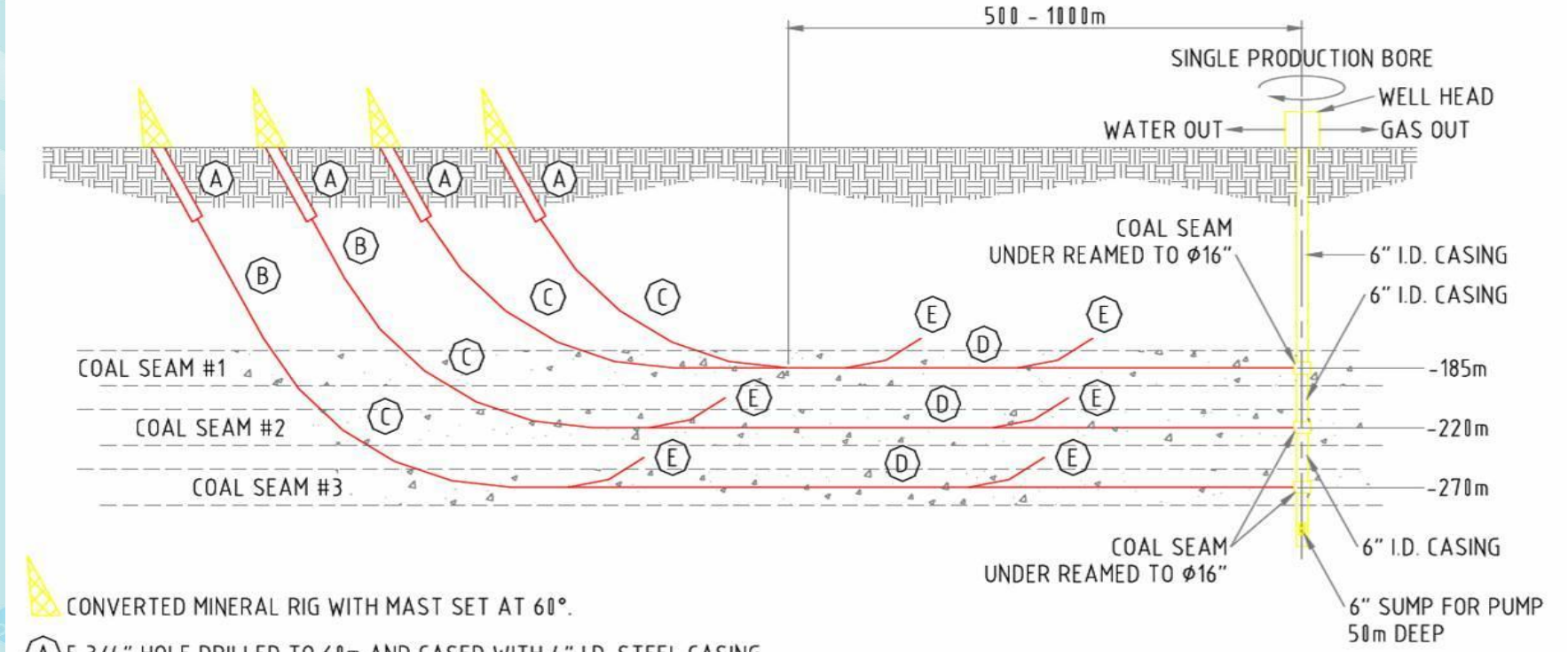
Surface to In-Seam Techniques Rely on Multiple Wells to Produce Gas

Dual Well System



Source: CDX Gas, 2005

Schematic of multiple horizontal wells drilled to a single vertical well



CONVERTED MINERAL RIG WITH MAST SET AT 60°.

(A) 5 3/4" HOLE DRILLED TO 60m AND CASED WITH 4" I.D. STEEL CASING.

(B) ø96mm HOLE DRILLED STRAIGHT TO WITHIN 125m OF THE TARGET COAL SEAM.

(C) ø96mm RADIUS BEND DRILLED TO LAND HORIZONTAL AND INTO THE COAL SEAM. BEND RATIO IS 7° PER 30m.

(D) ø96mm HOLE STEERED TO STAY WITHIN THE TARGET SEAM AND TO INTERSECT THE VERTICAL PRODUCTION WELL. - DRILLED DOWN DIP.

E LIMITED "ROOF TOUCH" BRANCHES TO ACCURATELY POSITION THE INSEAM HOLE IN THE SEAM AND TO CONFIRM SEAM DIP ANGLES.

Source: Mitchell Drilling, 2005

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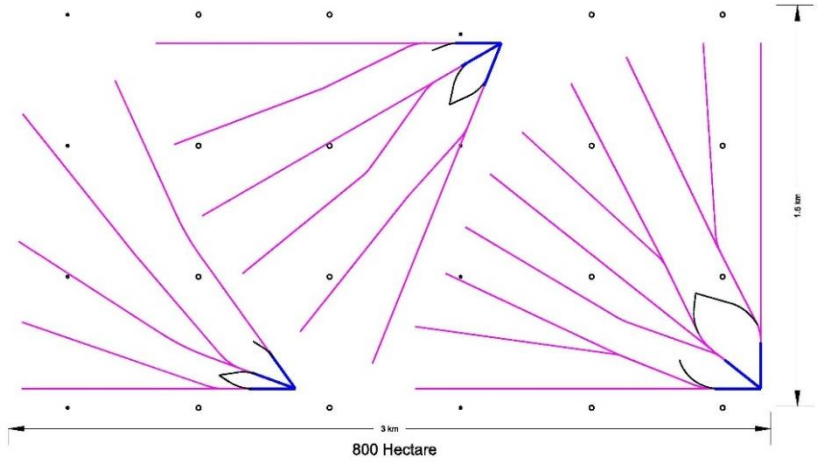
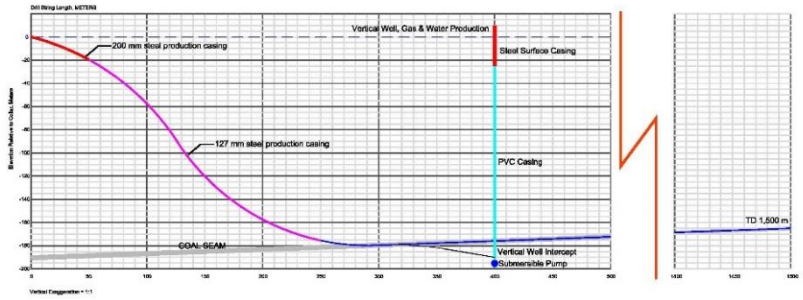
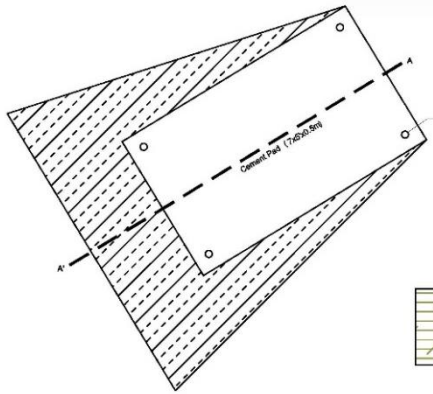
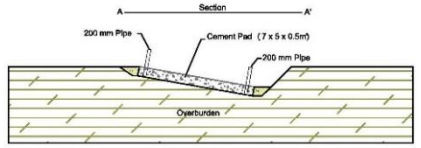
Example of a Surface to In-Seam for a Coal Mine in Mexico









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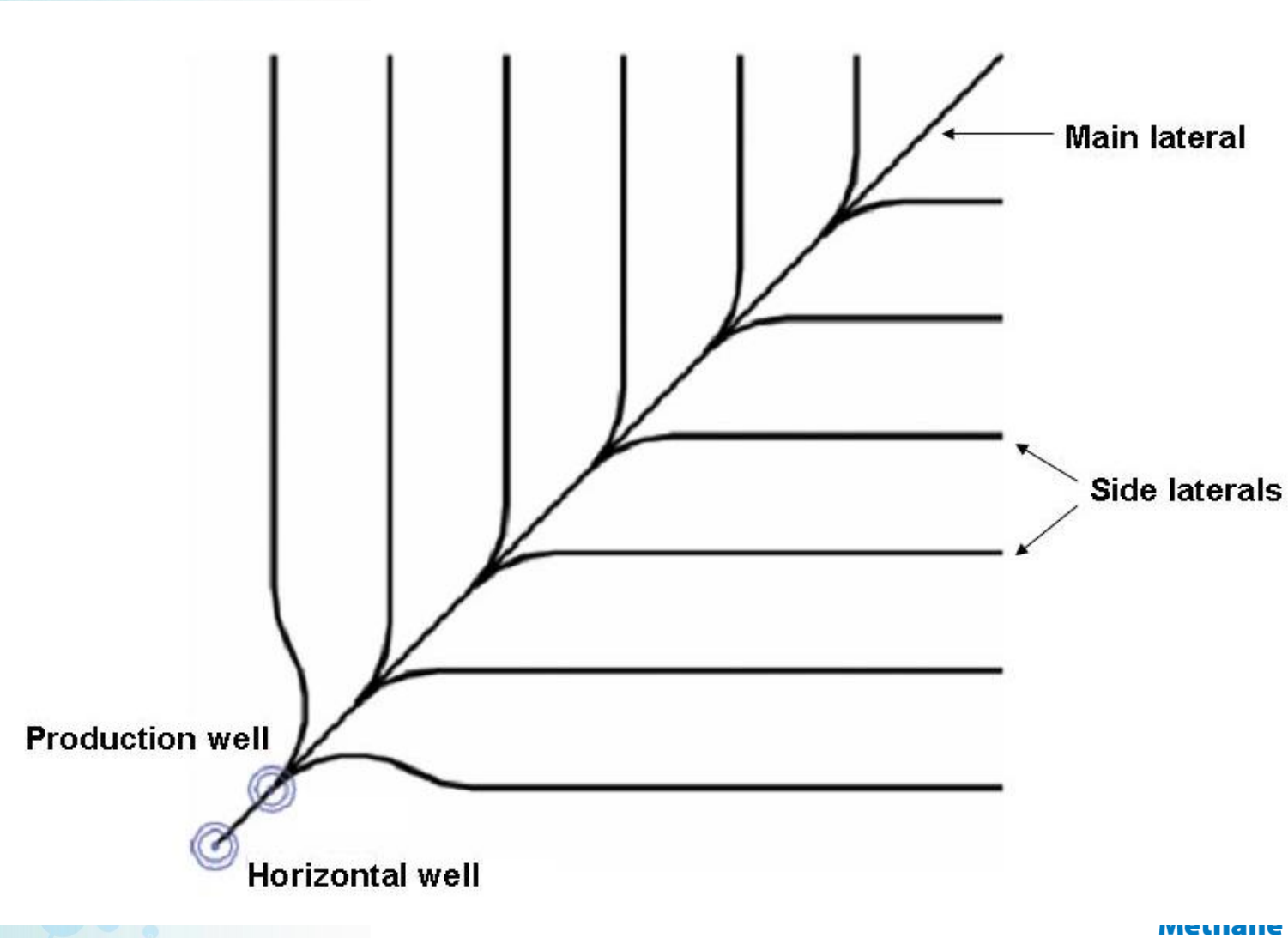
Top view of pinnate drainage pattern



Source: CDX Gas, 2005

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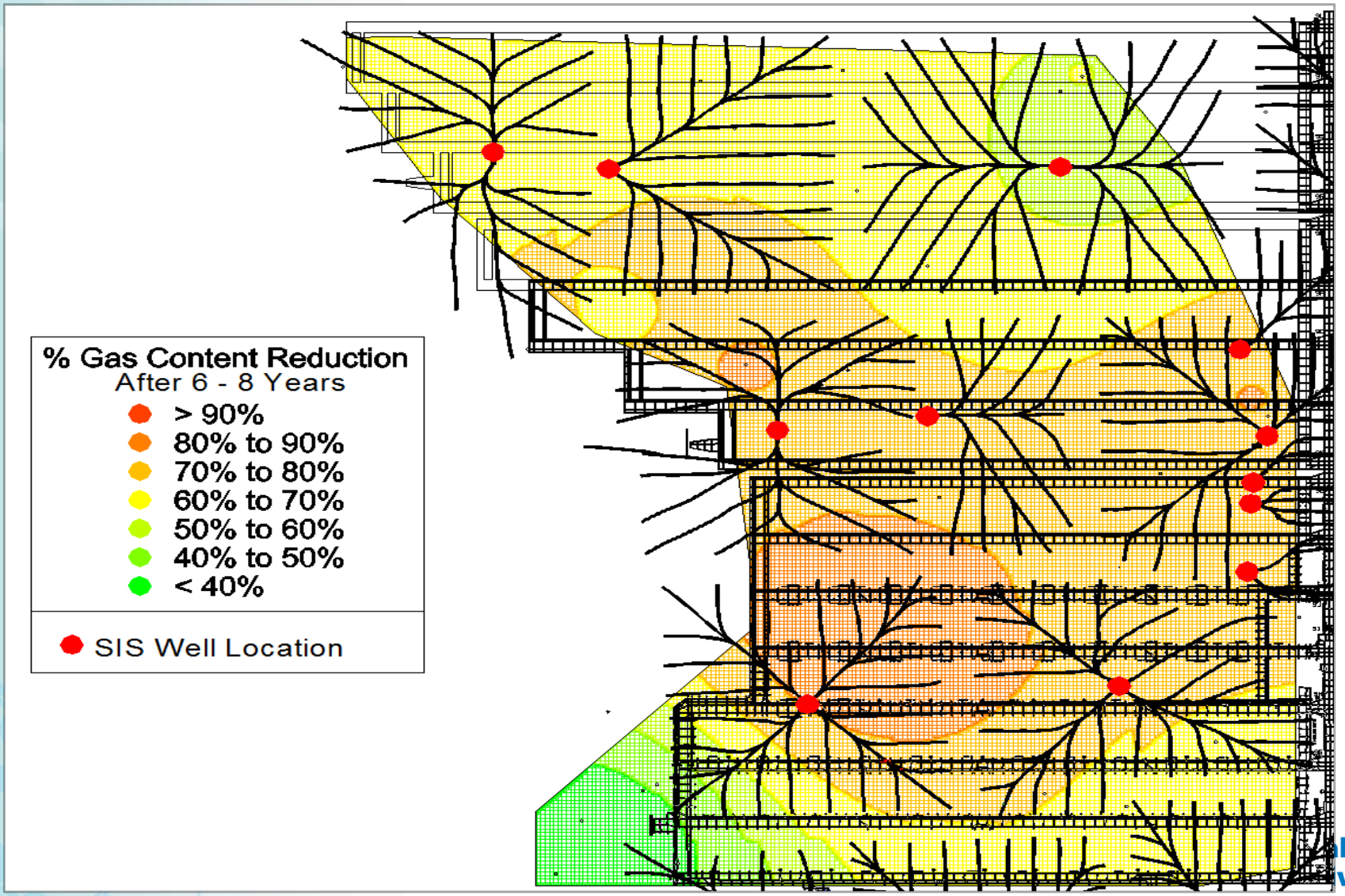
Effectiveness of SIS drainage



Post-Mining Techniques

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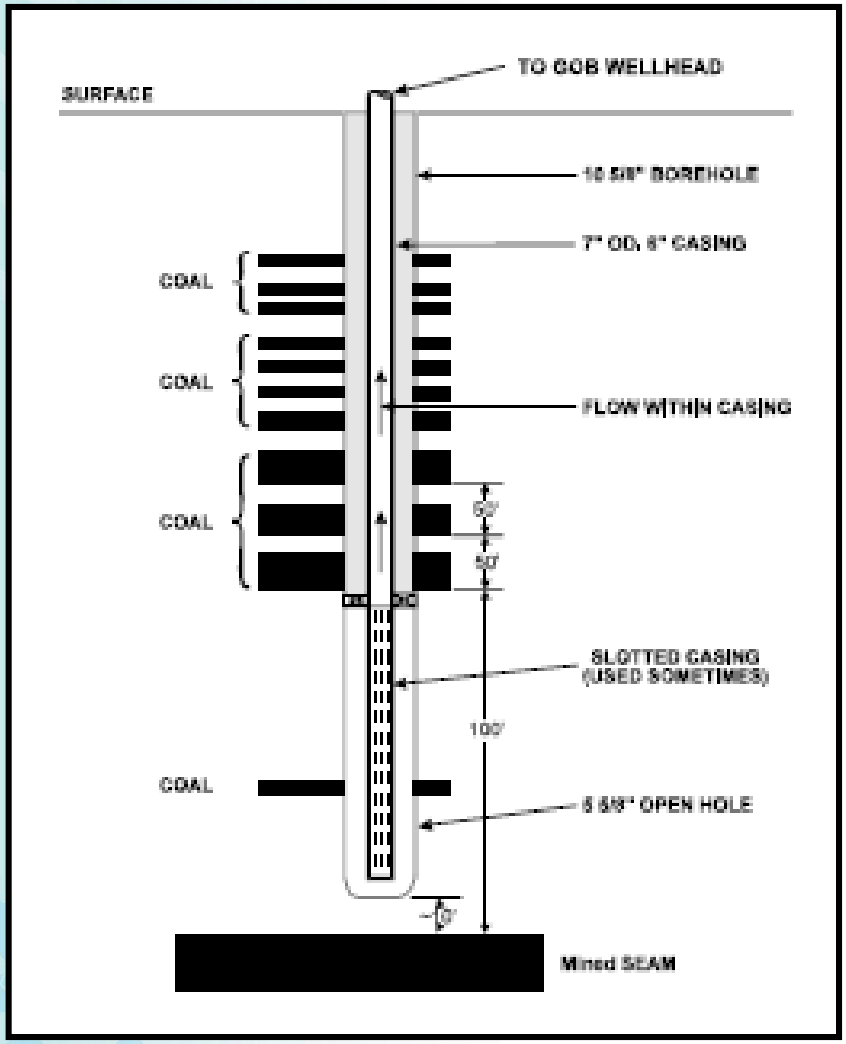
Vertical Gob Gas Drainage



Gob Gas – Vertical Gob Wells

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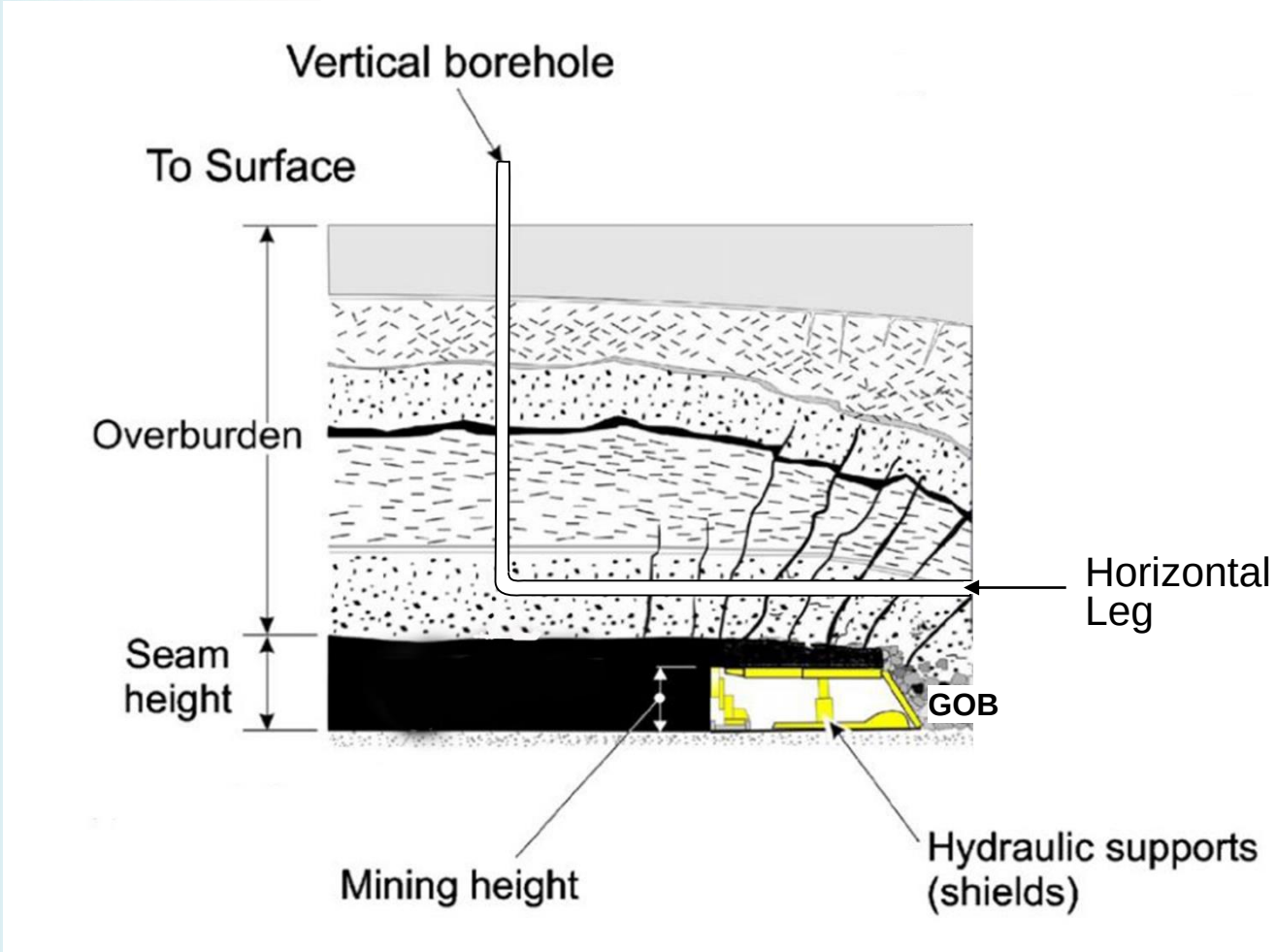
Schematic representation of longwall mining environment and surface drilled horizontal gob well



Source: Modified from C. Ozgen Karacan.

Thank You!

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Case Studies on the Simultaneous Extraction of Coal and Gas in the U.S.

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Global Methane Initiative

Presentation Outline

- Overview
- Warrior Met Coal, Alabama
- Consol (Coronado Coal)/CNX, Virginia
- Indian Potential

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Overview

- In the U.S., a number of mines produce coal and CBM/CMM simultaneously from within the area of the mine boundary;
- The CBM/CMM is produced using a combination of vertically fractured wells, in-mine horizontal boreholes, and gob wells. The combination of these wells can drain 70 to 80% of the in-situ gas from the coal seams prior to mining, thus improving mine safety and productivity, as well as generating an additional revenue stream;
- In some cases, even conventional oil and gas is produced from within the mine boundary. This requires close coordination between the mining company and oil and gas operator.

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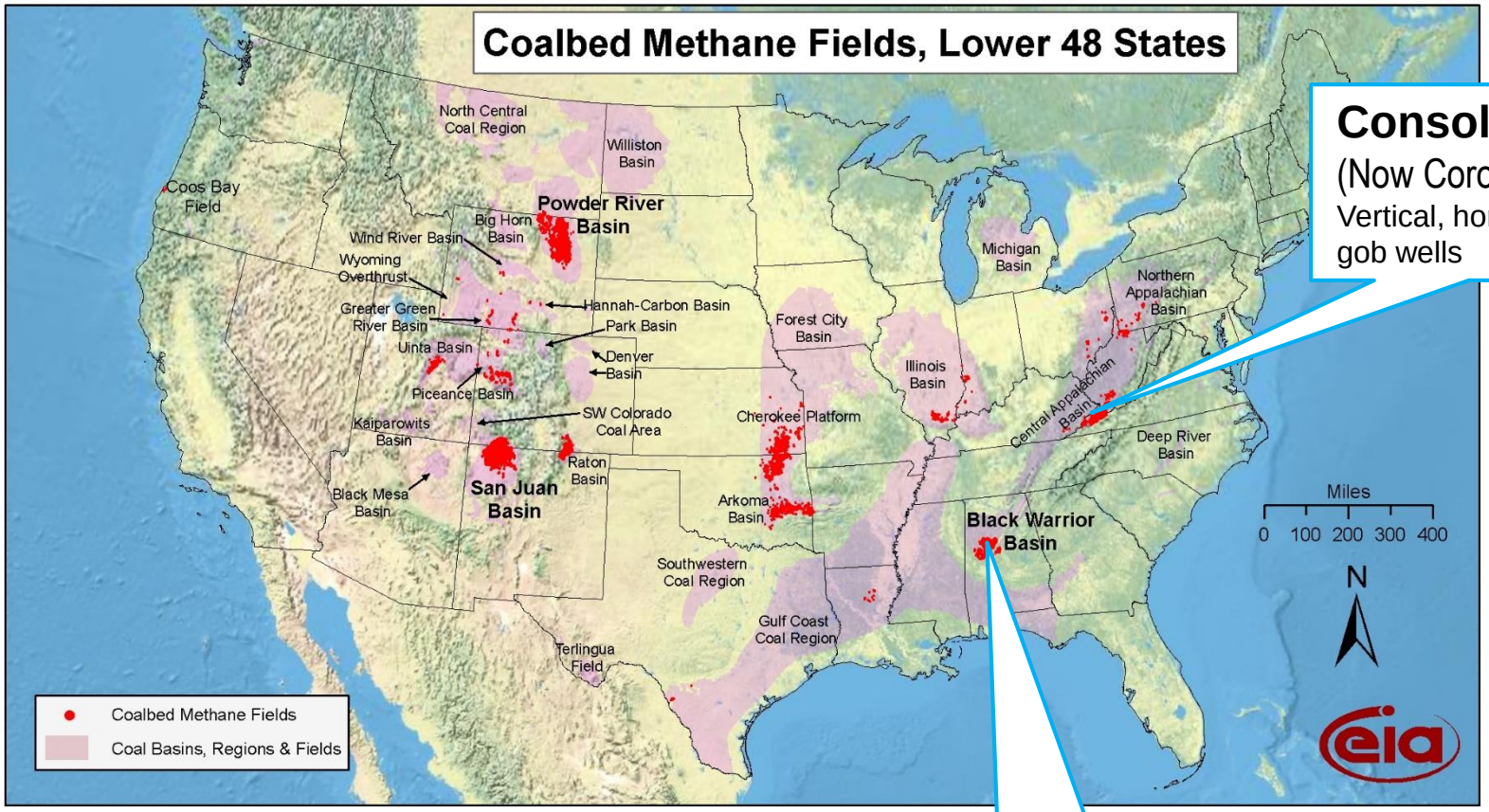
Map of U.S. Coal Basins and Project Locations



Source: Energy Information Administration based on data from USGS and various published studies
Updated: April 8, 2009

Consol Coal
(Now Coronado Coal)
Vertical, horizontal, and gob wells

Warrior Met
Vertical, horizontal and gob wells

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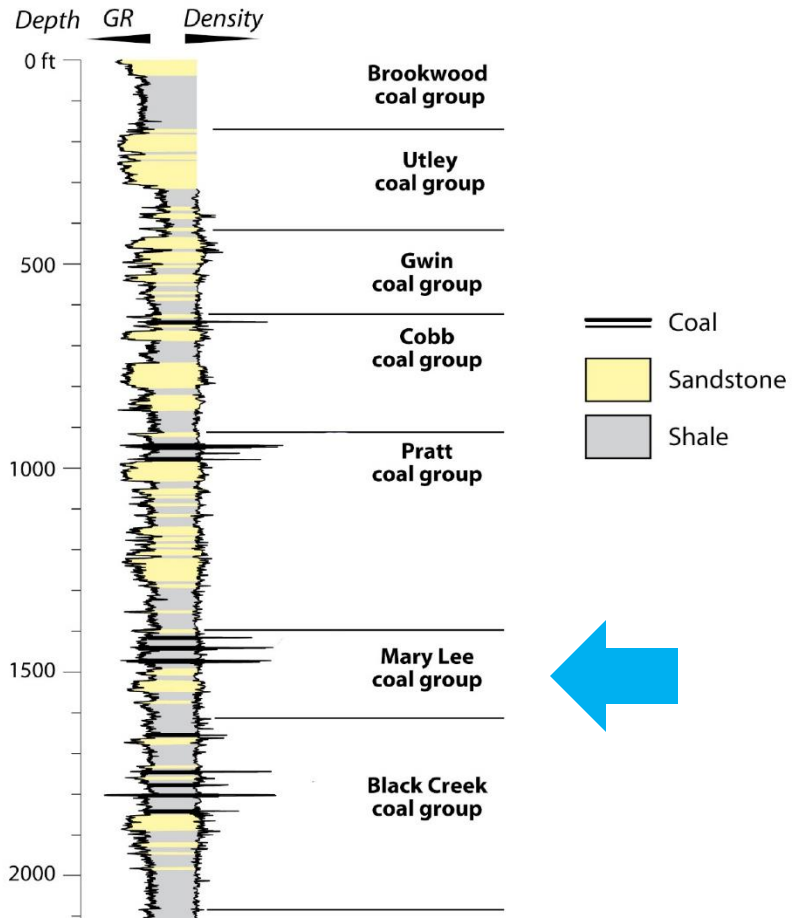
Warrior Met Coal Overview

- Warrior Met Coal produces high quality, metallurgical coal with gas contents ranging from 11 to 16 m^3/tonne (350 – 500 cf/ton);
- Two seams are mined, the Mary Lee (0.5m to 0.8m (1.6 – 2.6 ft)) and the Blue Creek (1.5m to 2.1m (5 – 7 ft)) ;
- The mine complex produces 500,000 m^3/day (17.6 MMcfd) of methane from a combination of vertical, hydraulically fractured wells, in-mine horizontal boreholes and vertical gob wells;
- Gas production operations are managed by Black Warrior Methane (BWM), which is a joint venture between Warrior Met Coal (coal producers) and Atlas Resource Partners, who handles the production, processing and transportation of the methane.



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Vertical Hydraulically Fractured Wells

- BWM operates about 350 vertical wells that were drilled into the coal seams prior to mining;
- Production is about 343,000 m^3/day (12 MMcfd);
- In the Warrior Basin as a whole, over 5,000 vertical wells have been drilled and have produced more than 71 Bm^3 (2.5 Tcf) of gas.
- For Mine-Through: Clean out, log, plug, cement perfs through coals, mill casing out, set plug and cement

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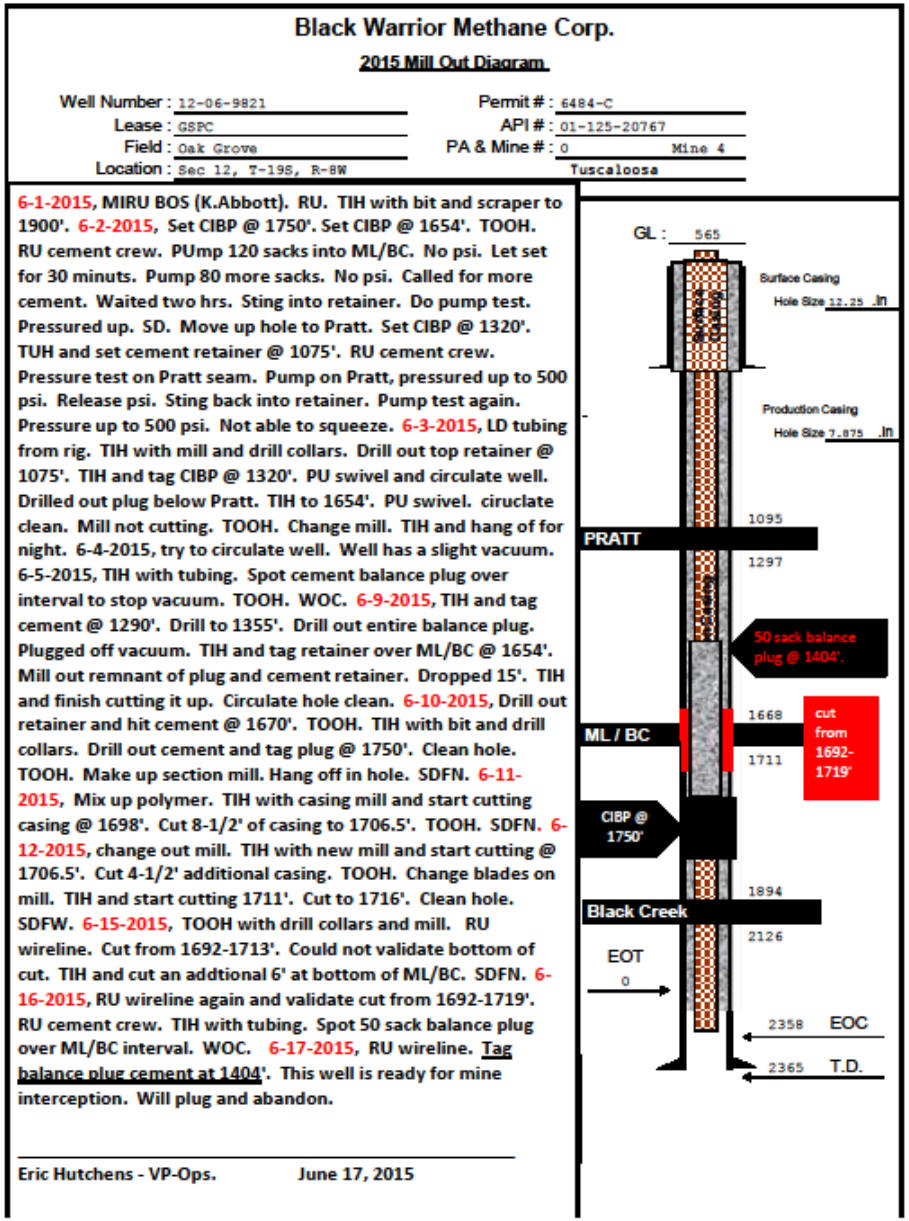
Warrior Met Coal

- Prior to Mine-Through:
- Re-enter to clean well;
- Run log inside of casing
- Set packer above and below mineable coal
- Inject cement under pressure through perfs
- Remove upper packer
- Re-enter with Milling Tool
- Cut the casing through the mineable coal
- Set a packer/plug above the mineable coal
- Cement well
- Abandon



Black Warrior Methane Corp.

2015 Mill Out Diagram

Well Number : 12-06-9821 Permit # : 6484-C
Lease : GSPC API # : 01-125-20767
Field : Oak Grove PA & Mine # : 0 Mine 4
Location : Sec 12, T-19S, R-8W Tuscaloosa

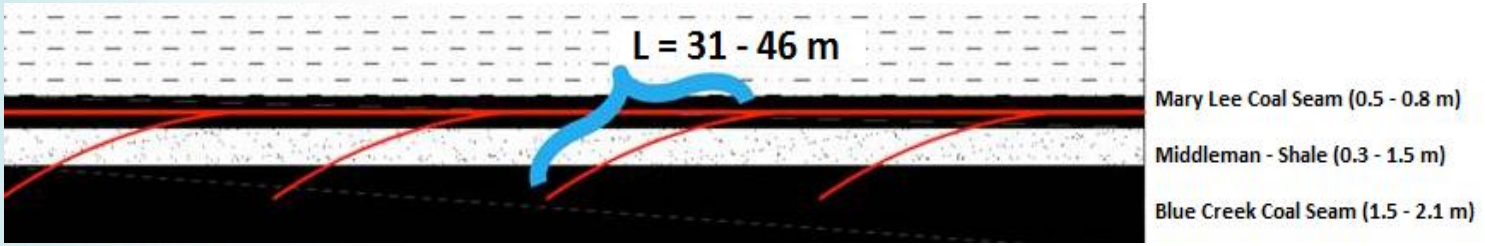
6-1-2015, MIRU BOS (K.Abbott). RU. TIH with bit and scraper to 1900'. 6-2-2015, Set CIBP @ 1750'. Set CIBP @ 1654'. TOOH. RU cement crew. PUmp 120 sacks into ML/BC. No psi. Let set for 30 minuts. Pump 80 more sacks. No psi. Called for more cement. Waited two hrs. Sting into retainer. Do pump test. Pressured up. SD. Move up hole to Pratt. Set CIBP @ 1320'. TUH and set cement retainer @ 1075'. RU cement crew. Pressure test on Pratt seam. Pump on Pratt, pressured up to 500 psi. Release psi. Sting back into retainer. Pump test again. Pressure up to 500 psi. Not able to squeeze. 6-3-2015, LD tubing from rig. TIH with mill and drill collars. Drill out top retainer @ 1075'. TIH and tag CIBP @ 1320'. PU swivel and circulate well. Drilled out plug below Pratt. TIH to 1654'. PU swivel. ciruclate clean. Mill not cutting. TOOH. Change mill. TIH and hang of for night. 6-4-2015, try to circulate well. Well has a slight vacuum. 6-5-2015, TIH with tubing. Spot cement balance plug over interval to stop vacuum. TOOH. WOC. 6-9-2015, TIH and tag cement @ 1290'. Drill to 1355'. Drill out entire balance plug. Plugged off vacuum. TIH and tag retainer over ML/BC @ 1654'. Mill out remnant of plug and cement retainer. Dropped 15'. TIH and finish cutting it up. Circulate hole clean. 6-10-2015, Drill out retainer and hit cement @ 1670'. TOOH. TIH with bit and drill collars. Drill out cement and tag plug @ 1750'. Clean hole. TOOH. Make up section mill. Hang off in hole. SDFN. 6-11-2015, Mix up polymer. TIH with casing mill and start cutting casing @ 1698'. Cut 8-1/2' of casing to 1706.5'. TOOH. SDFN. 6-12-2015, change out mill. TIH with new mill and start cutting @ 1706.5'. Cut 4-1/2' additional casing. TOOH. Change blades on mill. TIH and start cutting 1711'. Cut to 1716'. Clean hole. SDFW. 6-15-2015, TOOH with drill collars and mill. RU wireline. Cut from 1692-1713'. Could not validate bottom of cut. TIH and cut an addtional 6' at bottom of ML/BC. SDFN. 6-16-2015, RU wireline again and validate cut from 1692-1719'. RU cement crew. TIH with tubing. Spot 50 sack balance plug over ML/BC interval. WOC. 6-17-2015, RU wireline. Tag balance plug cement at 1404'. This well is ready for mine interception. Will plug and abandon.

Eric Hutchens - VP-Ops. June 17, 2015

In-Mine Horizontal Boreholes

- In-mine horizontal boreholes are currently directionally drilled in the Mary Lee coal to lengths of about 1,000m (3,280 ft) in the longwall panels. Once the well has been drilled to its total length, a series of downward directed “touches” into the Blue Creek coal are performed. This is necessary because of poor drilling conditions in the Blue Creek coal.

Section of coal seams of methane pre-drainage



- A pattern of these boreholes from one location into a longwall panel produces approximately 420,000 m^3/day (1.5 MMcfd).
- Boreholes injected with water at collar prior to mine-through.

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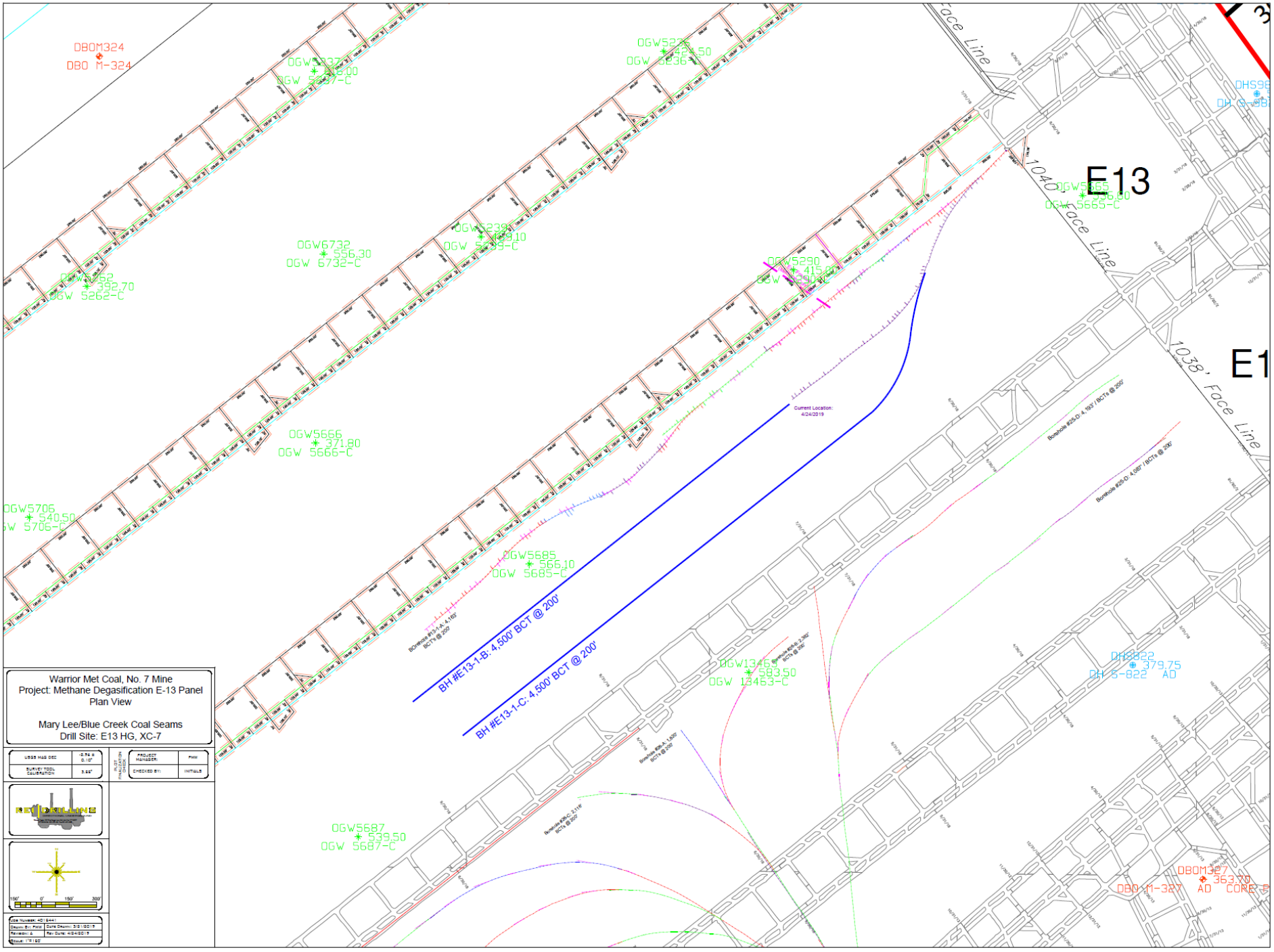
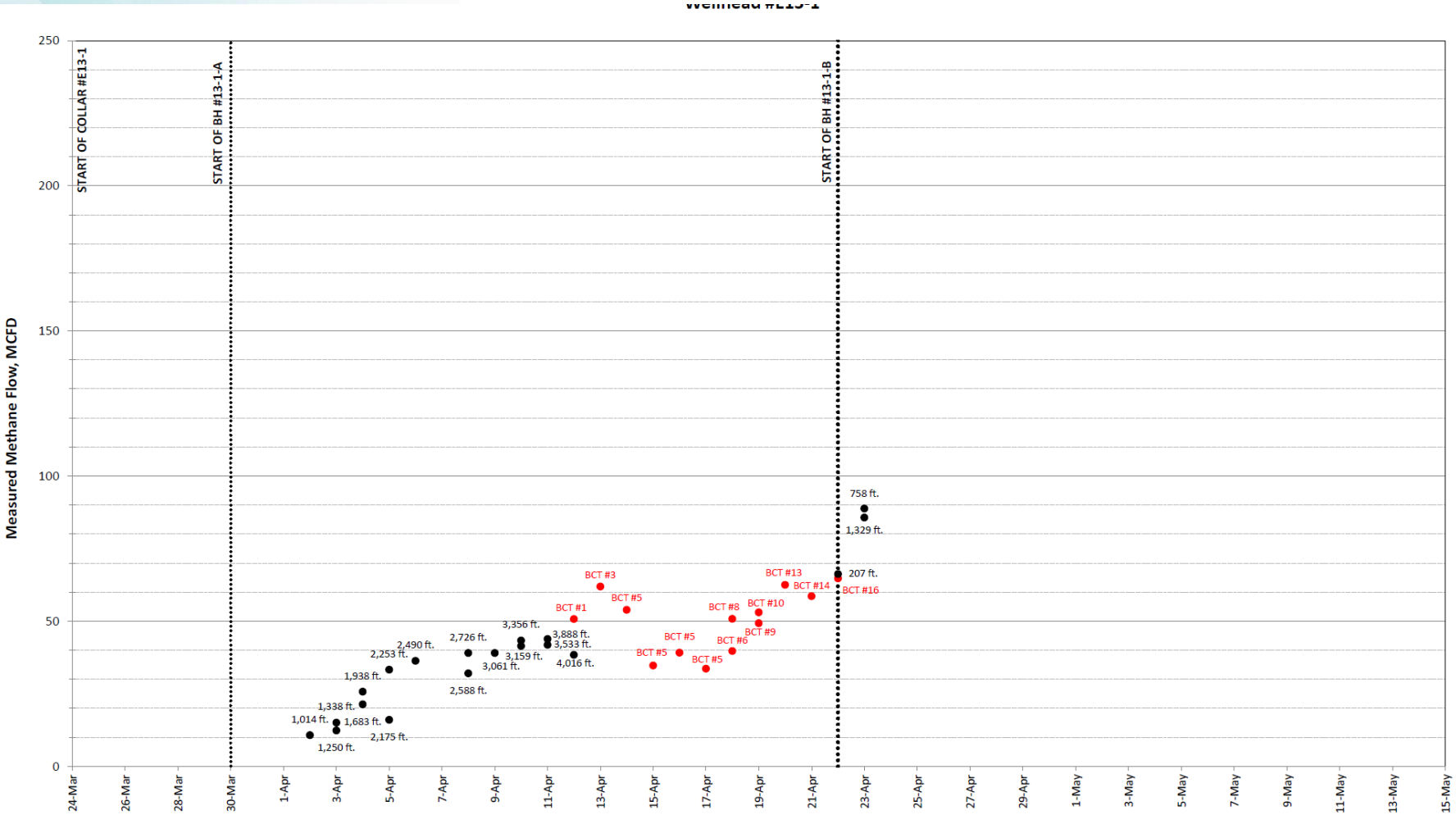

DBOM324
DBO M-324
OGW5237
OGW 5237-C
OGW5238
OGW 5238-C
OGW5239
OGW 5239-C
OGW6732
556.30
OGW 6732-C
OGW5262
392.70
OGW 5262-C
OGW5290
OGW5666
571.80
OGW 5666-C
OGW5706
540.50
OGW5685
566.10
OGW 5685-C
OGW5687
539.50
OGW 5687-C
OGW13463
583.50
OGW 13463-C
OGW5665
OGW 5665-C
DHS822
379.75
DH S-822 AD
DBOM327
363.70
DBO M-327 AD CORE
1040' Face Line
1038' Face Line
E13
E1
Current Location:
4/24/2019
BH #E13-1-B: 4,500' BCT @ 200'
BH #E13-1-C: 4,500' BCT @ 200'
Warrior Met Coal, No. 7 Mine
Project: Methane Degasification E-13 Panel
Plan View
Mary Lee/Blue Creek Coal Seams
Drill Site: E13 HG, XC-7

In-Mine Horizontal Boreholes



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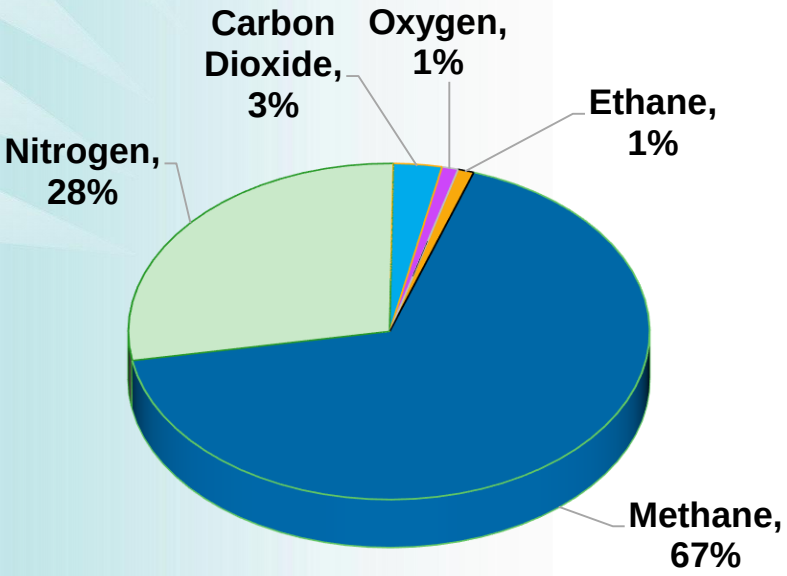
Gob Wells



View of GOB well

- Gob wells collect methane from sealed and active areas. The gas produced from these wells is about 60% methane.
- The gas is sent to a gas processing plant, where nitrogen, oxygen, and carbon dioxide are removed and the gas is upgraded to 96% quality methane.
- The gob wells produce about 107,000 m^3/day (3.8 MMcfd) which is sent to an interstate pipeline for sale.
- An added benefit to the processing of gob gas is that the rejected nitrogen is injected into the gob and old working areas as an inert gas to minimize spontaneous combustion and mine fires.

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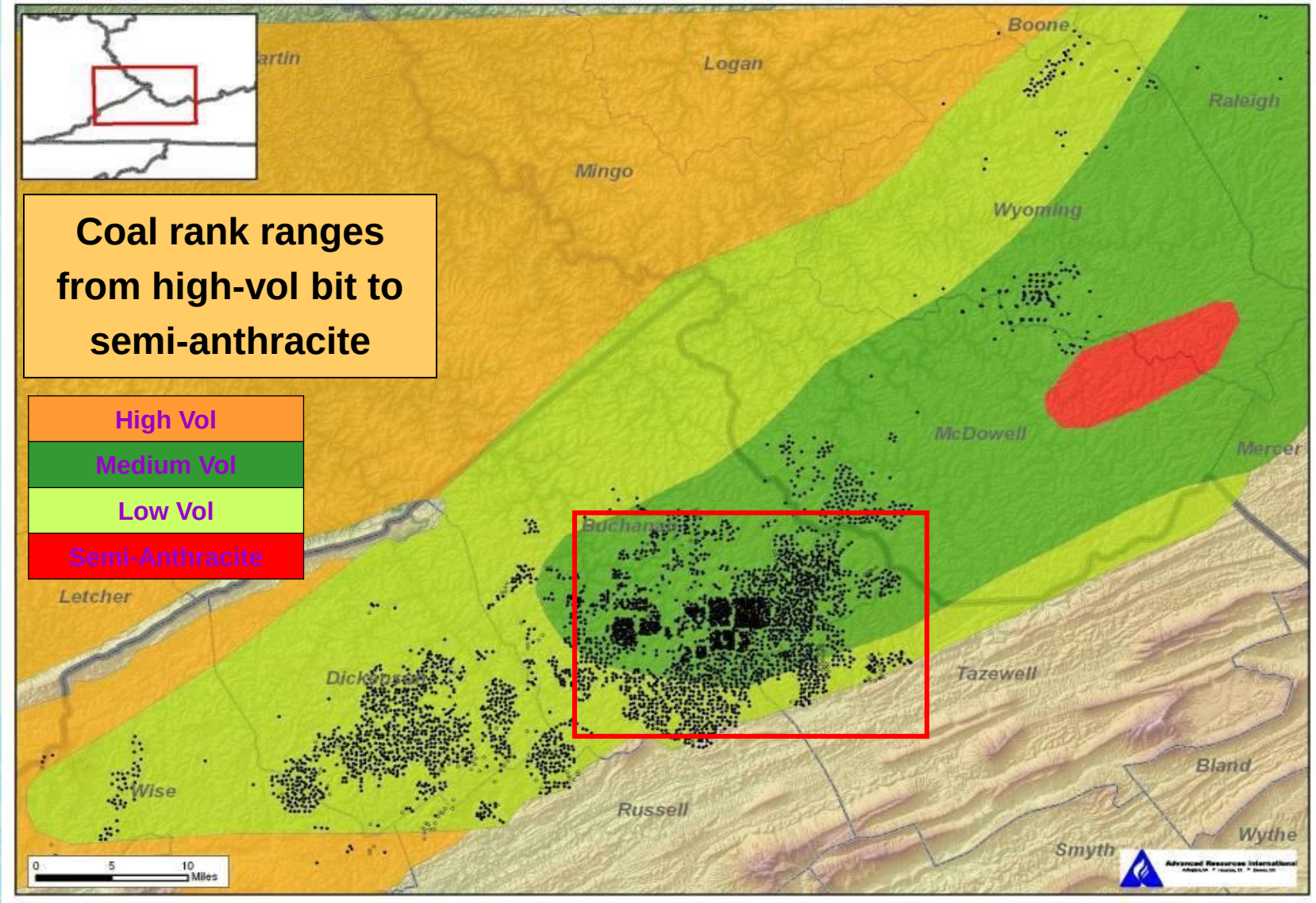
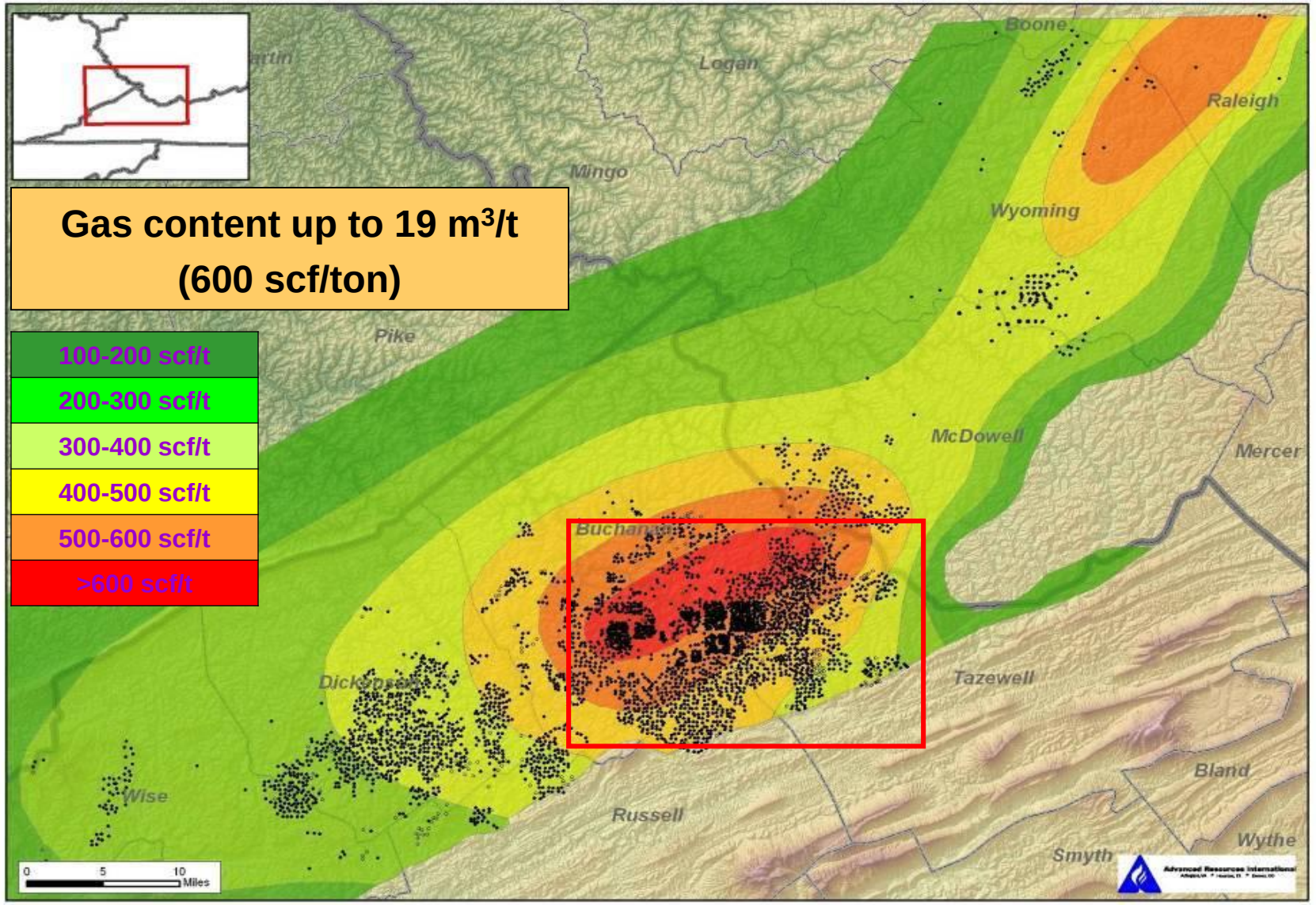
Coronado Coal/CNX, Virginia

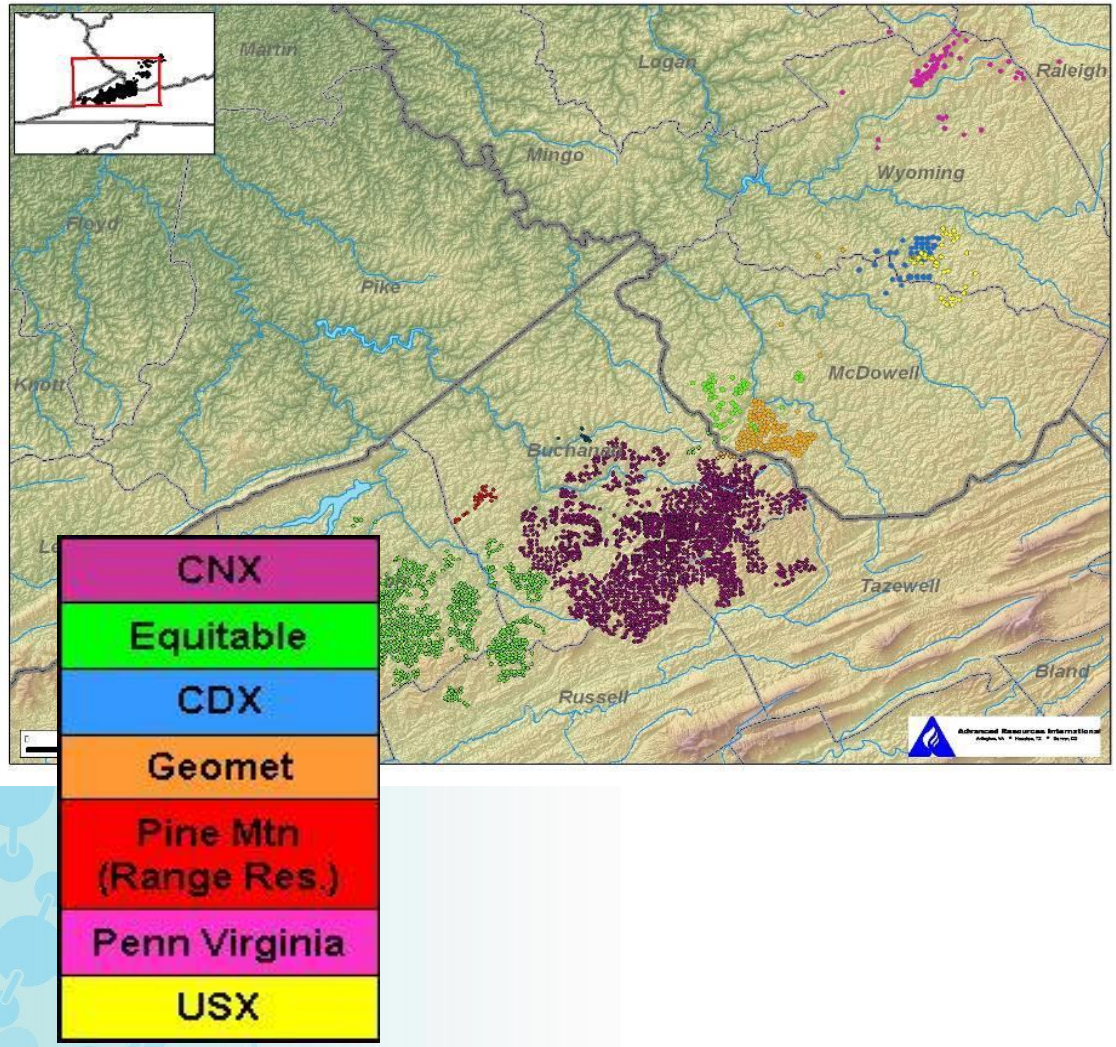
Central Appalachian Basin Coal Rank



Central Appalachian Basin Gas Content



Central Appalachian Basin
Virginia & W. Virginia CBM Development



Operator	Gross Gas (MMcf/D)	Producing Wells	Avg Per-Well (Mcfd/w)	Cum Gas (Bcf)
CNX Gas/Consol Energy	97.1	1109	88	285.1
Equitable	44.6	855	52	124.7
Penn Virginia	16.4	49	335	8.7
Geomet	11.3	146	77	7.0
CDX Gas	5.0	32	155	22.4
Other	2.2	20	111	7.2
Cabot	2.1	30	70	3.8
Pine Mountain	0.4	9	41	0.1
Total/Avg	**179.1**	**2250**	**80**	**459**

- Current production 5.1 Mm^3/d (179 MMcfd) from about 2250 wells, 2,290 $m^3/d/well$ (80 Mcfd/w).
- 13 Bm^3 (0.46 Tcf) produced to date, with estimated 57 B m^3 (2 Tcf) proved reserves.
- CNX Gas and Equitable Resources/Range Resources dominate.

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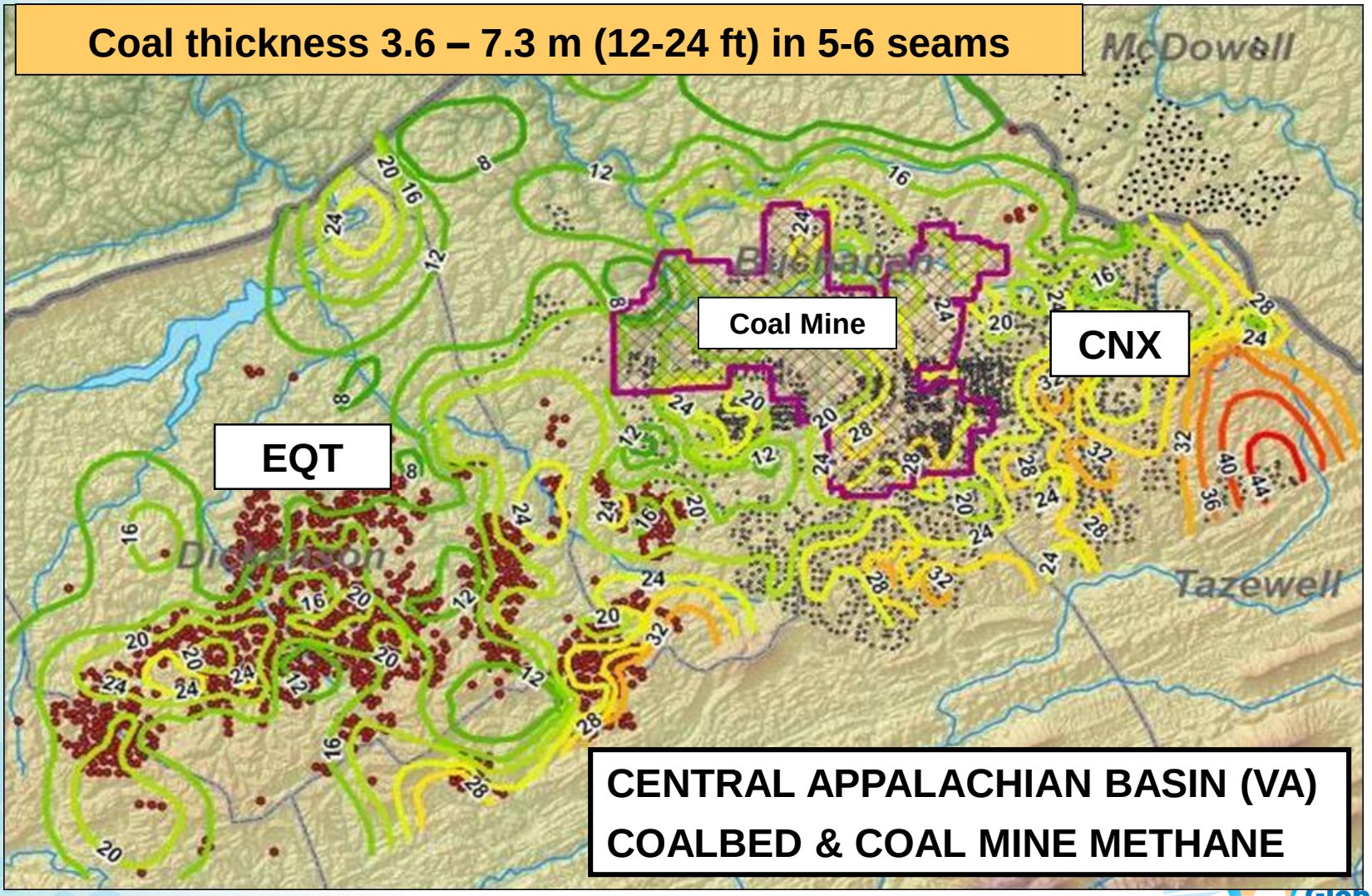
Enlarged Area of Buchanan County



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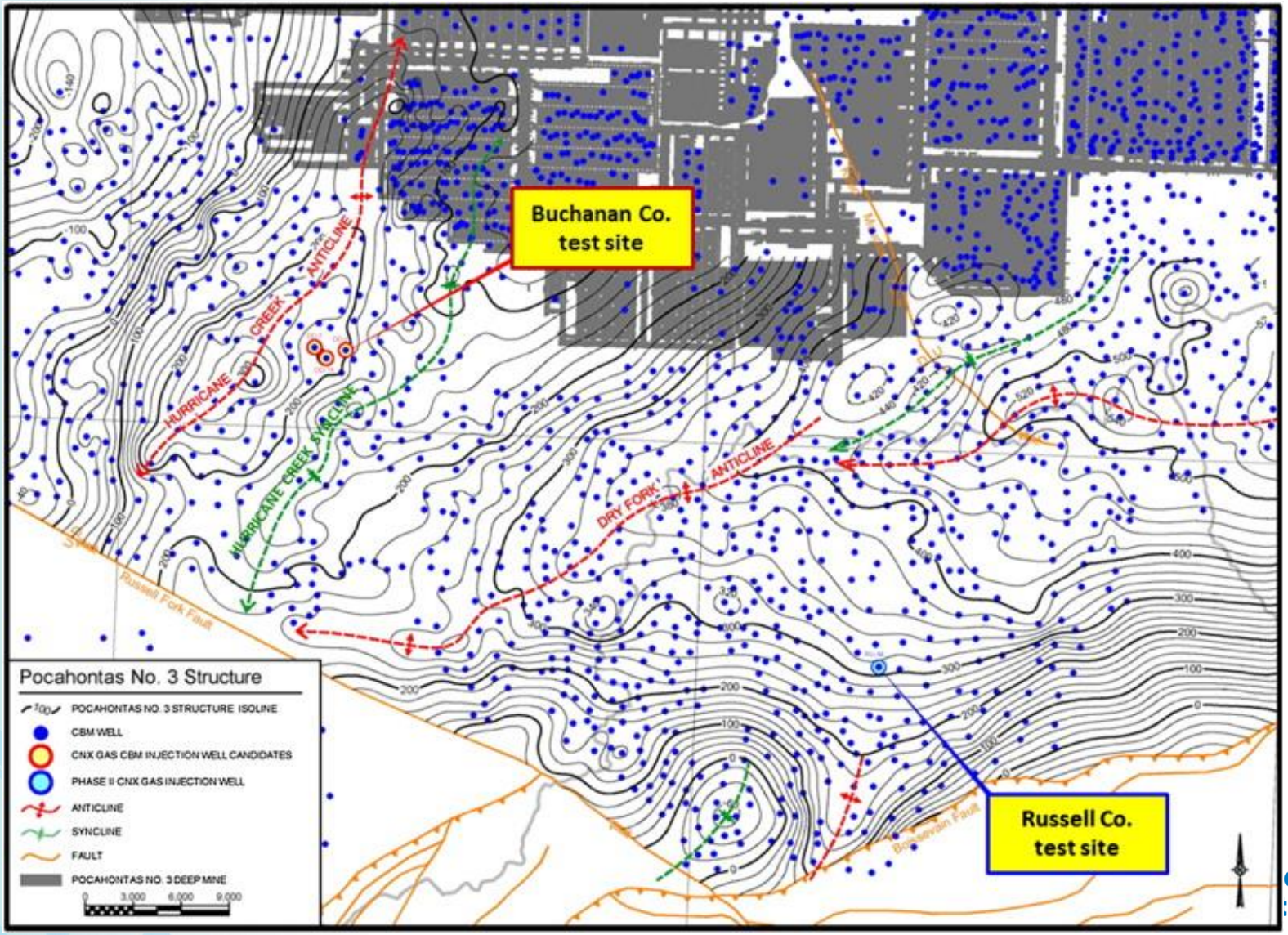
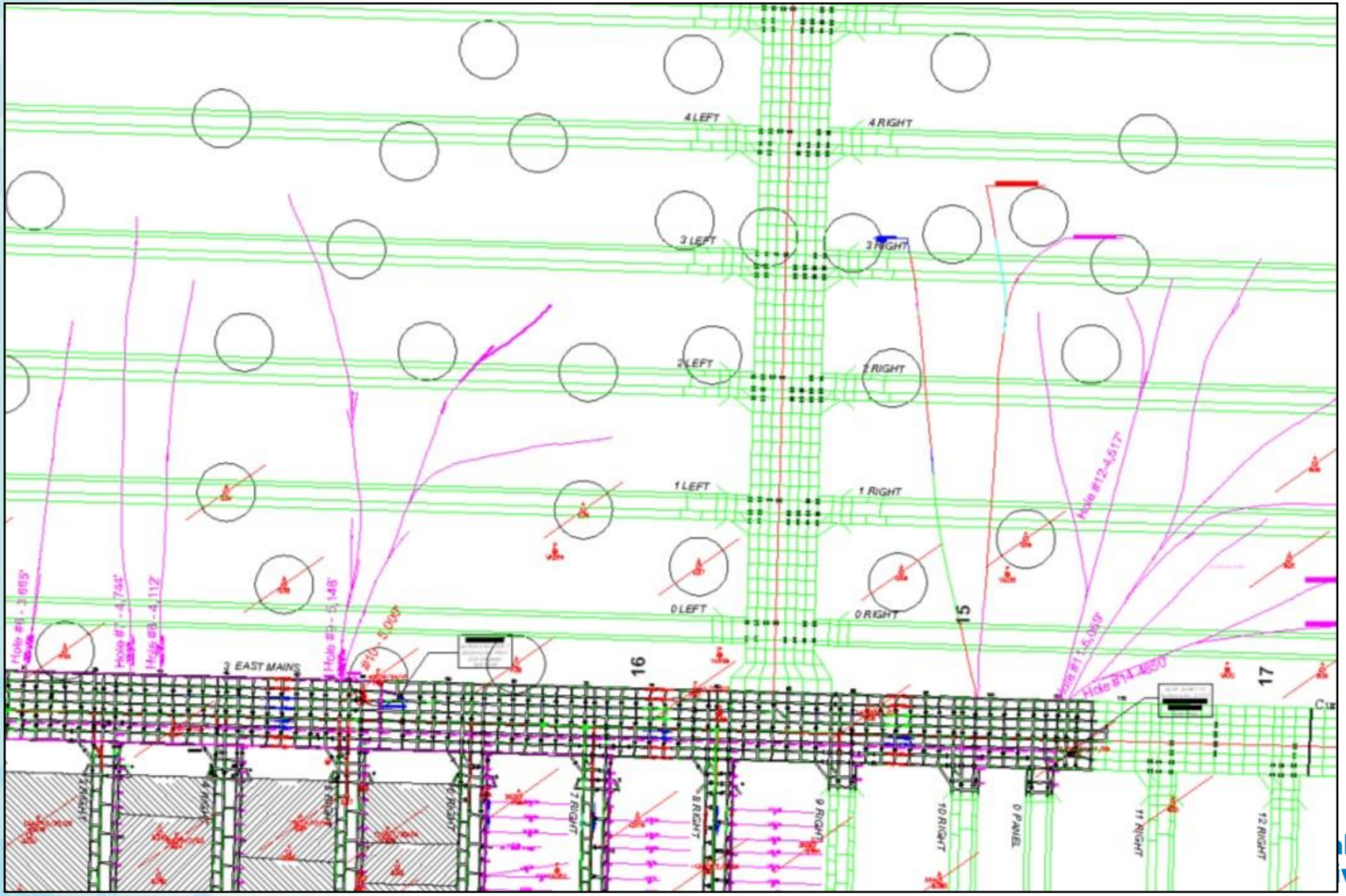
CBM Wells in Mining Area



CBM Wells in Buchanan Mine



Consol (now Coronado Coal)/CNX Buchanan and VP mines, SW Virginia

- Consol began an extensive pre-mine degasification program in the early 1990s that employed vertical frac wells, horizontal pre-mine boreholes, and vertical gob wells at their Buchanan and VP mines;
- The pre-mine vertical frac wells and in-mine horizontal boreholes produce 1.6 million cubic meters per day (58.5 MMcfd) of high quality (95%+ methane). The mine complex produces an additional 200,000 m^3 (7 MMcfd) from gob wells.
- There are multiple uses for the gas including:
  - Injection into the interstate pipeline system via 3, 500 mm diameter (20-inch) lines
  - Power generation for an 88 MW power plant owned jointly by Consol and Allegheny Energy
  - On-site usage for thermal coal drying

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Indian Potential

Indian Potential

- The highly successful Warrior Met and Consol projects demonstrate that coal and gas can be simultaneously produced both safely and profitably;
- The high grade metallurgical coal deposits of the Jharia Coalfields are similar to what is mined at the Warrior Met and Consol Mine: multiple, high rank coal seams with gas contents of up to 15 to 16 m^3/t (480 – 520 cf/ton);
- The recent policy change allowing CIL to extract CBM/CMM from within their mine blocks should help facilitate development;
- The completion of the GAIL pipeline through the Damodar Valley coalfield area will provide a ready market for the gas. The lifting of price controls on CBM improves project economics.
- Reduce gas contents in advance of mining to improve mine safety, drill frac wells for a minimum of 10 years of operation.

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Thank You!

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Overview of the Global Methane Initiative

Global Methane Initiative

- International public-private partnership focused on reducing barriers to the recovery and use of methane as a clean energy source (established in 2004; charter renewed in 2016)
- Includes 45 Partner Countries and more than 500 Project Network members
- Targets sector-specific areas for methane reduction
  - Biogas (Agriculture, Municipal Solid Waste, Municipal Wastewater)
  - Coal Mines
  - Oil & Gas Systems
- Collaborates with the Climate and Clean Air Coalition (CCAC), the United Nations Economic Commission for Europe (UNECE), and the International Energy Agency (IEA)

Global Methane Initiative

Organizational Structure

Steering Committee

Administrative Support Group (ASG)

Biogas Subcommittee

Technical Groups:
- Agriculture
- Municipal Solid Waste
- Wastewater

Coal Mines Subcommittee

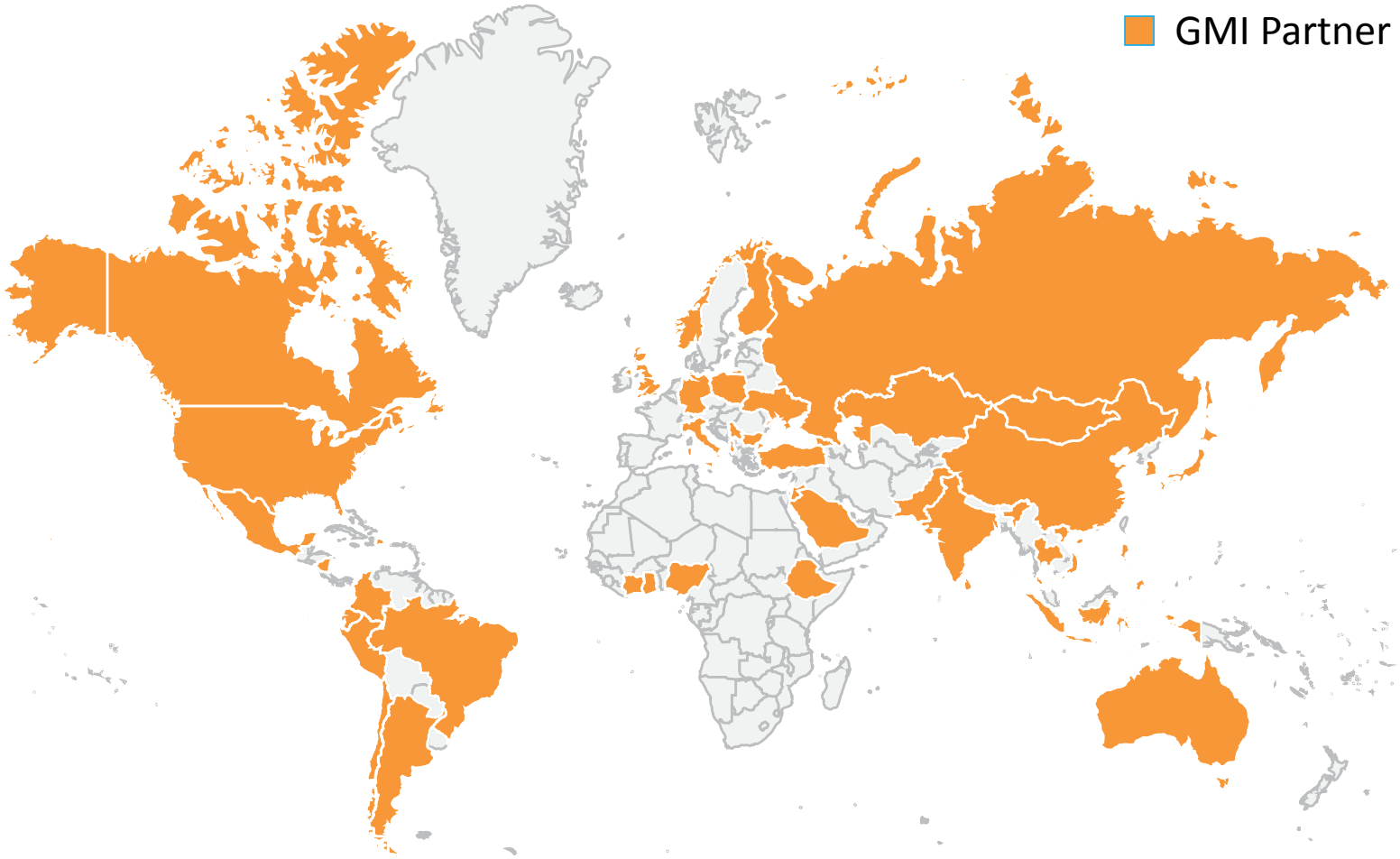
Oil & Gas Subcommittee

Project Network

Proud Member Global Methane Initiative Project Network

Global Methane Initiative

Partner Countries



GMI Partner Countries represent approximately
75% of the world's man-made methane emissions

Global Methane Initiative

Outputs Since 2004

Grown from 14 to 45 partner countries

More than $610 million in leveraged funding for projects and training

More than 500 Project Network members

Conducted more than 600 resource assessments, feasibility studies, study tours, and site visits

Provided trainings for more than 15,000 people in methane mitigation

Developed more than 50 tools and resources for methane mitigation

GMI support has yielded cumulative emissions reductions of nearly **370 MMTCO$_2$e**, resulting in many benefits, including:

- Decreased greenhouse gases
- Improved human health
- Increased worker safety
- Better air and water quality
- Enhanced energy security
- Expanded economic growth

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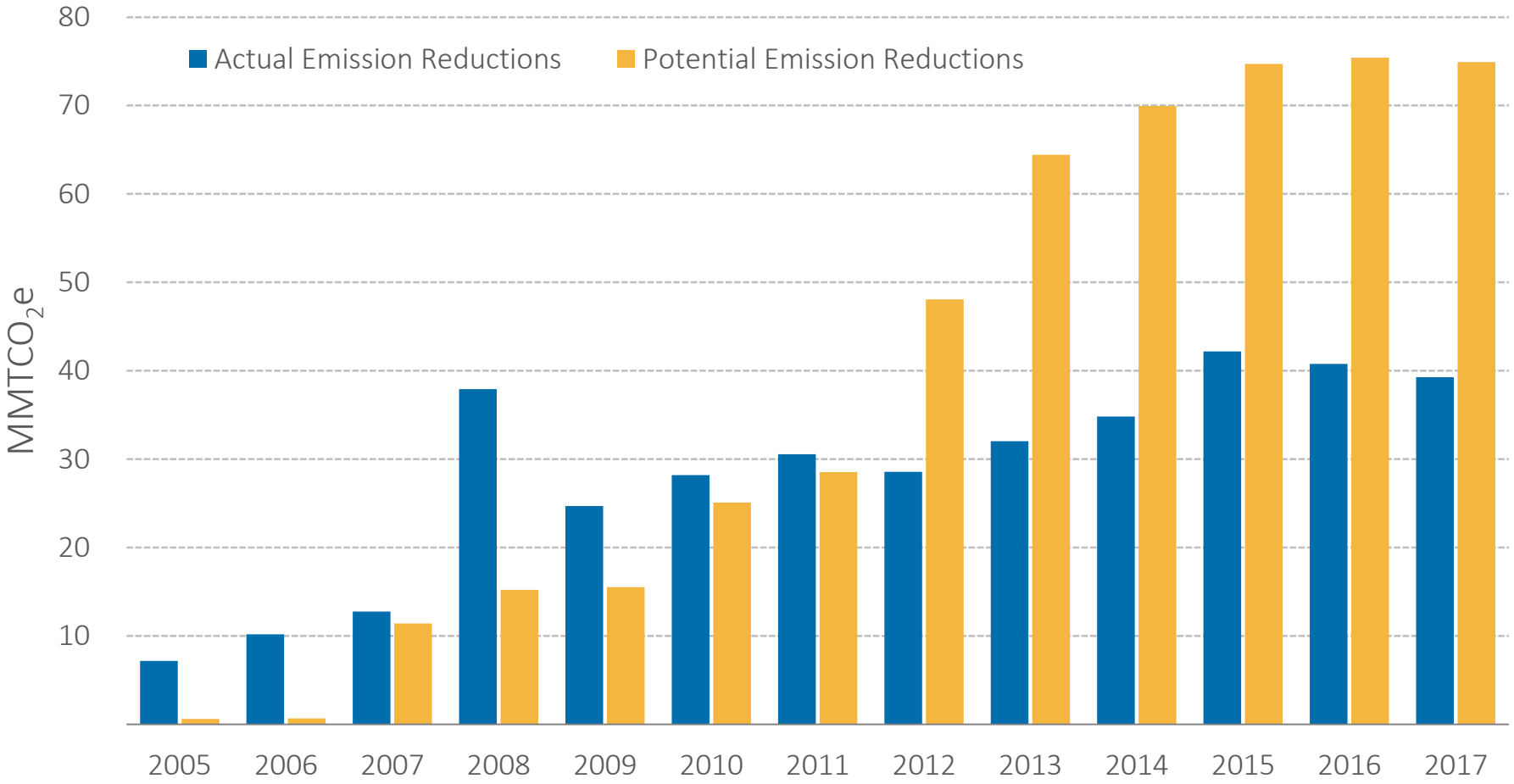
GMI Emission Reduction Accomplishments



These data represent the best available yet conservative estimates of emission reductions, including actual emission reductions from GMI projects and potential emission reductions from other projects identified through GMI efforts.

Global Methane Initiative

Announcing the 2019 Global Methane Challenge

Global Methane CHALLENGE

It’s time to take action!

Challenge Overview

Global Methane CHALLENGE

- **Why:** Raise awareness and catalyze ambitious action to reduce methane emissions
- **What:** An opportunity to showcase policies and technologies being used to reduce methane emissions around the world
- **When:** 2019 calendar year
- **Who:** The Challenge is open to all public- and private-sector actors interested in showcasing their actions to reduce methane emissions
- **Recognition:** Participants will be publicly recognized for actions to reduce methane emissions and actions will be celebrated at a 2020 capstone event

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Examples of Actions

Coal Mine Sector

- Ventilation Air Methane oxidation
- Capture pre-mine drainage coal mine methane for recovery and usage (power generation, pipeline injection, boiler usage, etc.)
- Install gas collection systems

All Sectors

- Monitor methane emissions and create an emissions inventory
- Provide technical or financial support to a methane mitigation project
- Develop or promote implementation of sector-specific best practices

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Visit globalmethane.org/challenge

Actions are highlighted on the website

Global Methane Initiative

Coal Mines Subcommittee

Coal mine methane sector activities focus on recovering methane that is released from coal seams as a result of mining activities

Coal Mines Subcommittee

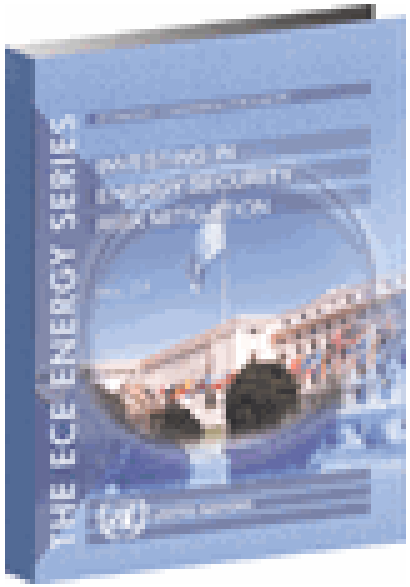
- Developed comprehensive profiles that characterize the coal and coal mine methane sectors of 37 countries (29 Partner countries)
- Completed country-specific action plans for 10 Partner countries
- Showcased 100+ project opportunities and success stories at Methane Expos in China, India, and Canada.
  - 40 project opportunities presented at the 2010 Expo in New Delhi
- Hosted meetings and workshops in more than a dozen countries
- Developed numerous technical resources and tools

Coal Subcommittee Statement of Purpose and Action Plan:
http://www.globalmethane.org/sectors/index.aspx?sector=coal

Global Methane Initiative

GMI Coal Mines Subcommittee: Collaboration with UNECE

- Best Practices Guidance for Effective Methane Drainage and Use in Coal Mines
  - Drafted by international CMM technical experts; peer reviewed
  - Updated in 2016
  - Collaborative project between GMI and UNECE Group of Experts on CMM
  - U.S. EPA financially supported outreach workshops organized by UNECE in China (Oct 2010), Kazakhstan (May 2011; Oct 2016), Ukraine (Sept 2011), and India (March 2017)
  - Guide can be found at: https://www.unece.org/energy/se/cmm.html



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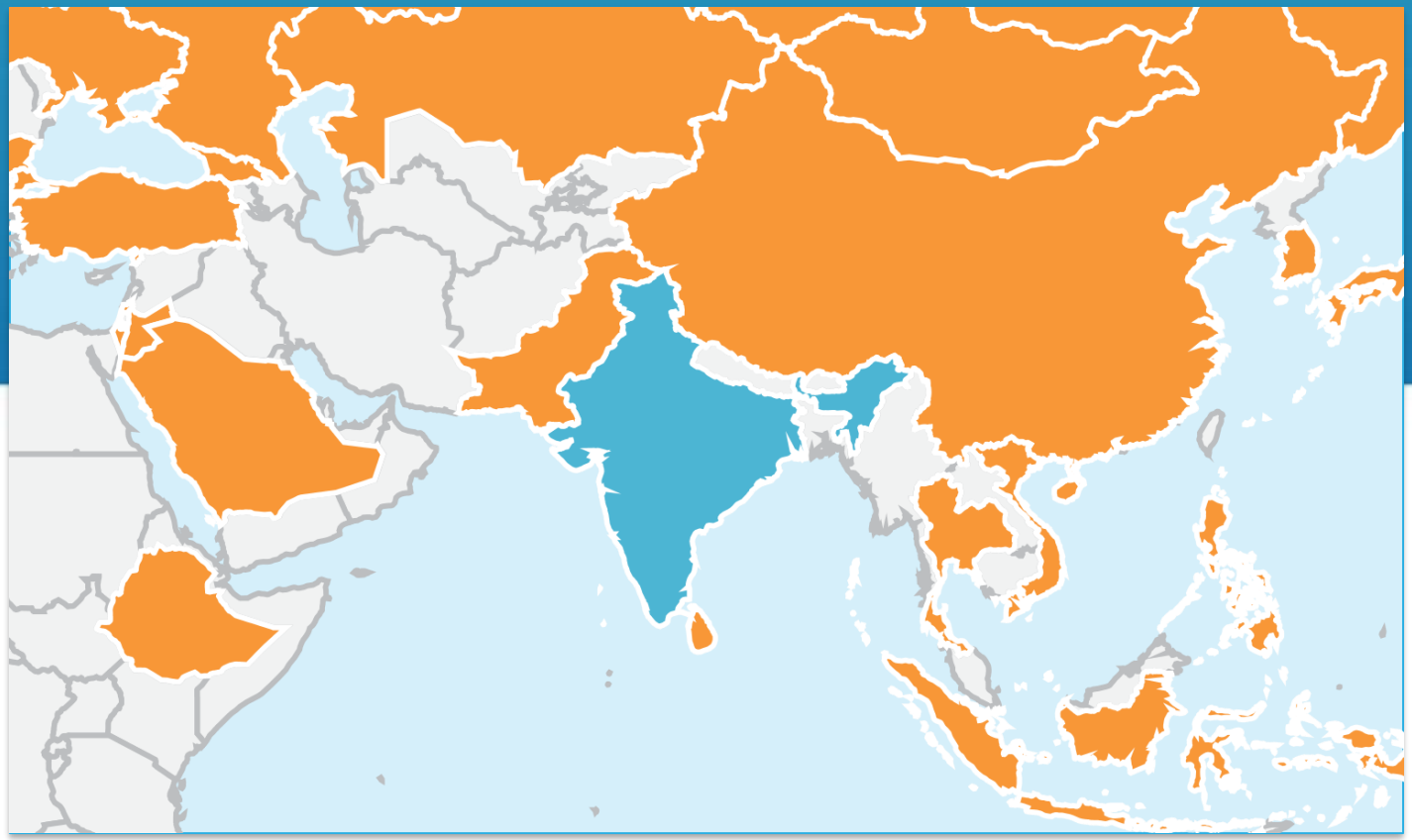
GMI in India



Background

- The U.S. EPA and India's government agencies have a long and productive history of cooperation in the area of CMM/CBM resource development
- Informal efforts were initiated in 2001, culminating in the establishment of the CMM/CBM Clearinghouse in 2008, at CMPDI (HQ) in Ranchi (Jharkhand)
- The Clearinghouse has facilitated numerous efforts to promote CMM/CBM development in India, including workshops and conferences, training and site visits, and technical studies

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India CMM/CBM Clearinghouse

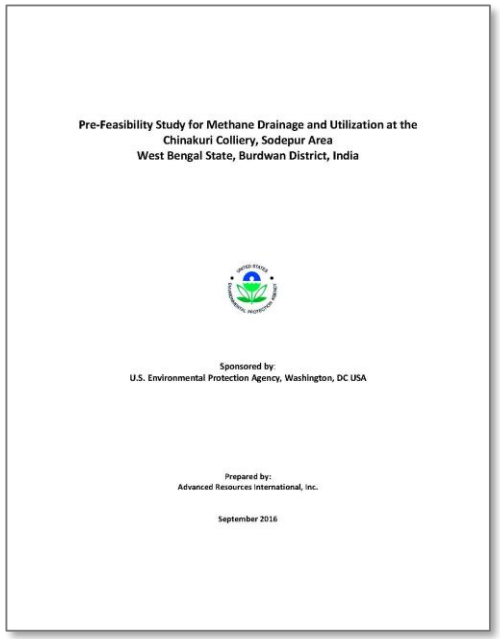
- Established in November 2008, with partner funding from U.S. EPA (25%) and Coal India, Ltd. (75%) under aegis of Ministry of Coal
- Non-profit and non-governmental organization with the aim to promote the development of CMM/CBM in India

- Intended to be the public face of the CMM/CBM industry in India through its communication and outreach efforts
- Initial point of contact for foreign and domestic investors

Global Methane Initiative

Technical and Economic Studies

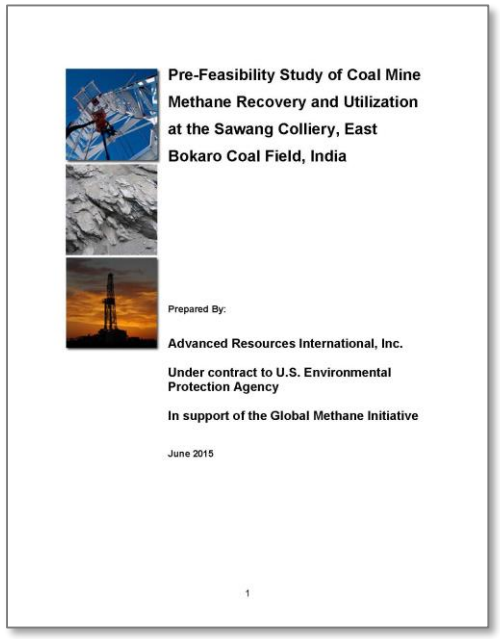
- The Clearinghouse has supported three technical and economic pre-feasibility studies funded by the U.S. EPA:
  - Sawang Colliery, East Bokaro coalfield (2013)
  - Chinakuri Coal Mine, Raniganj coalfield (2015)
  - Pootkee-Bulliary Mine, Jharia coalfield (2019)


Pre-Feasibility Study for Methane Drainage and Utilization at the Chinakuri Colliery, Sodepur Area
West Bengal State, Burdwan District, India

Sponsored by:
U.S. Environmental Protection Agency, Washington, DC USA

Prepared by:
Advanced Resources International, Inc.

September 2016


Pre-Feasibility Study of Coal Mine Methane Recovery and Utilization at the Sawang Colliery, East Bokaro Coal Field, India

Prepared By:

Advanced Resources International, Inc.

Under contract to U.S. Environmental Protection Agency

In support of the Global Methane Initiative

June 2015

1

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Workshops and Conferences

- November 2008: Following the inauguration of the Clearinghouse, a two-day workshop entitled "CMM Development in India: An Opportunity Area" was held in Ranchi
- March 2010: Supported the 2010 Methane to Markets Partnership Expo in Delhi, presented various prospect opportunities, and created working models of CMM/CBM operations
- November 2013: The India Clearinghouse hosted an International Workshop entitled "Development of Coal-Based Non-Conventional Resources in India"
- March 2017: CMPDI Hosted an International Workshop on "Best Practices in Methane Drainage and Use in Coal Mines" in conjunction with the UNECE

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Training and Technology Transfer

- Since the establishment of the Clearinghouse in 2008, coal industry personnel have visited the U.S. to learn about a number of areas of CMM/CBM development, including:
  - CBM drilling and completions techniques
  - In-mine directional drilling
  - Development of CMM/CBM in active oil and gas fields
  - Legal and regulatory aspects of CMM/CBM development
  - End-use technologies for CMM/CBM
- Recently, a high-level delegation visited in-mine drilling operations at the Warrior Met Coal mine in Tuscaloosa, AL, as the geology and mine conditions are similar to the Moonidih mine of the Jharia Coalfield, an area actively being pursued for CMM development by CIL

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Future Activities

- With the recent permission by the Government of India to Coal India Limited to explore and develop CBM from areas under coal mining leases held by CIL and its subsidiaries, the Clearinghouse will continue to serve as a catalyst for Indian CMM/CBM development
- Future activities will include:
  - Organizing in-house training and workshops for capacity building of Coal India Limited, Government officials, Industry personnel, and other stakeholders involved with CMM/CBM development
  - Organizing international seminars and technical workshops in India for exploring the existing opportunities in the development of CMM in India
  - Gathering the latest technical information on CMM/CBM development and enhancing international exchange and cooperation in CMM/CBM development
- As the first commercial CMM projects are developed, the U.S. EPA looks forward to continued cooperation with the India CMM/CBM Clearinghouse in association with CIL- CMPDI under aegis of MoC

Global Methane Initiative

Overview of In-Mine Directional Drilling Technology

International Workshop on Optimum Utilization of CMM/CBM in India, Ranchi, India, April 24-25 2019

Daniel J. Brunner
President, Resource Enterprises
REI Drilling Inc., DPI Inc., DPI-IPG LLC.
Salt Lake City, UT, USA

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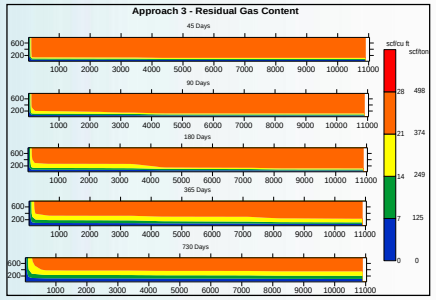
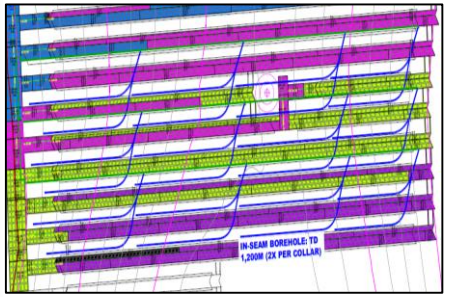
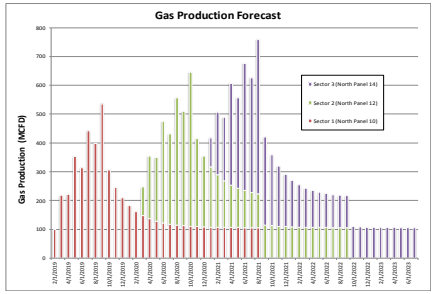
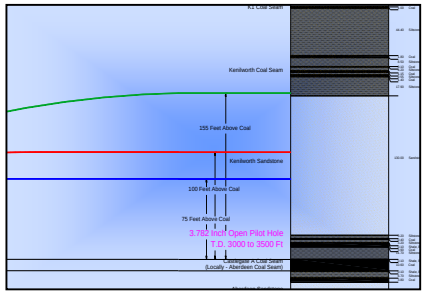
Methane Drainage Service Provider

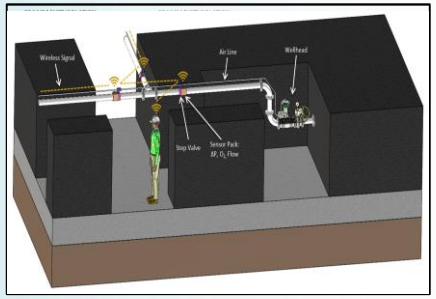
- **Characterization, Engineering Design, Implementation**

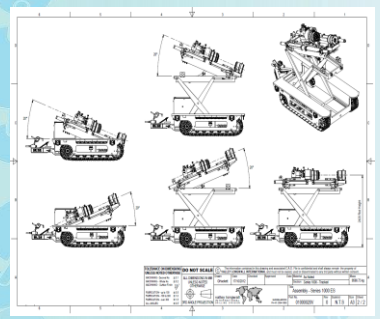


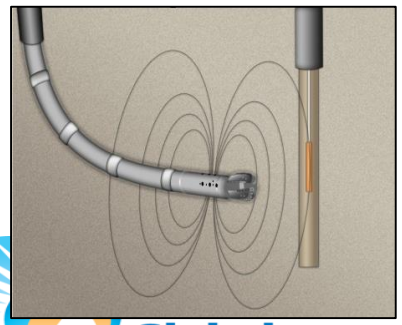








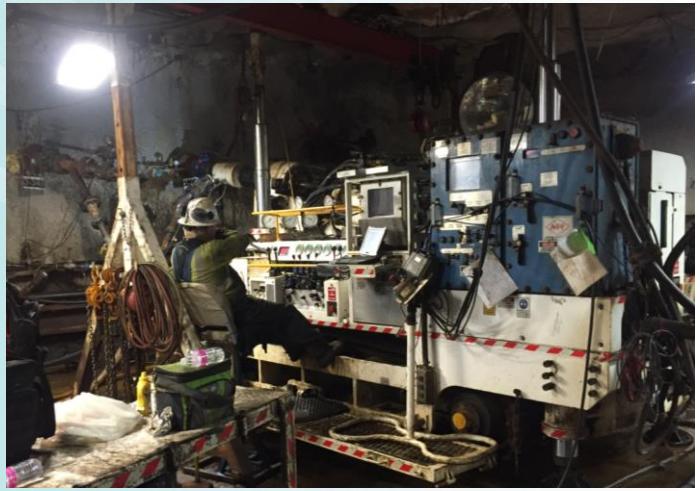


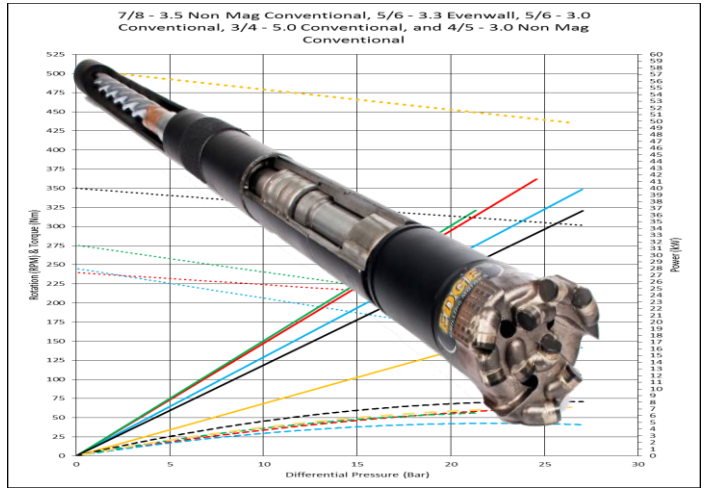


Global Methane Initiative

Developments in Technology

- **Extended Reach Directional Drilling Equipment**





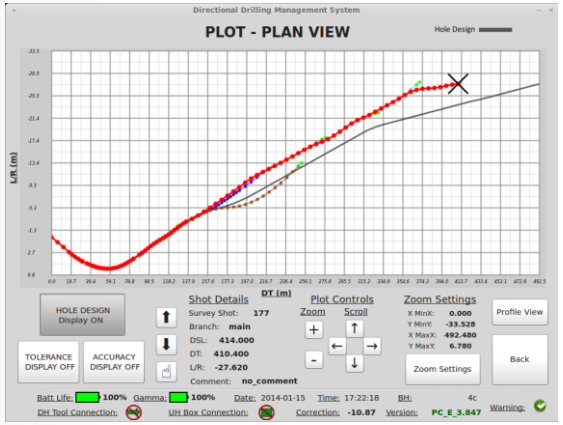
- **ER Permissible Drill**
  - 555 kN/7,500 NM
  - > 2,000 m
- **ER Drill Steel**
  - Designed to be Comparable to X95 73 mm XH Oil Field Pipe Used for Extended Reach
  - Installed with High Pressure RCS I+ Communication System
- **ER Mud Systems**
  - 150 kW Permissible Unit
  - Variable Flow
  - Used for Reaming and Extended Reach (> 2000 m drill string length)
- **ER Downhole Motors**
  - High Torque for WOB
  - Centralized Multi-Stage Systems
  - 89 mm Systems with Reaming Capability

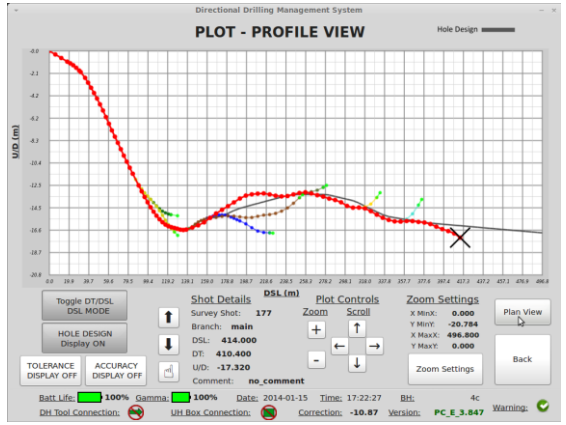
Global Methane Initiative

Developments in Technology

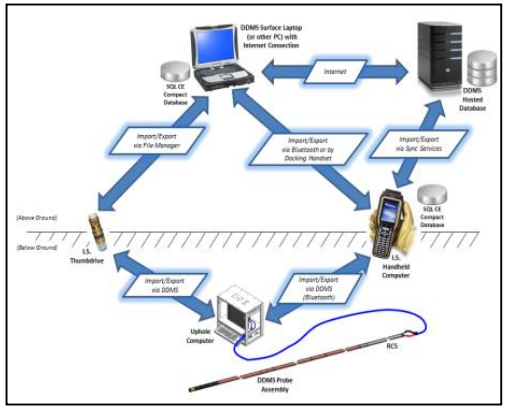
- **Enhanced Extended Reach DDMS with LWD Capability**

- **On-Board Drill to Plan**

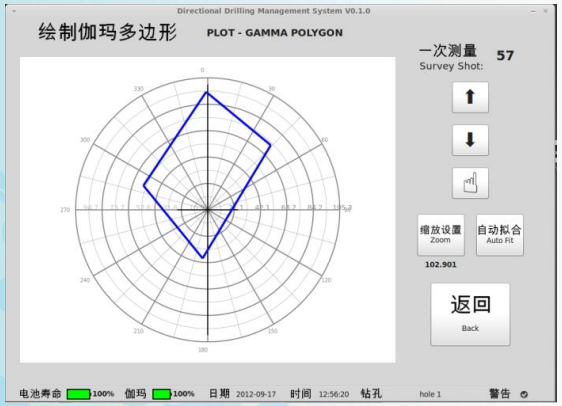




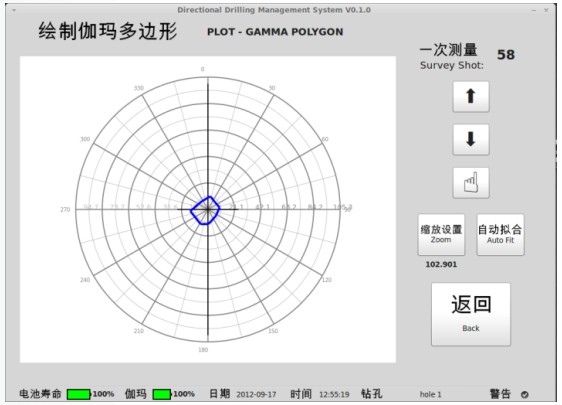
- **Data Management**



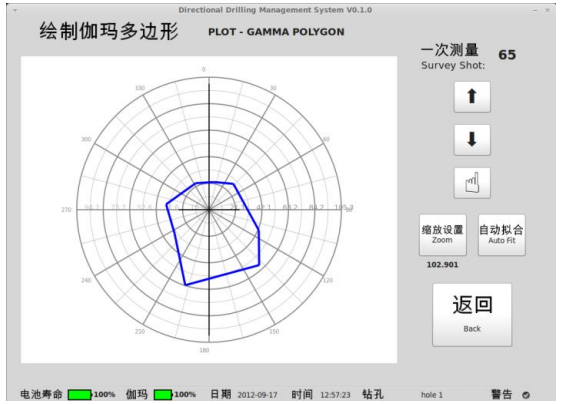
- **On-Board Focused Gamma Polygon Guidance**



- **Roof**

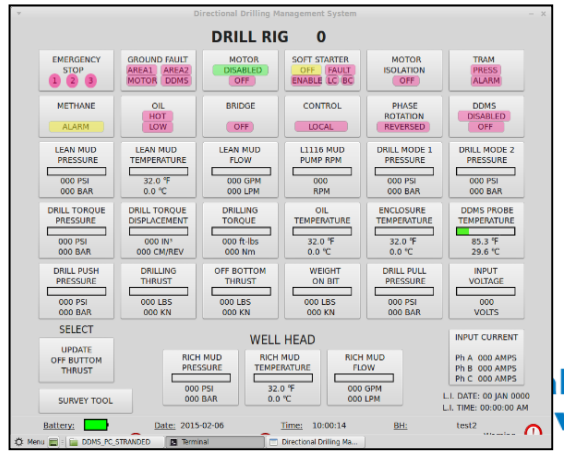


- **Coal**



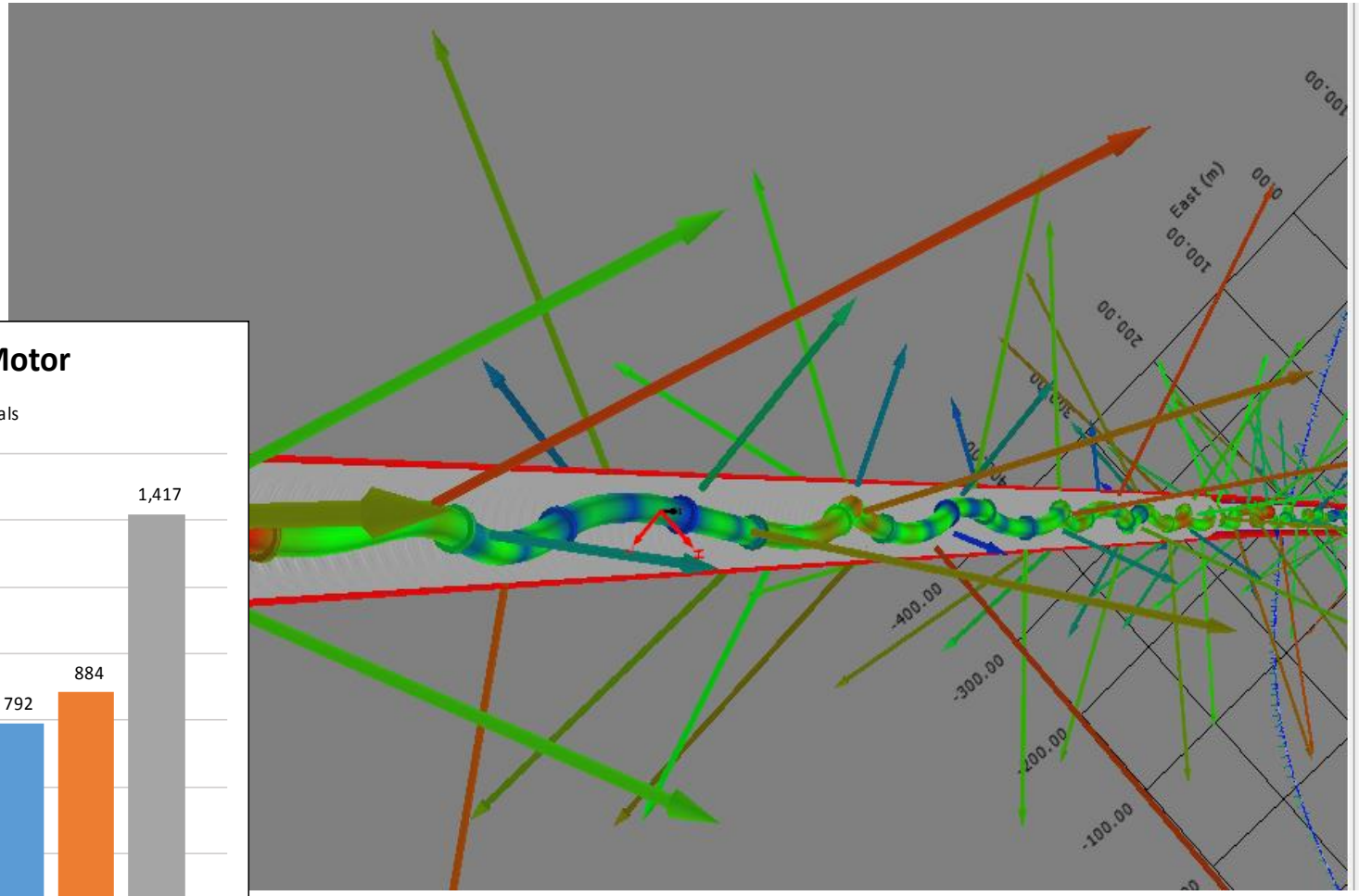
- **Floor**

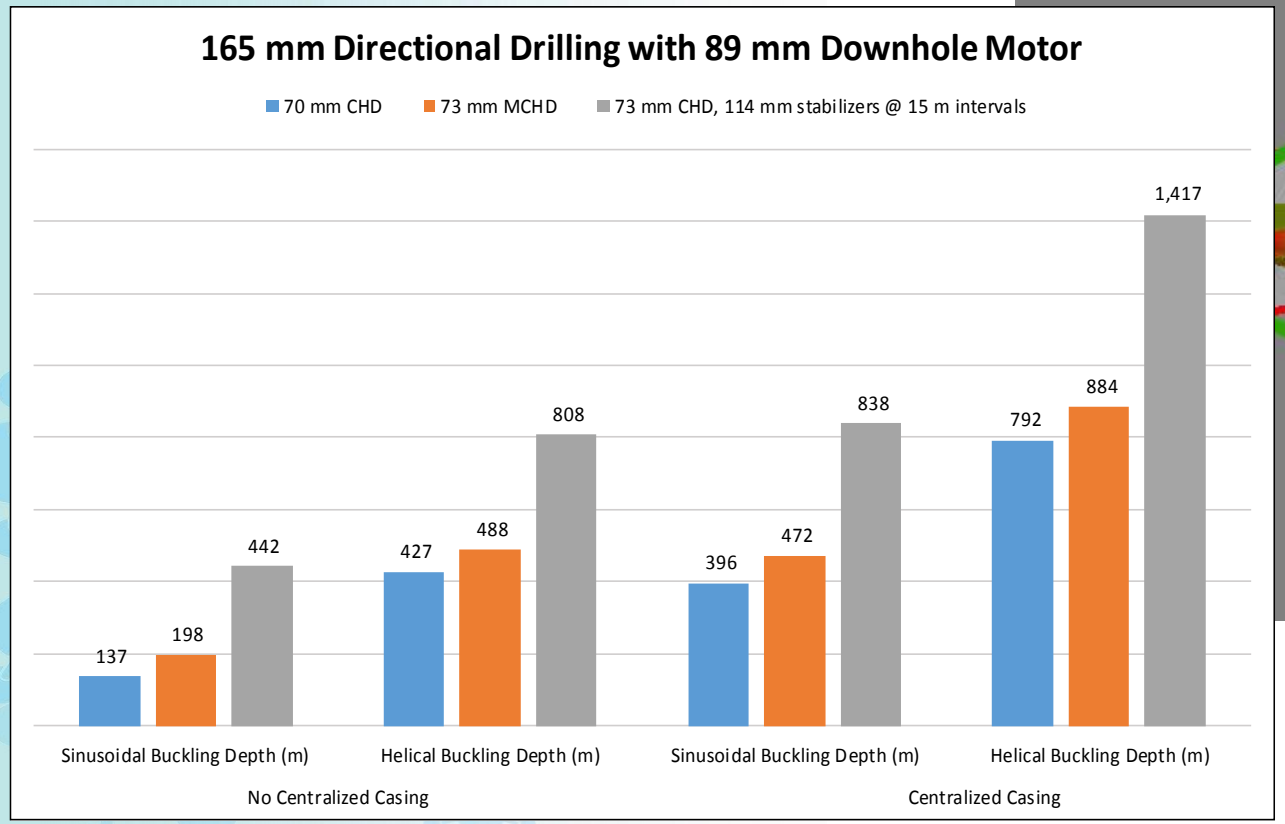
- **Drill Performance Monitoring**



Developments in Technology

- **Torque and Drag Simulation**
  - String Model of Drill Steel
  - Buckling Limits, Tension – Depth
  - Range Chart, Thrust – Depth
  - Plan Drilling Strategy





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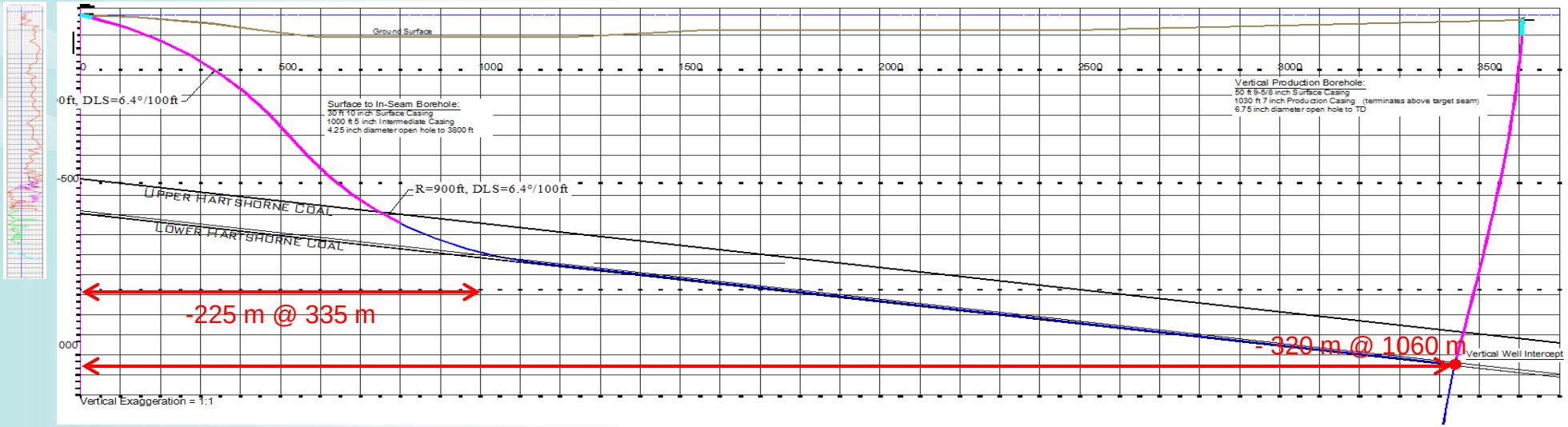
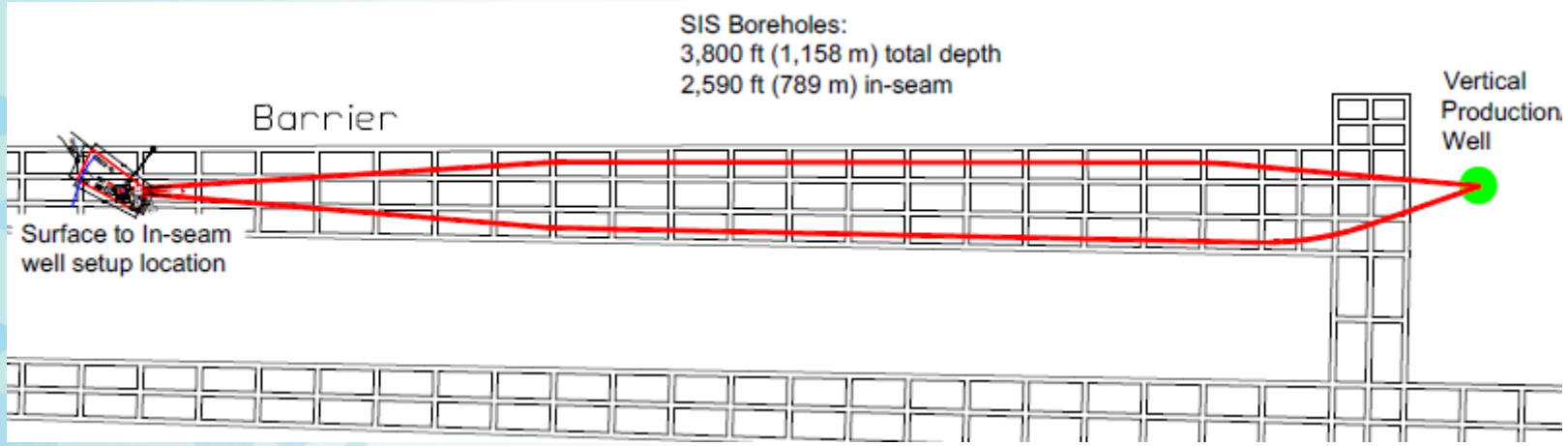
Developments in Technology

- **Well/Borehole Interception Capabilities**

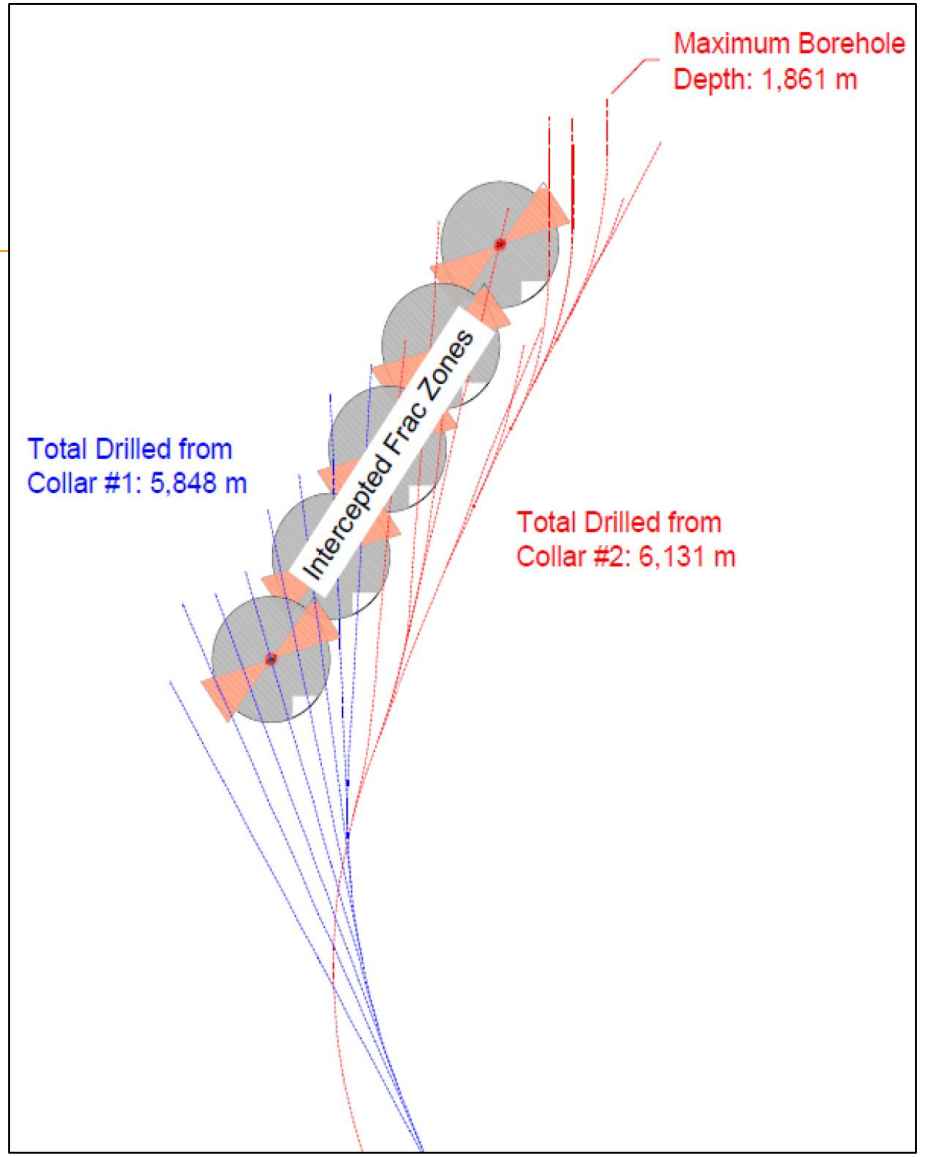


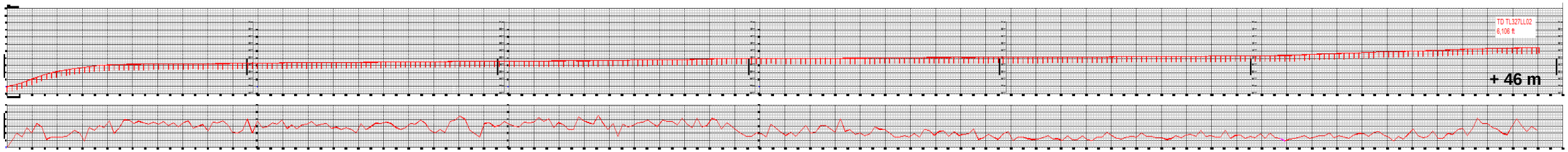
- Magnetic Vector Technology
- Intercept 150 mm Dia. Vertical Well



Enhanced Capabilities

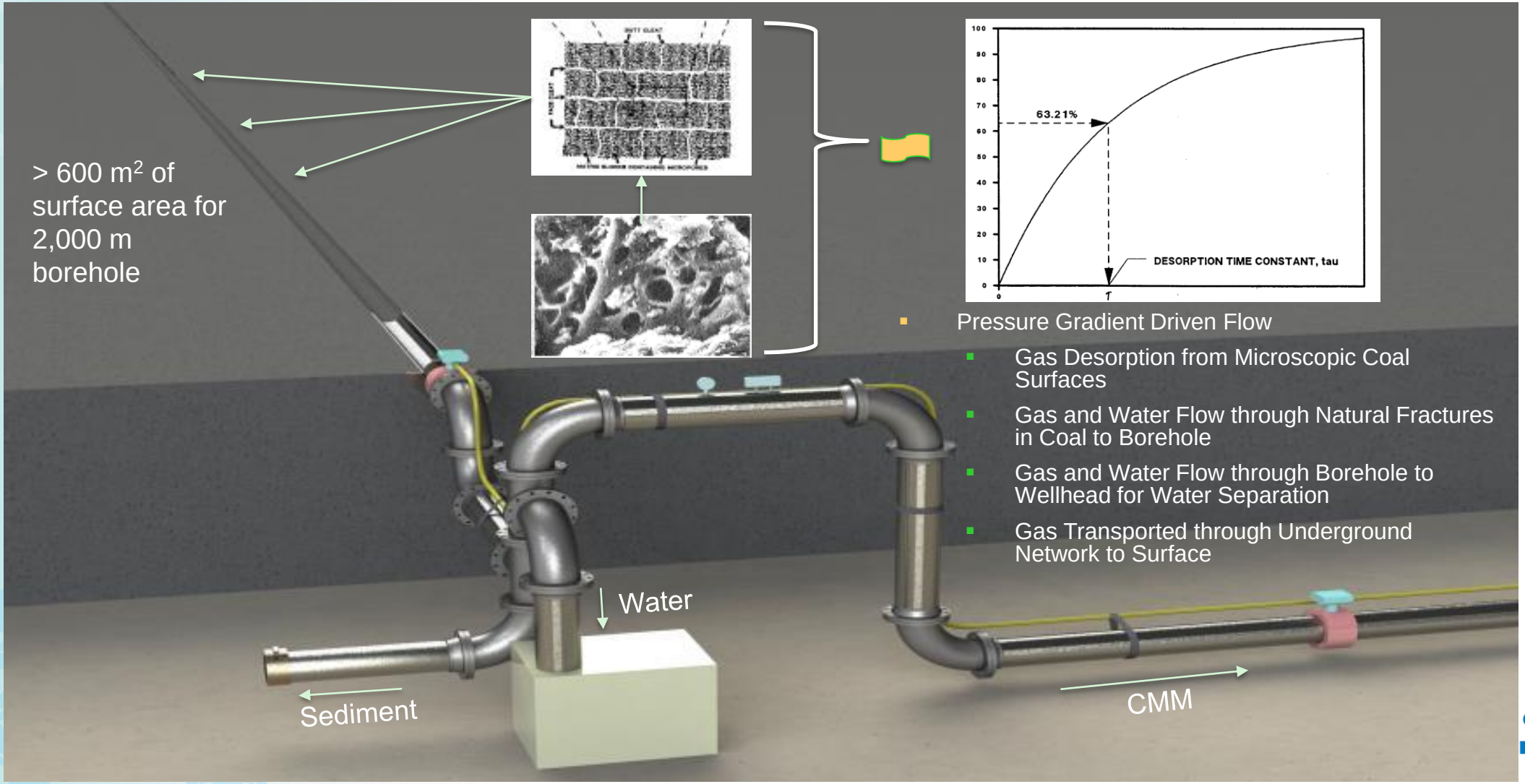
- **Extended Reach Drilling**
  - 68,580 m drilled in rock
  - Longest underground directionally drilled borehole at 1,861 m at + 46 m above collar elevation
  - 14,520 m drilled from a single wellbore – record in Oil and Gas
  - Combined systems





Pre-Mining Methane Drainage Considerations

- **Impact of Reservoir Conditions**



- 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

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Geologic and Reservoir Characteristics

- **Reservoir Characteristics of CMM Pre-Drainage Projects Compared to Moonidih**

Reservoir Properties	Pocahontas No. 3	Lower Hartshorne	Double Seam	Blue Creek	Moonidih XVIT
Rank	Medium Volatile Bituminous	Low-Medium Volatile Bituminous	Medium Volatile Bituminous	Low-Medium Volatile Bituminous	Low-Medium Volatile Bituminous
Depth (m)	180 -390	320 - 610	150 - 350	427 - 640	594
Reservoir Pressure Gradient (kPa/m)	5.39	9.73	6.79	3.39	9.80
Reservoir Pressure at Depth (kPa)	969 - 2,100	3,103 - 5,929	1,018 - 2,376	1,447 – 2,170	5,838
Permeability (md)	5 - 27	1.2 - 1.6	20 - 35	12-20	1.0-5.0
Thickness (m)	2.1 - 2.4	1.4 - 4.3	1.6 - 3.1	1.5 – 1.9	1.5-3.0
Gas Content (m3/t dmaf)	8.0 - 12.9	15.9 - 16.4	7.8 - 12.8	12.2 - 16.1	8-15
Langmuir Volume (m3/t)	22.4	20.9	27.16	20.8	26.3
Langmuir Pressure (kPa)	1,165	N/A	1,419	1,710	1,650
Sorption Time (hours)	168	37	56.6 - 66.7	72 - 96	36

- **Moonidih XVIT seam reservoir conditions are generally comparable to those of similarly ranked coal seams in the U.S. where methane drainage is performed.**

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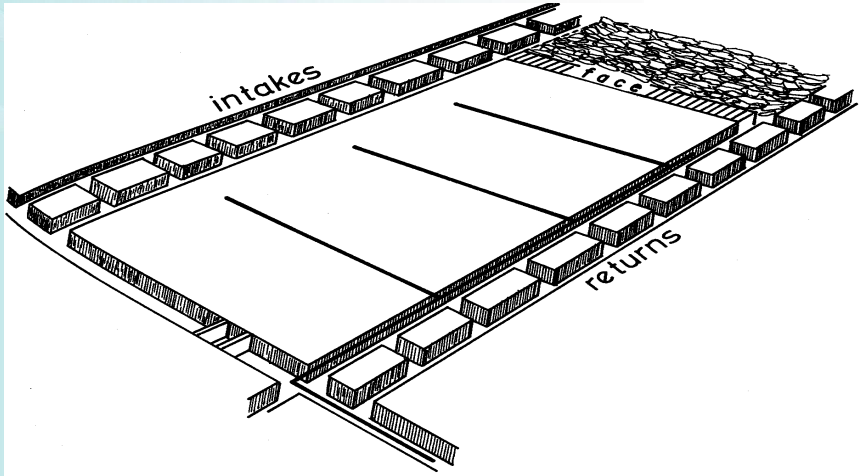
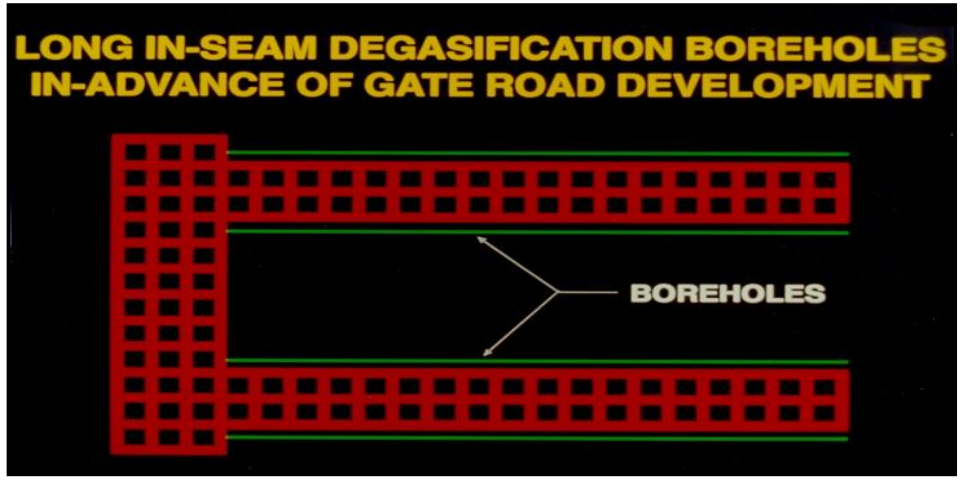
Directional Drilling Solutions

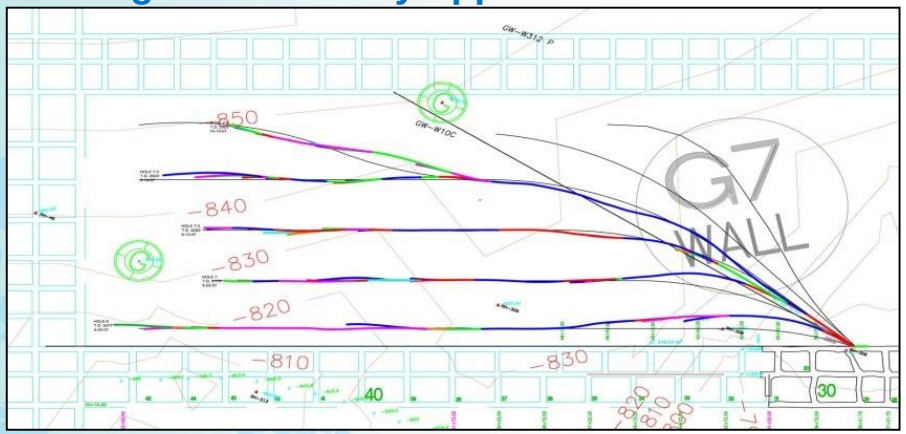
- **Displacing Conventional In-Seam Drainage Techniques**
  - **Conventional Cross-Panel Boreholes**



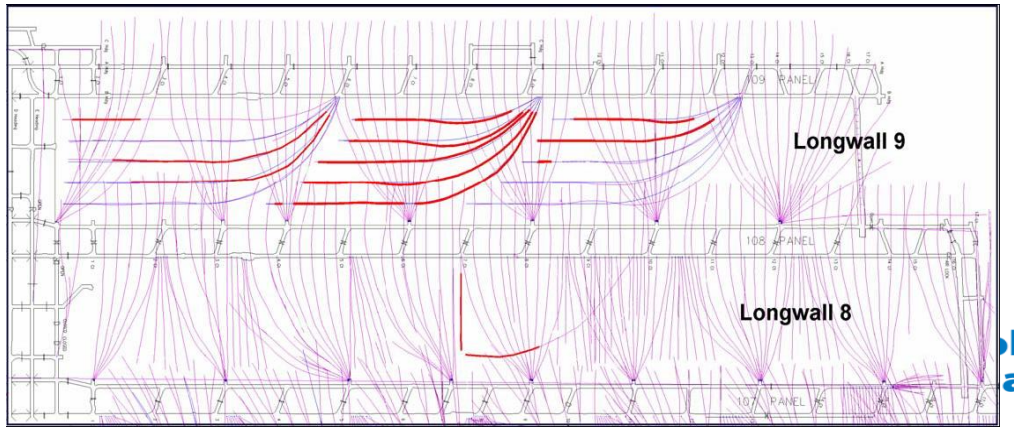
  - **Directionally Drilled Shielding Boreholes**



  - **High Permeability Application**



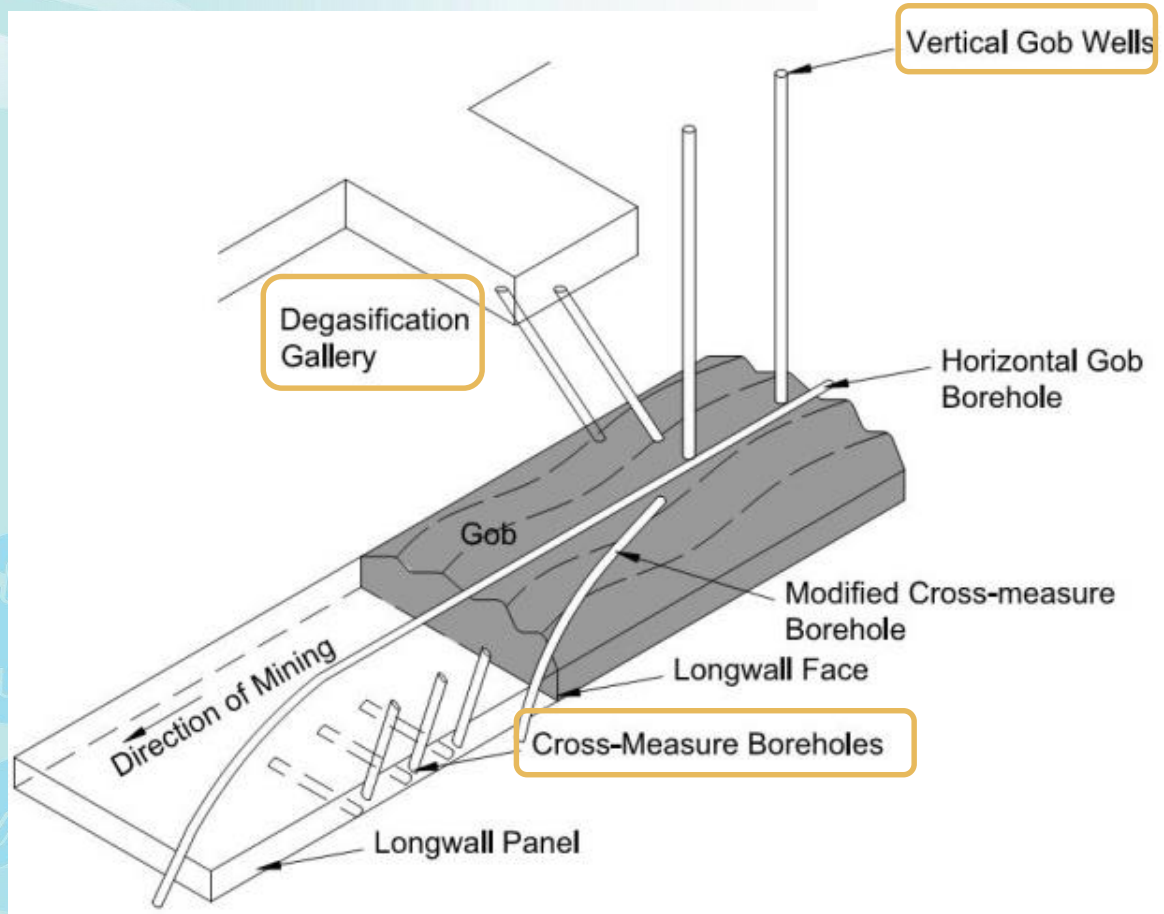
  - **Low Permeability Application with Outburst Protection**



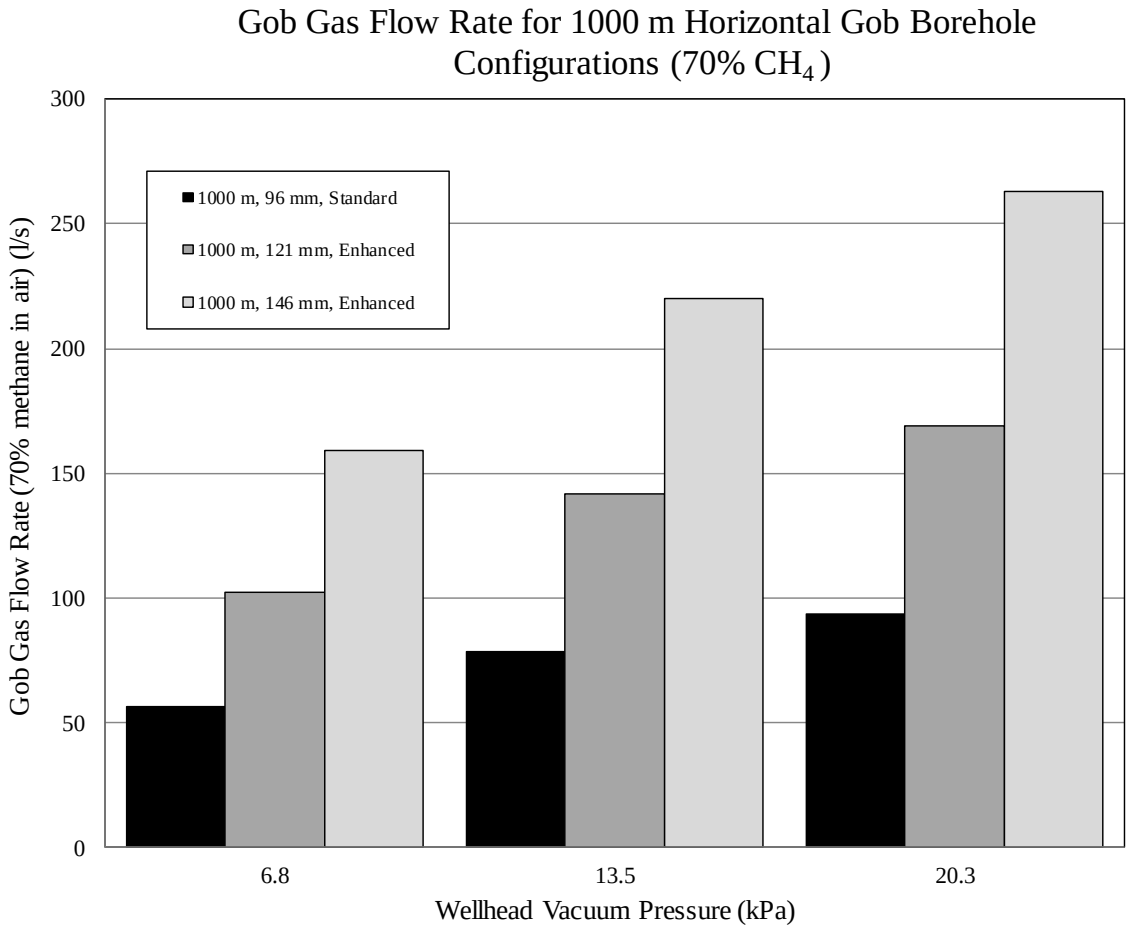
Directional Drilling Solutions

Displacing Conventional Gob Degasification Techniques

Gob Degasification Techniques

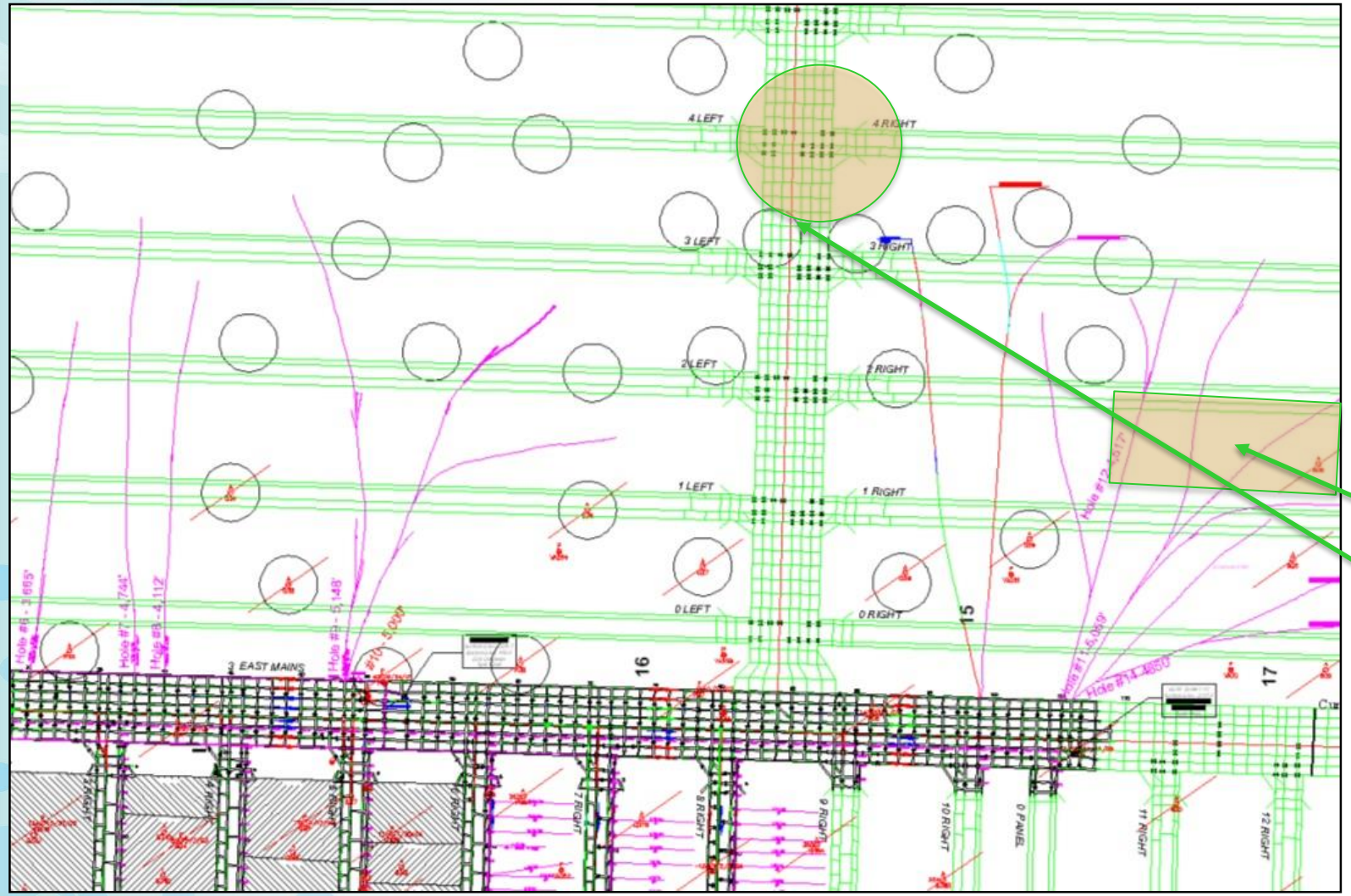


High Capacity Horizontal Gob Boreholes



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**

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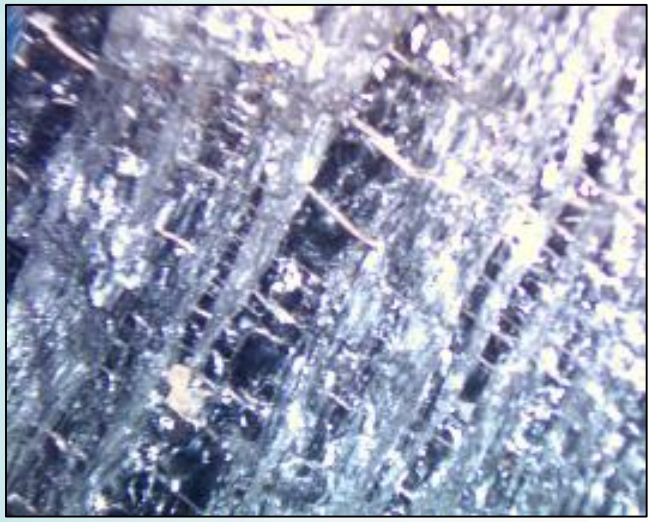
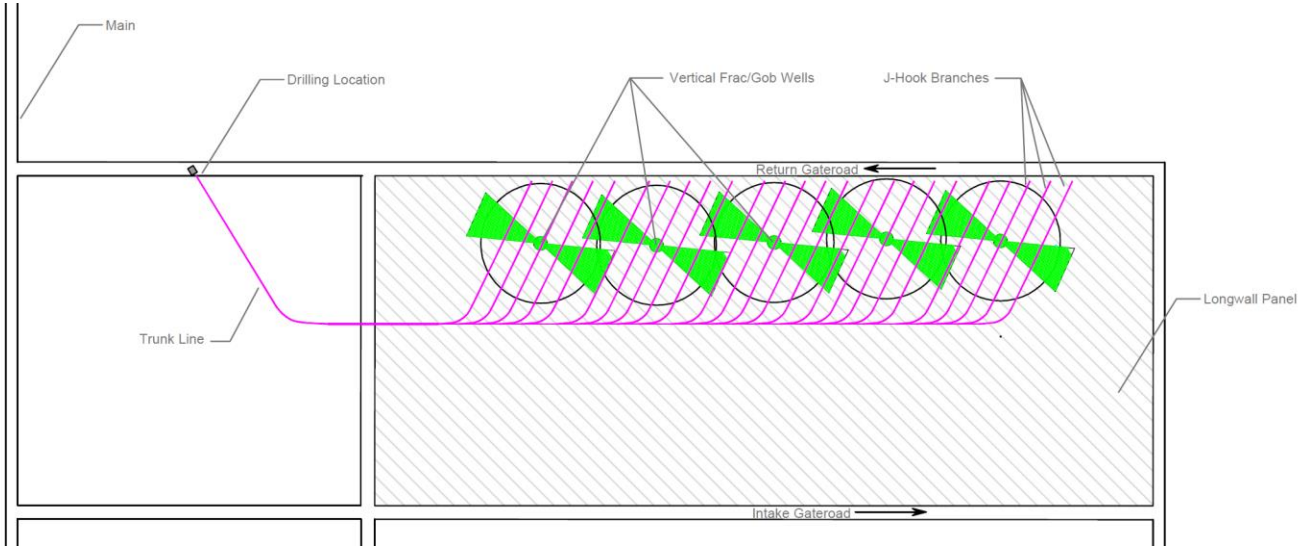
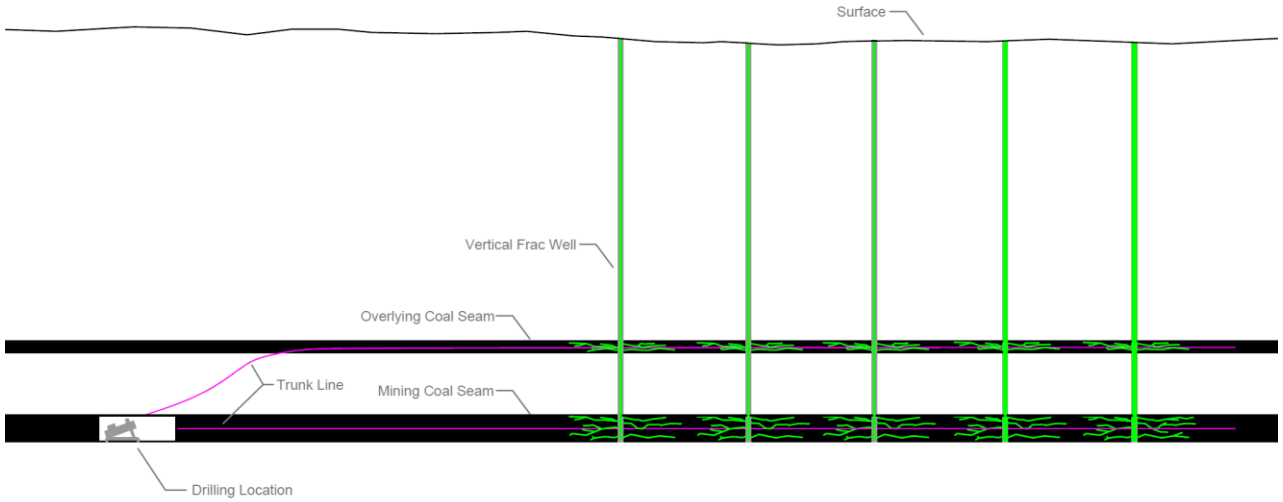
Directional Drilling Solutions

- **Combining Systems of Methane Drainage in Tight Coals**



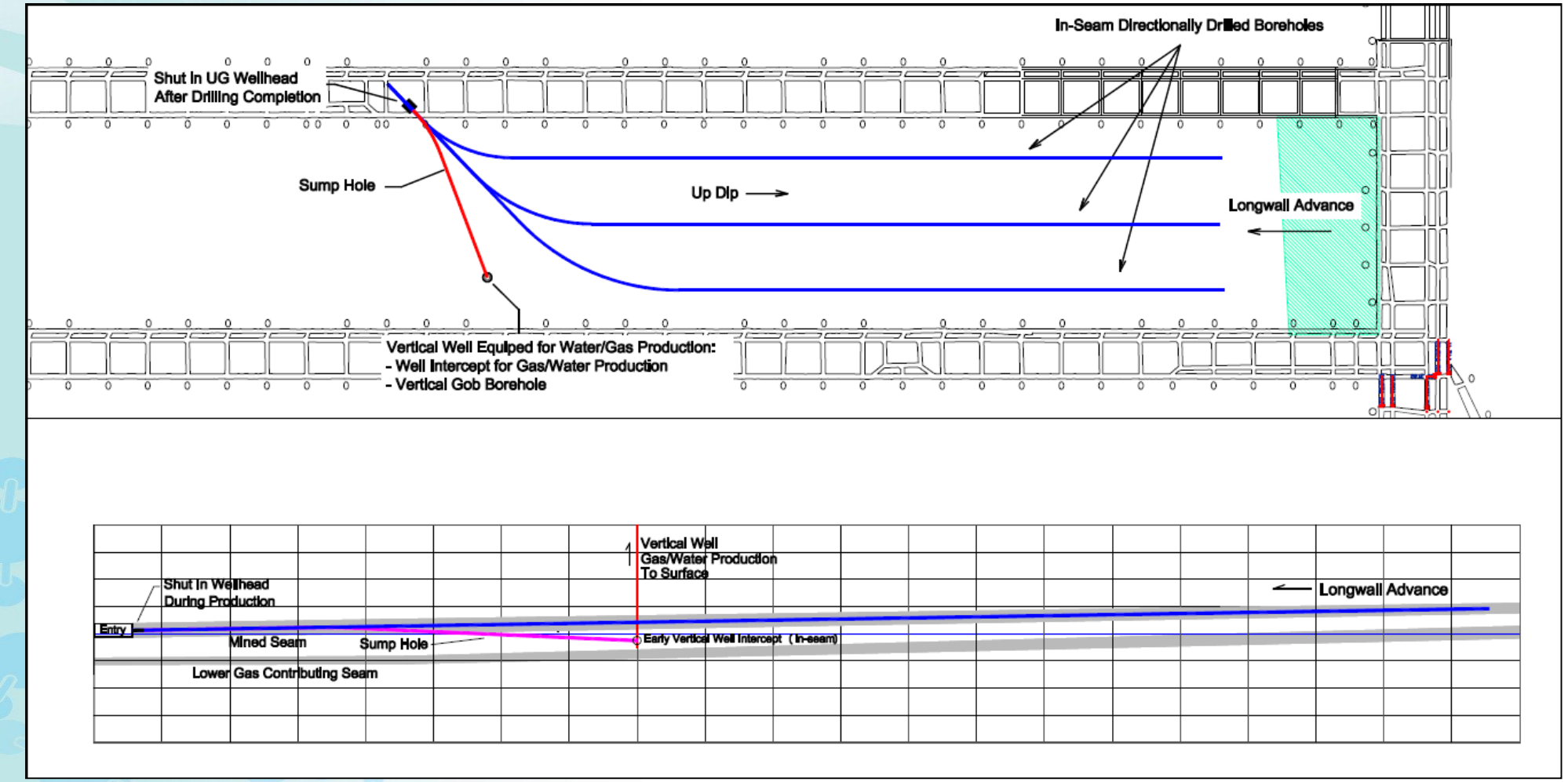




- **Applicable in Tight or Cemented Coals**
- **Where In-seam Gas Production Increases with Mining Related Stress Changes**
- **Intercept Fracs Orthogonally, both Mining and Adjacent Seams**
- **Vertical Wells Serve as Future Gob Wells**
- **CMM Recovered from Surface as Mining Advances**

Directional Drilling Solutions

- **Connecting Vertical Wells with In-Seam Boreholes to Implement Stand-Alone Systems**



- Connect in-seam manifold of directionally drilled boreholes to a vertical well
- Water and gas is produced from the vertical well on the surface.
- Minimizes underground gas collection
- Vertical well can be completed to be used as a gob-well post pre-mining drainage

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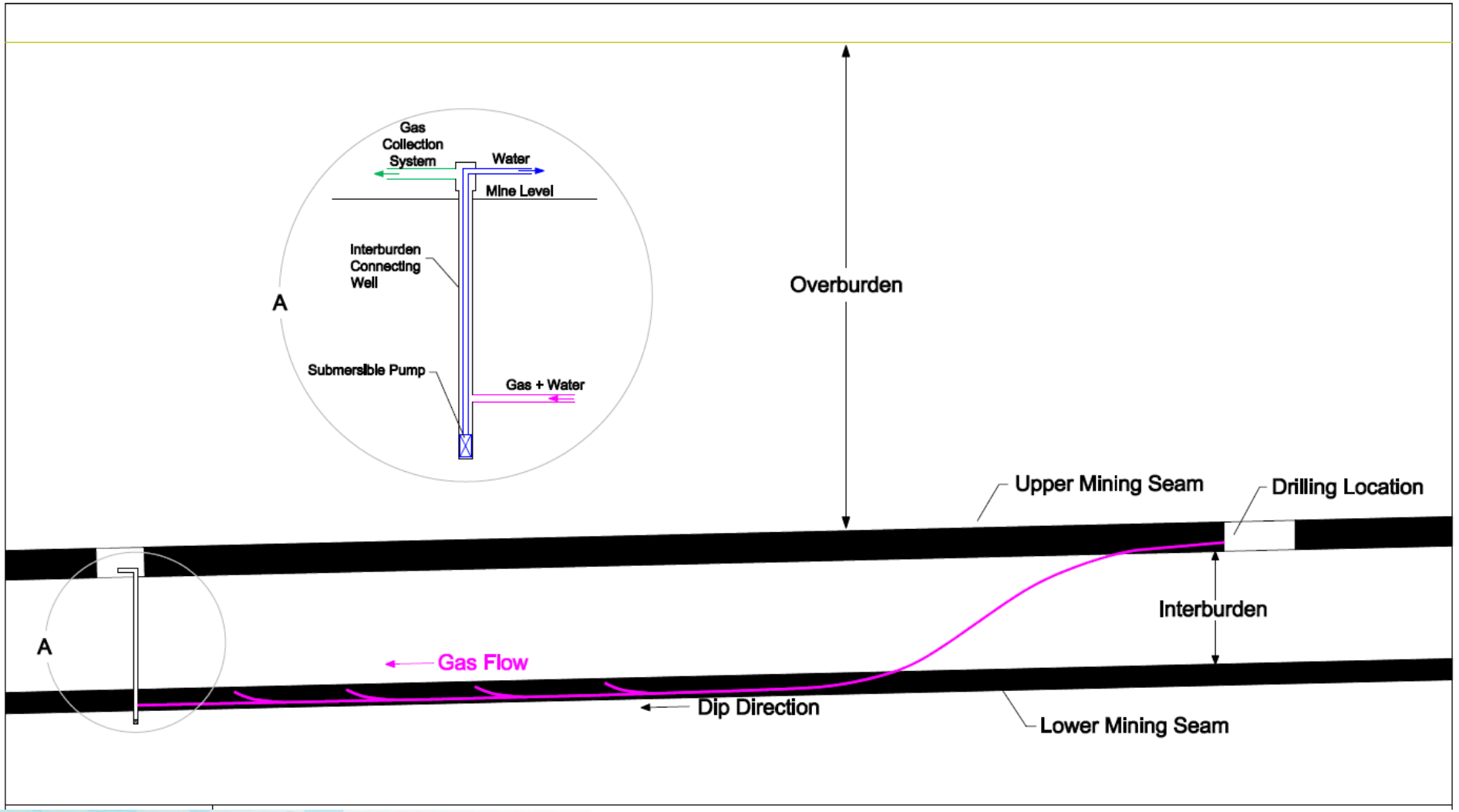
Directional Drilling Solutions

- **Connecting Vertical Wells with In-Seam Boreholes to Reduce GC of Underlying Coals**



- Reduce gas contents of underlying mineable coals from current mining level
- Intercept inter-burden wells to recover water and gas from the horizontal in-seam boreholes
- Provides for significant drainage time
- Maintain all gas collection infrastructure on the current mining level

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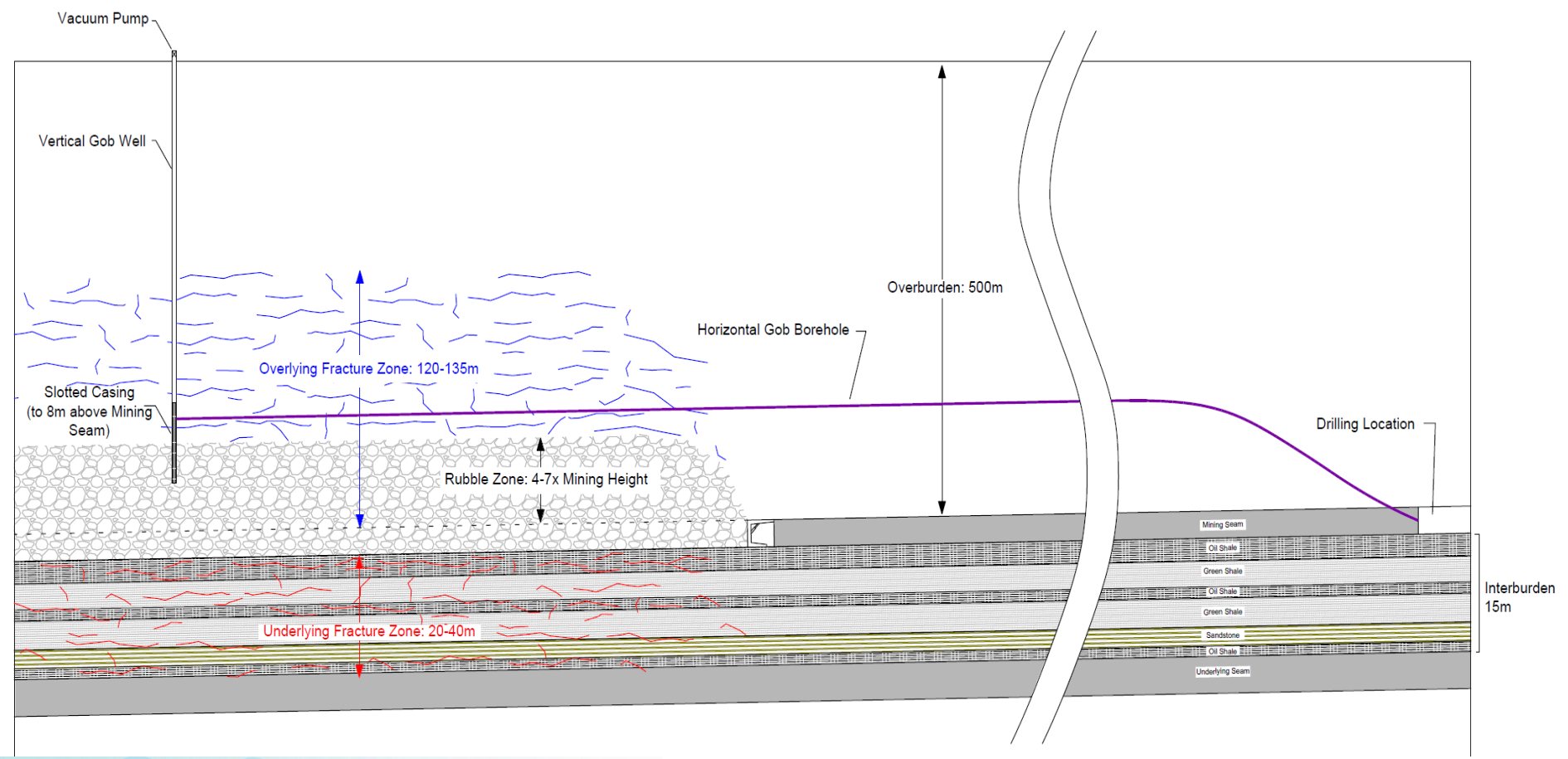
Directional Drilling Solutions

- **Coupling Systems for Gob Gas Drainage**



- Intercepting surface drilled vertical gob wells with horizontal gob boreholes developed from underground
- Improves the performance of vertical gob wells
- Extends the productive life of vertical gob wells
- Reduces vertical gob well spacing
- Improves gob gas effectiveness at start and end of panels
- Gas collection and vacuum on surface

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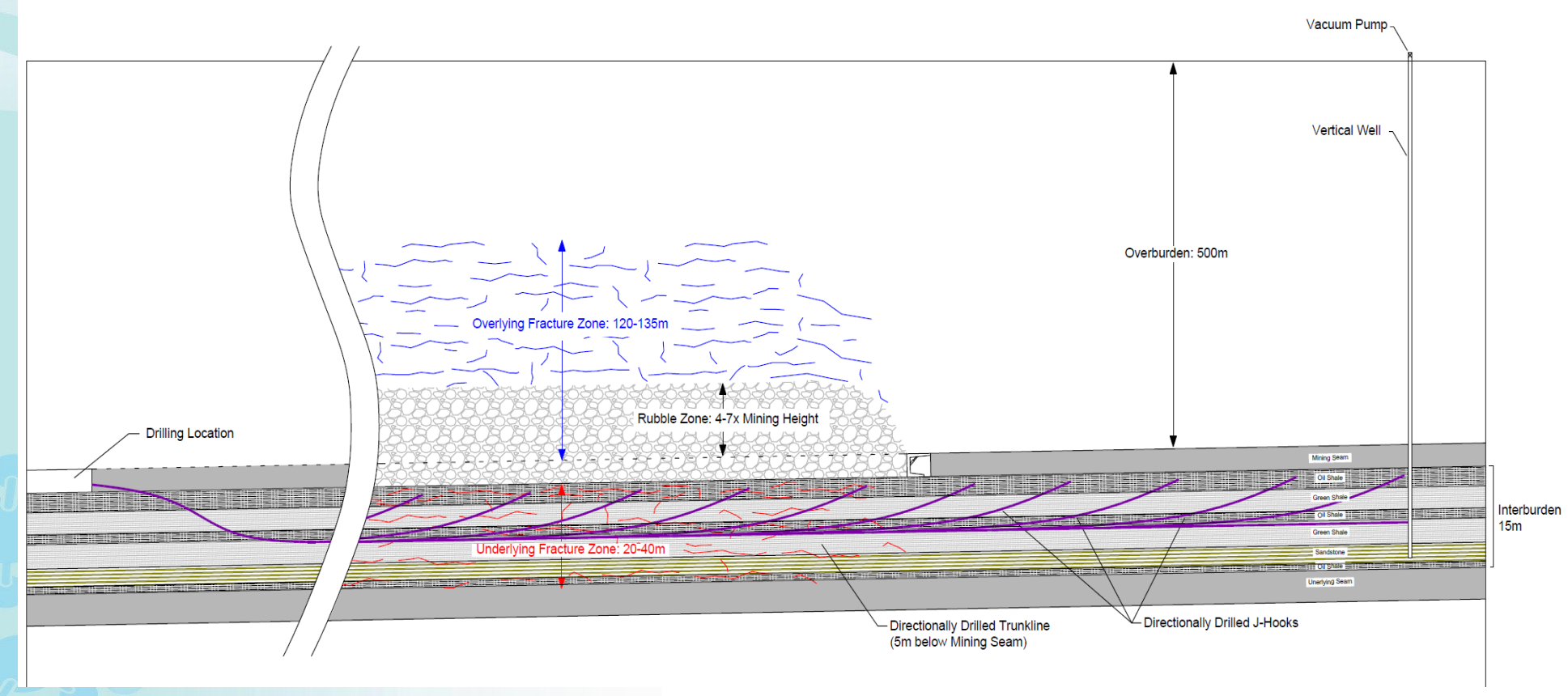
Directional Drilling Solutions

- **Coupling Systems of Gob Gas Drainage to Control Floor Gas**



- **Intercepting vertical wells with underlying horizontal gob boreholes**
- **Gob gas production from surface with vacuum**
- **Controls floor gas emissions along the longwall face during mining**
- **Vertical well can be completed as an overlying gob well to operate after undermining**

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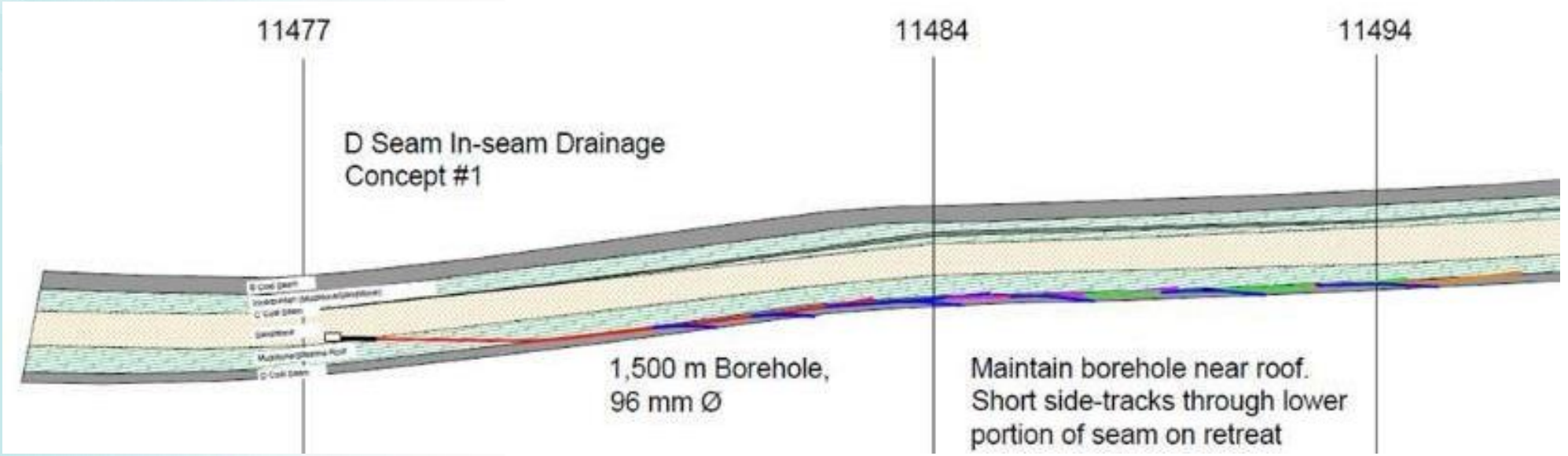
Directional Drilling Solutions

- **Using LWD to Reduce GC in Coals with Vertical Permeability Barriers and Friable Layers**



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

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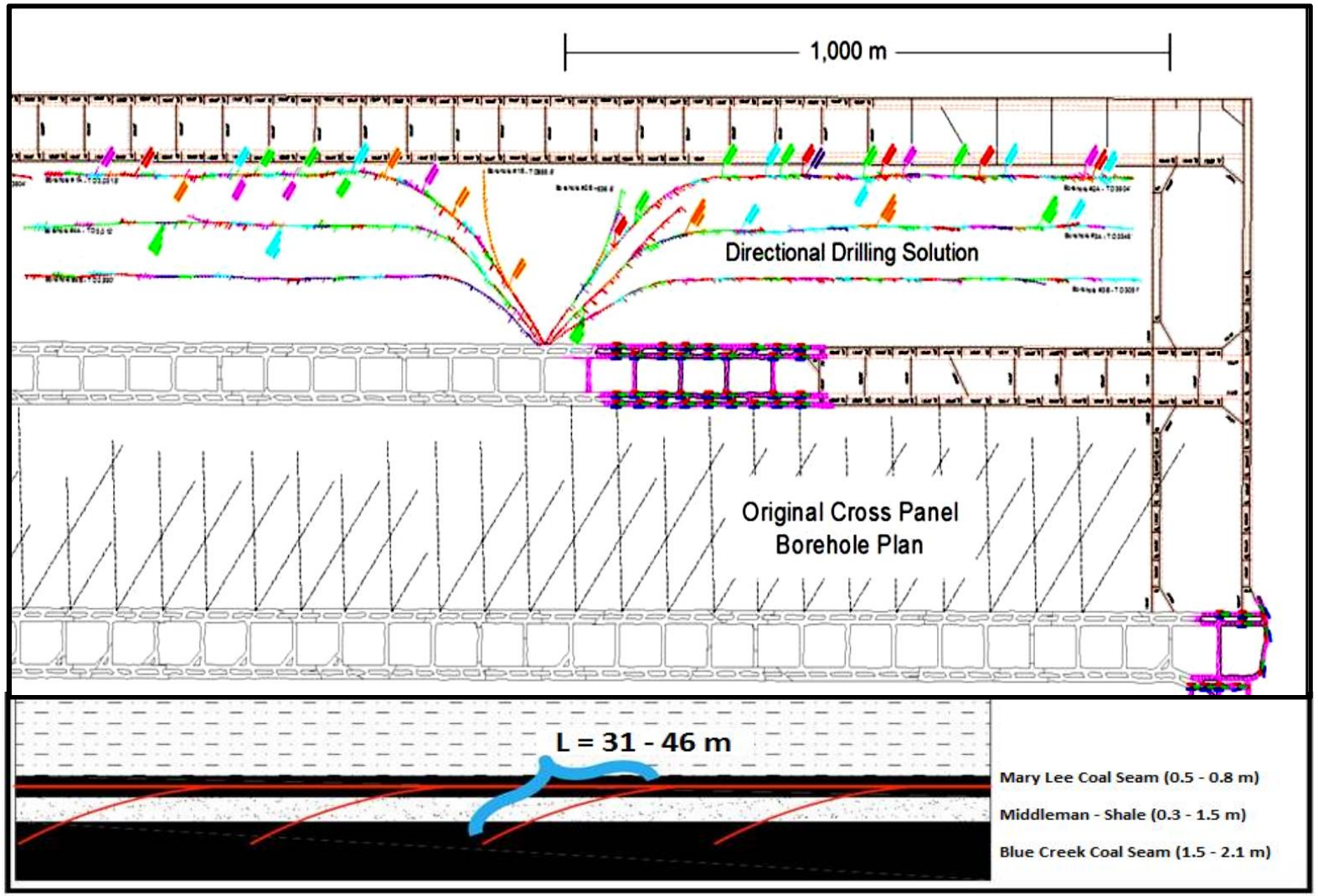
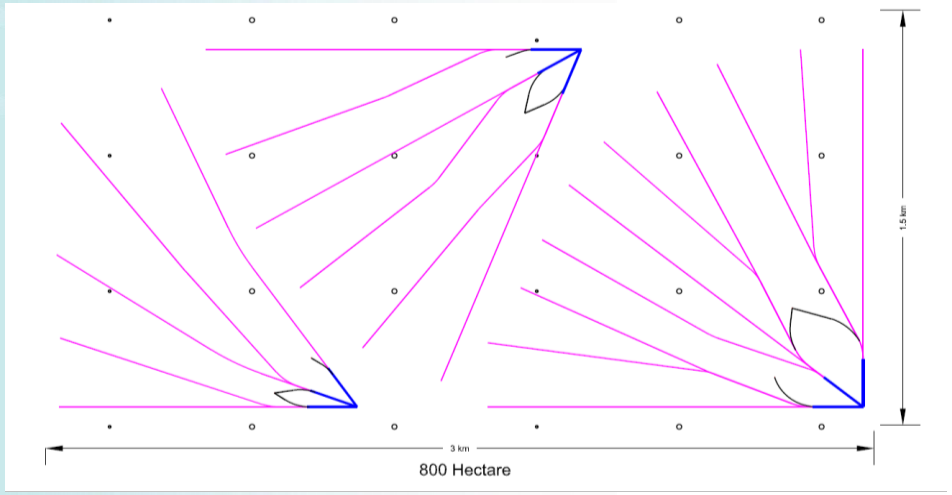
Directional Drilling Solutions

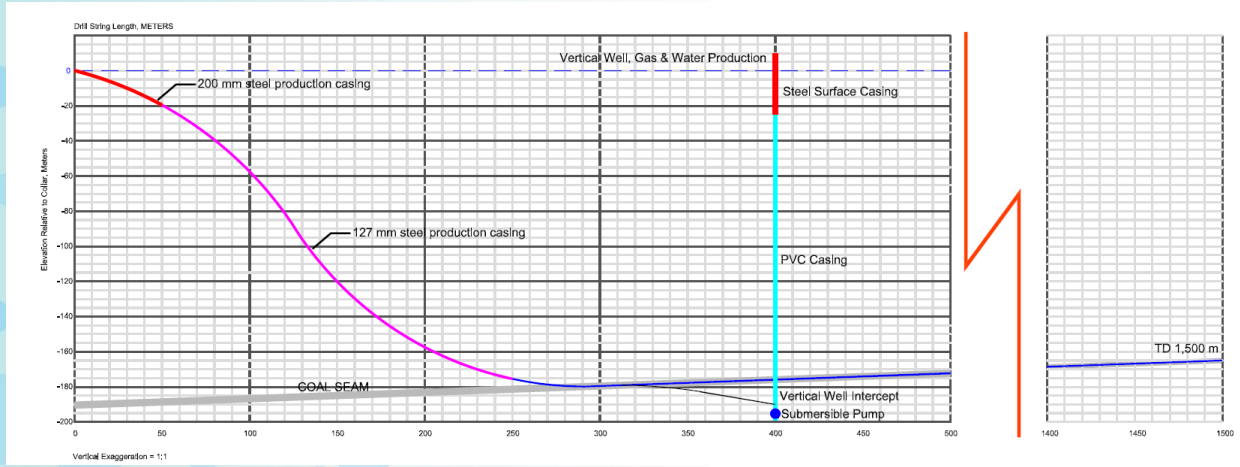
- **Using LWD to Navigate in Adjacent Seams to Access Friable Coals for Pre-Mine Drainage**



Directional Drilling Solutions

- **Using a Mine Appropriate SIS Approach**
  - **Early Vertical Well Intercept Approach**

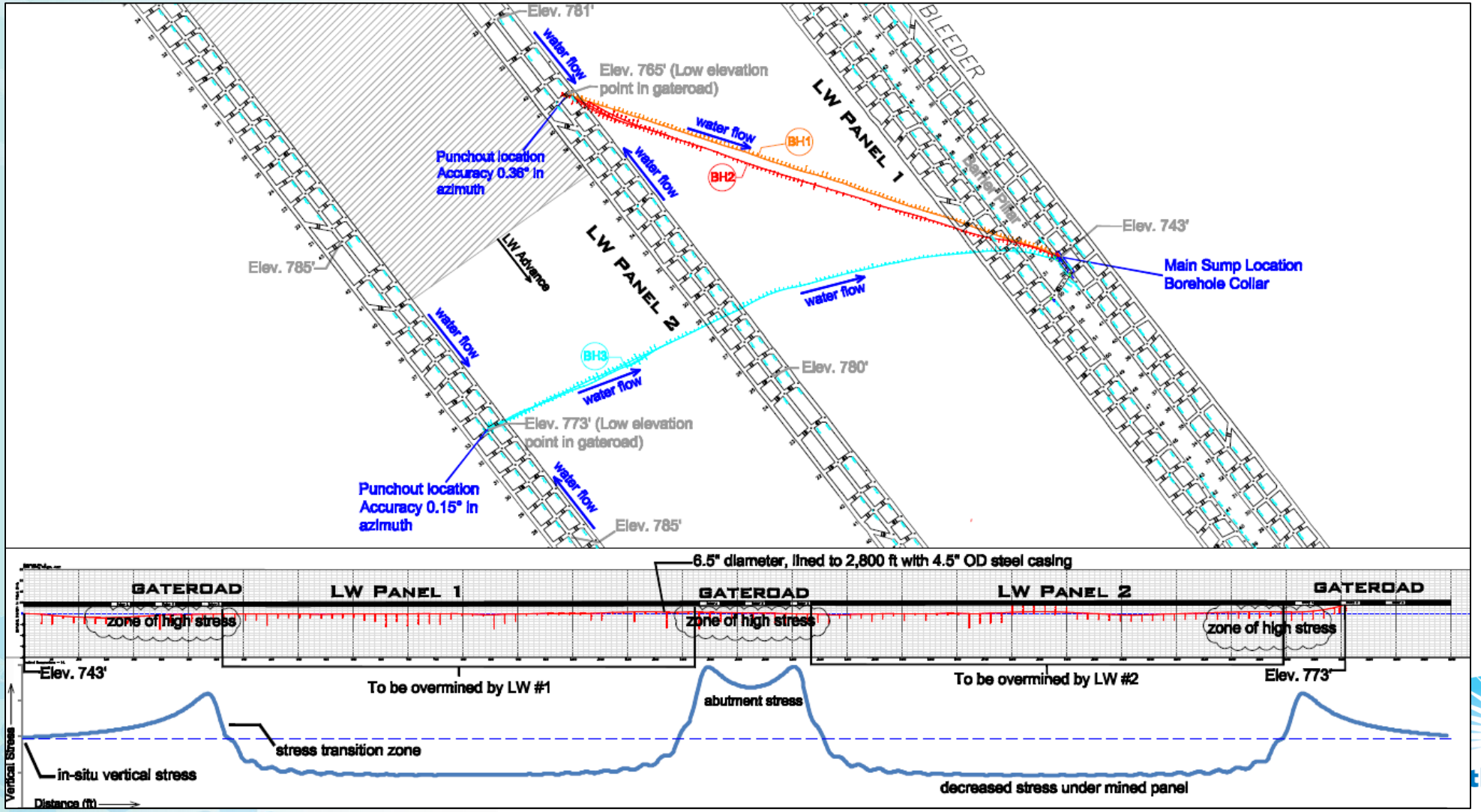




- **Rapid Surface Casing Installation**

Directional Drilling Solutions

- Ultra-Long Water Transfer Boreholes in Underlying Rock



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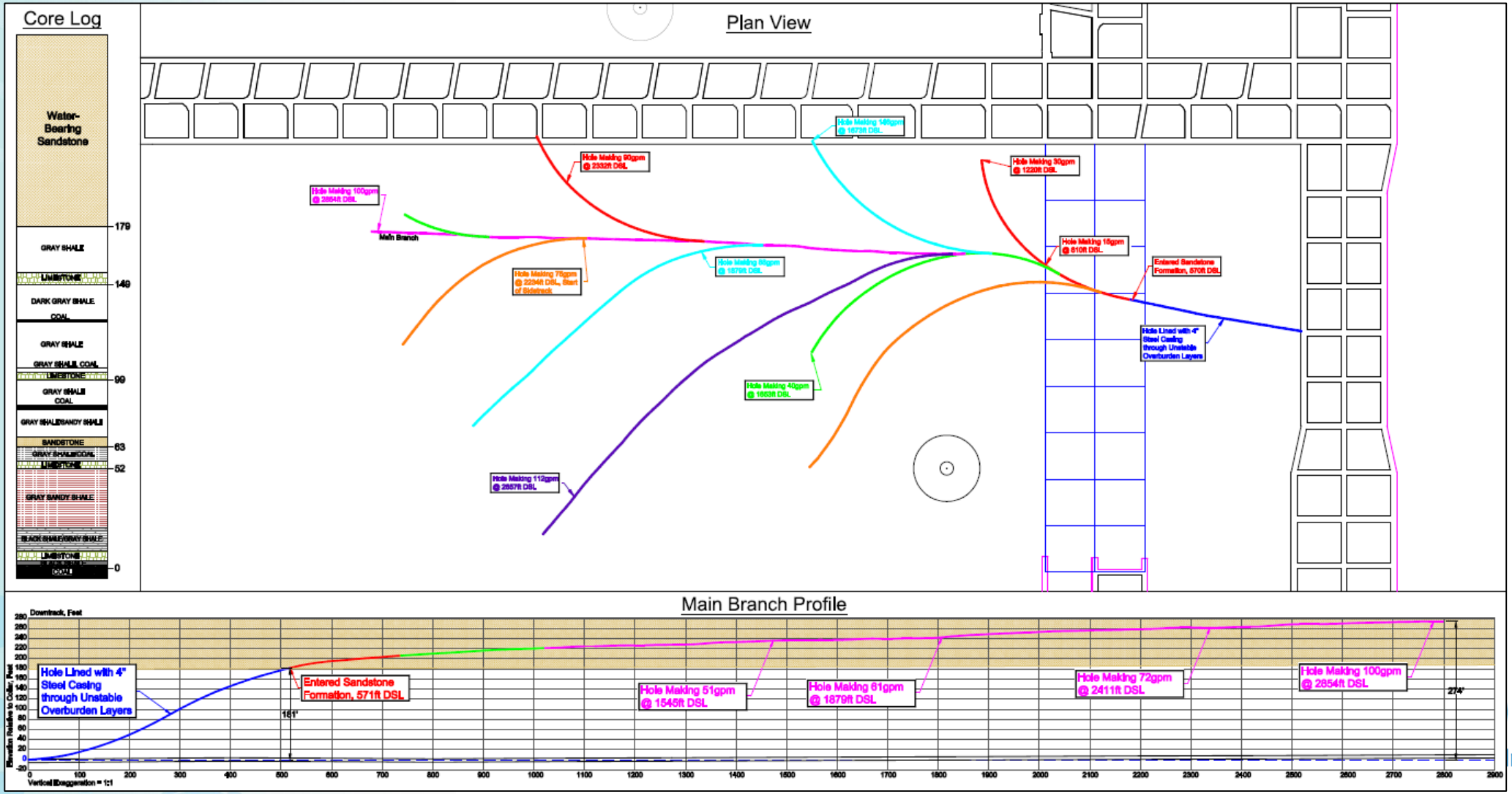
Directional Drilling Solutions

- Reduce Water Saturation in Overlying Sands



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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 for gob gas and pre-mining solutions..**
- **Geo-Steering technology provides the ability to maintain boreholes in-seam or in adjacent seams or strata, or specific coal layers, and characterize geological anomalies in advance of mining such as faults, sandstone intrusions, dikes and sills, and burnt coal (Jhama).**
- **Directional drilling solutions involving complementing, combining, and coupling surface and underground methane drainage systems, and connecting in-mine directionally drilled boreholes with vertical wells provide unique pre-mining and gob gas drainage solutions.**