Conducting CMM Project Pre-Feasibility Studies

Training by the U.S. EPA in Support of the Global Methane Initiative (GMI)

Global Methane Initiative

Welcome

The United States Environmental Protection Agency (EPA) developed this course in support of the GMI and in conjunction with the United Nations Economic Commission for Europe (UNECE). What is the GMI?

This course introduces principles for assessing the potential of developing projects to capture and/or use Coal Mine Methane (CMM). The general approach described in the course should be underpinned by mine-specific data and analyses, allowing the principles to be tailored to the unique conditions at each mine. Ideally, such an assessment will lead to project development and implementation.

What Is the Global Methane Initiative?

Global Methane Initiative

The Global Methane Initiative (GMI) is a voluntary, multilateral partnership that aims to reduce methane emissions and to advance the abatement, recovery, and use of methane as a clean energy source.

GMI Partner Countries

GMI Partner Countries account for nearly 70% of total global manmade methane emissions, which is equivalent to approximately 5,000 $MMTCO_2e$.

Conducting CMM Project Pre-Feasibility Studies: Course Modules

Module 1: Introduction and Objectives

Module 2: Mine Background Information and Evaluation

Module 3: Resource Assessment

Module 4: Forecasting Methane Production from Gas Drainage Systems

Module 5: Improvements to Gas Drainage

Module 6: Quantifying the Benefits of Improvements to Methane Drainage Systems

Module 7: Market, Risk, and Financial Analyses

Module 8: Case Study – Liulong Mine, China

Module 5

Improvements to Gas Drainage

What You Will Learn

In this module, you will learn about:

- What makes an effective gas drainage system.
- How to calculate gas drainage efficiency.
- Benefits of improving the effectiveness of gas drainage systems.
- Methods to improve gas drainage efficiency.

This module builds on what you learned about gas drainage in *Module 2: Mine Background Information and Evaluation* and *Module 3: Resource Assessment*.

Time needed to complete this module:

Approximately 60 minutes

Overview of Mine Gas Drainage

Mine gas drainage refers to the capture and transport of gas, principally methane, through a system of pre-mine and post-mine boreholes or drainage methods, followed by the collection and movement of that gas through a pipeline network to the surface.

Mine gas drainage systems are developed to prevent methane from entering mine workings.

This mine gas can be diluted to safe levels by the mine's ventilation system.

Mine Gas Drainage System Design

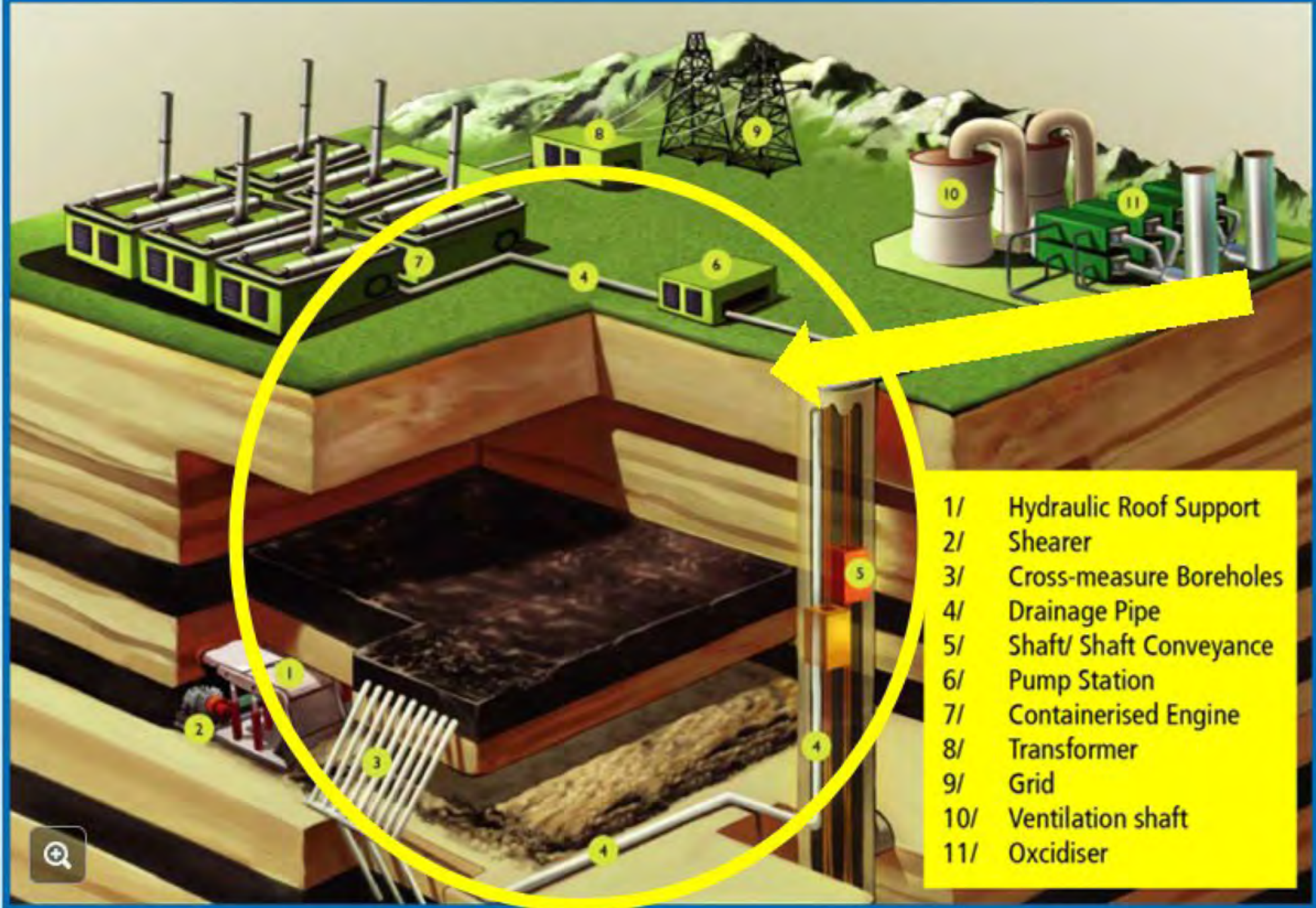
Gas drainage systems are deployed at some, but not all, mines to maintain safe methane concentrations in the mine workings.

The design of gas drainage systems deployed (see Module 2: Gas Drainage Current Practices: Boreholes) depends on the type of mining (longwall vs. room and pillar) and geologic conditions.

Gas drainage systems can differ widely in design depending on the properties of the mine and other factors.

Systems can be as small as one well, or they can be a complex network of multiple boreholes, gathering systems, and pumps.

Components of a Gas Drainage System

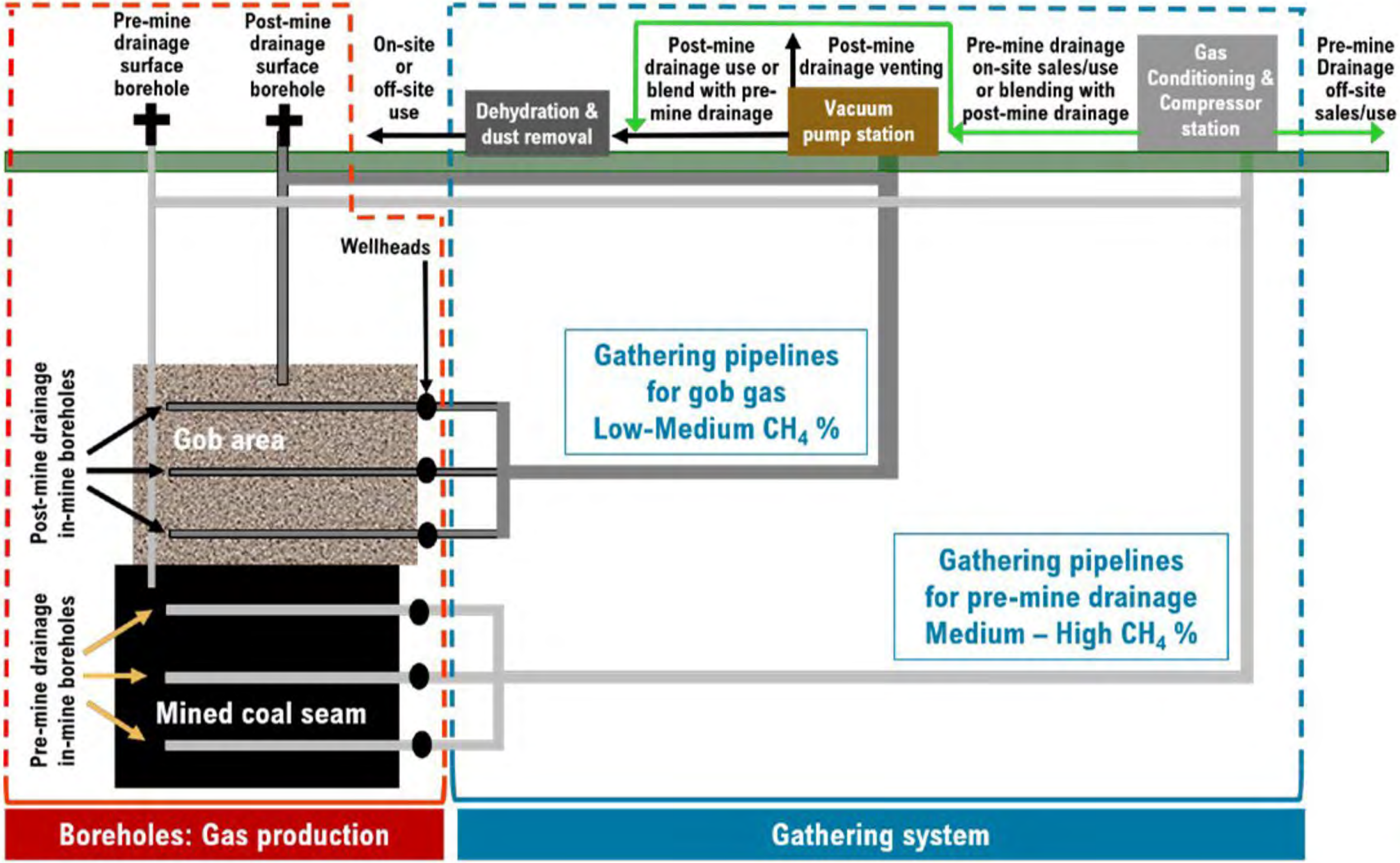


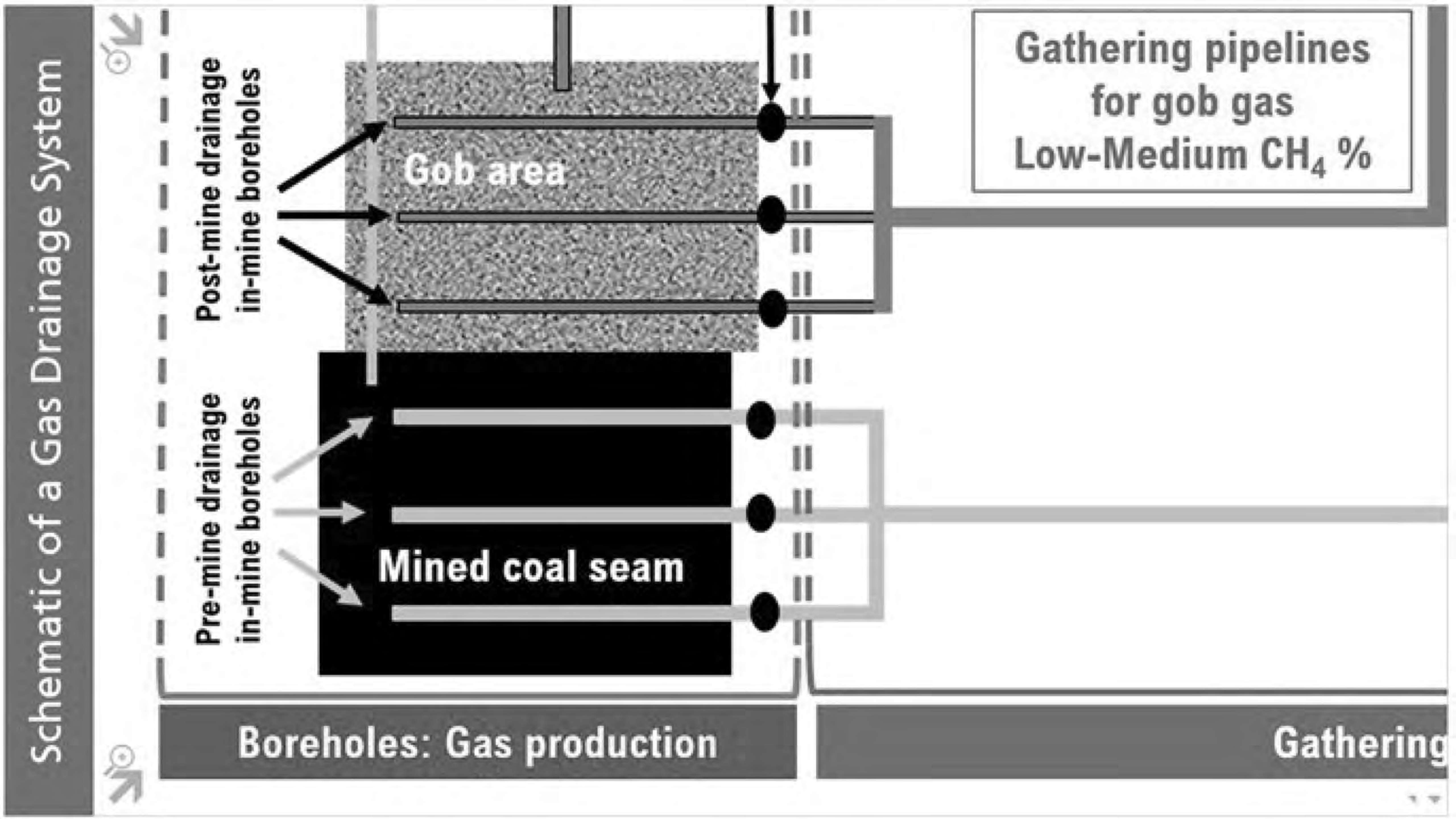
Components of a gas drainage system include:

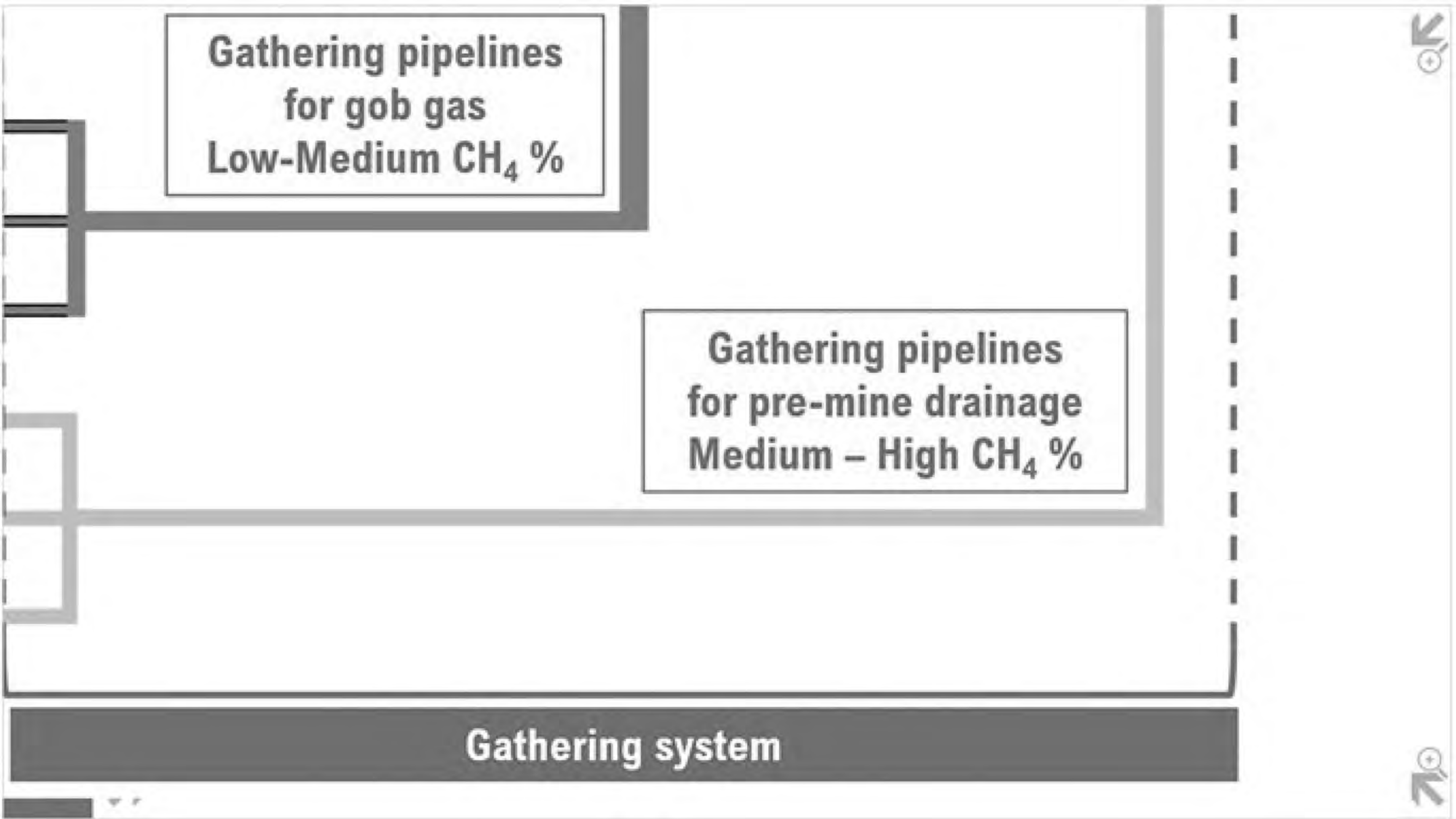
- Boreholes
- Gas pipeline to the surface
- Surface pump station

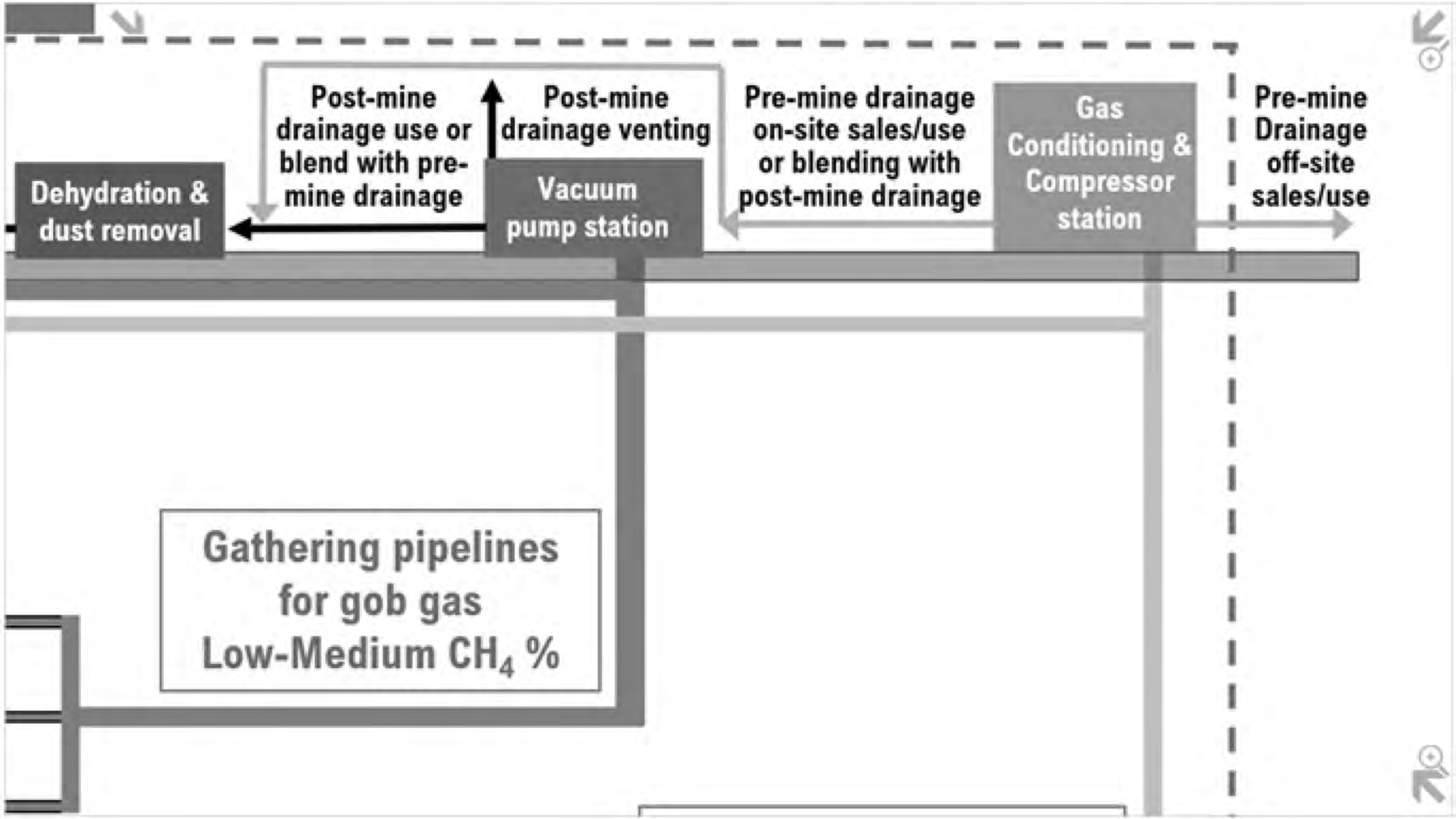
Source: *Best Practice Guidance for Effective Drainage & Use in Coal Mines.* UNECE (2016)

Schematic of a Gas Drainage System

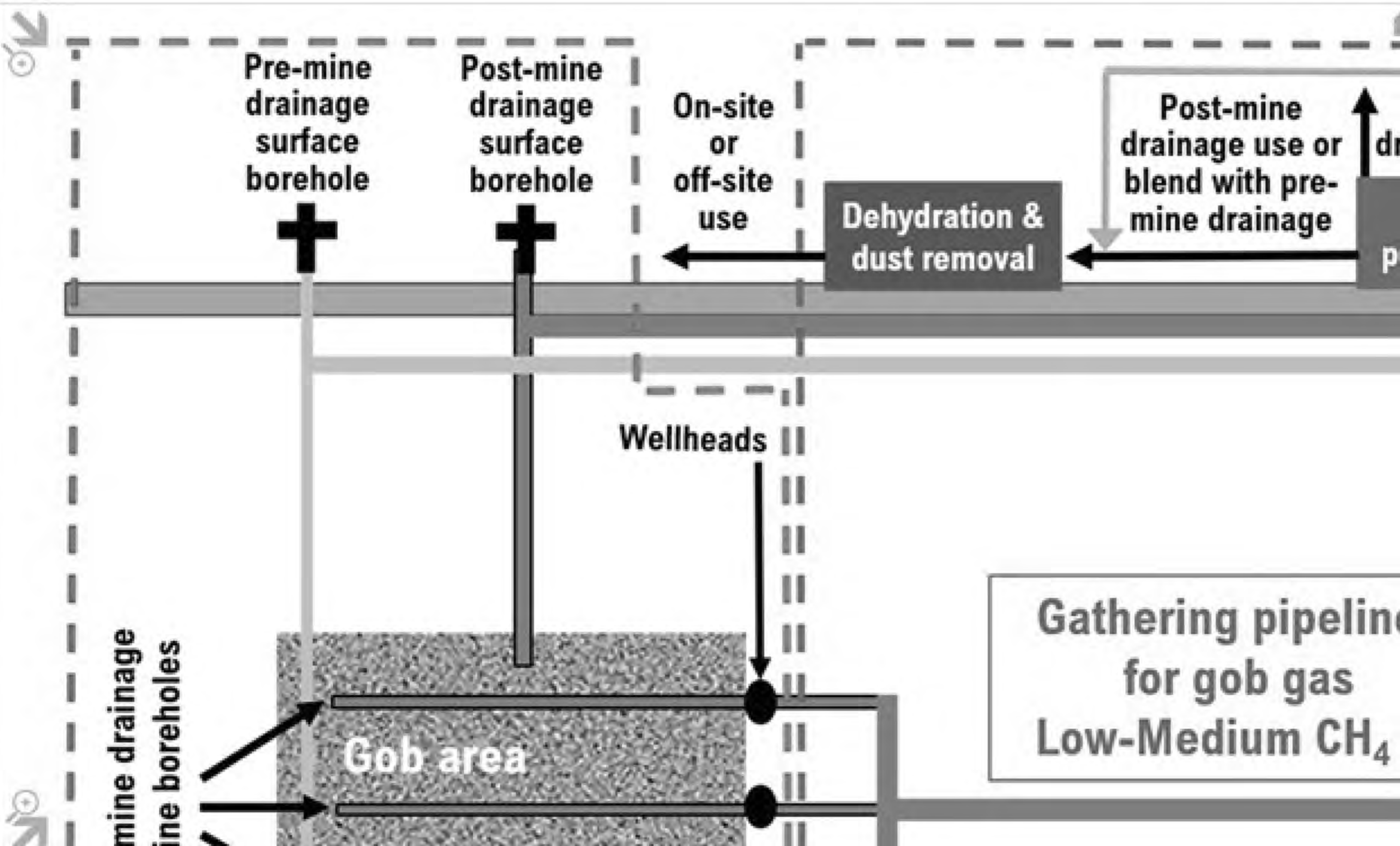



Schematic of a Gas Drainage System
Gathering pipelines
for gob gas
Low-Medium CH_4 %
Post-mine drainage
in-mine boreholes
Gob area
Pre-mine drainage
in-mine boreholes
Mined coal seam
Boreholes: Gas production
Gathering


Gathering pipelines for gob gas Low-Medium CH_4 %
Gathering pipelines for pre-mine drainage Medium – High CH_4 %
Gathering system


Post-mine drainage use or blend with pre-mine drainage
Post-mine drainage venting
Pre-mine drainage on-site sales/use or blending with post-mine drainage
Gas Conditioning & Compressor station
Pre-mine Drainage off-site sales/use
Dehydration & dust removal
Vacuum pump station
Gathering pipelines for gob gas Low-Medium CH_4 %

Schematic of a Gas Drainage System



What is an Effective Gas Drainage System?

Gas drainage systems are considered to be effective if they produce a significant amount of methane with high gas recovery efficiencies and low air ingress into the drainage system:

- **Primary**: Produce and transport enough gas to ensure that methane concentrations in the ventilation air do not exceed regulatory standards.
- **Secondary**: Maximize gas drainage to achieve enhanced safety, environmental mitigation, and energy recovery.

Methane Reduction Targets for an Effective Drainage System

The design of an effective gas drainage system should deliver the following methane emission reductions:

- 50-80% of gas emissions from a longwall district and 50% of total mine gas emissions
- ≥ 30% methane concentration by volume for post-mine drainage techniques
- ≥ 60% methane concentration by volume for pre-mine drainage methods

Calculating Gas Drainage Efficiency

To measure effectiveness of a gas drainage system, mine operators calculate gas drainage efficiency. During the mine evaluation stage of a pre-feasibility study, the CMM project developer should assess the efficiency of their proposed drainage system improvements.

Proposed improvements of the gas drainage efficiency should increase gas quantity and quality. Gas drainage efficiency is defined as the gas flow produced by the gas drainage system from a location, divided by the total gas produced from that location.

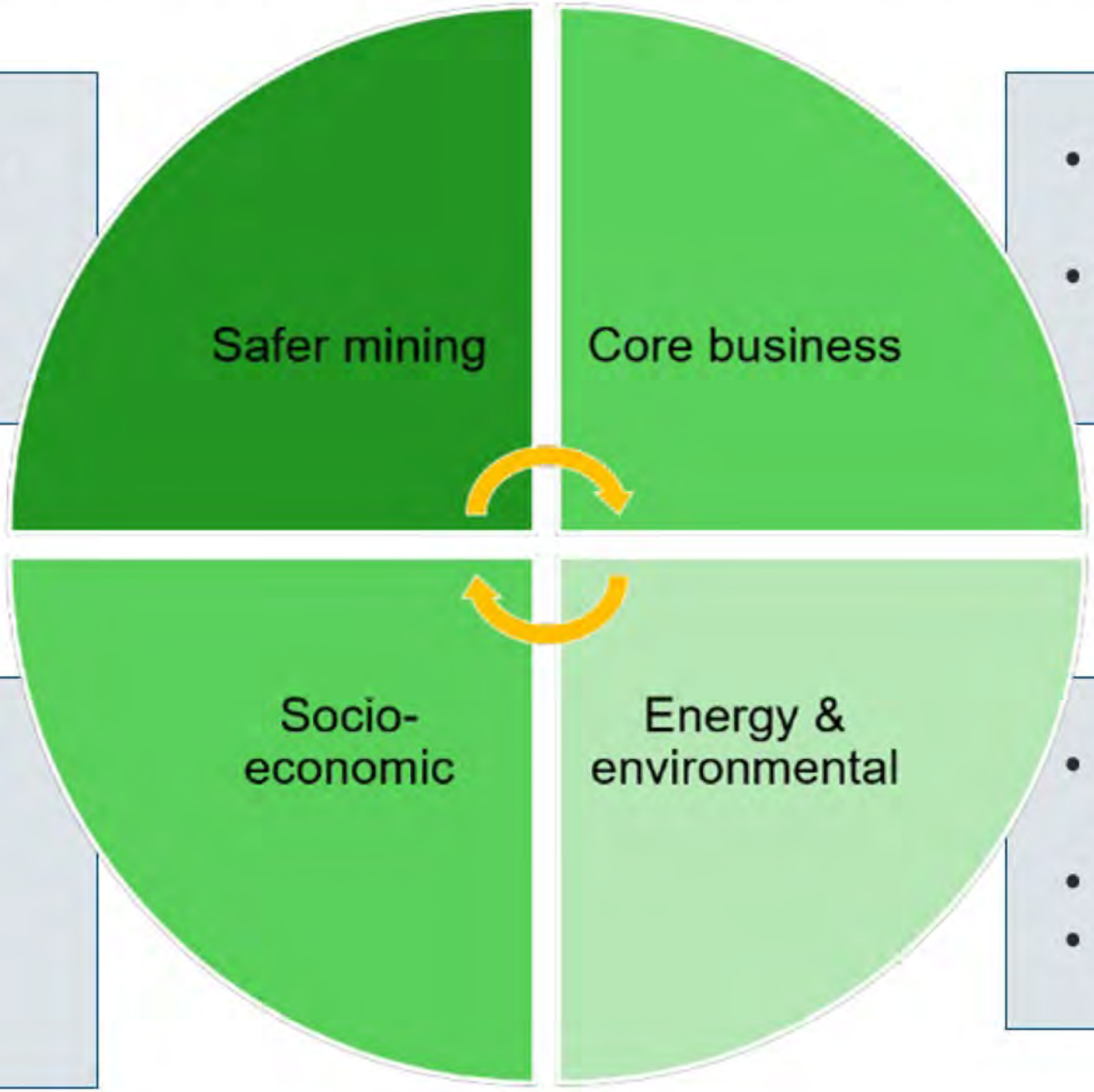
Drainage Efficiency (%) Calculation:

$$\frac{\text{Volume of } CH_4 \text{ drained } (m^3)}{\text{Volume of } CH_4 \text{ in ventilation } (m^3) + \text{Volume of } CH_4 \text{ drained } (m^3)}$$

Benefits of Improving Mine Gas Drainage

- CH_4 concentration ≥ 30%
- Reduces explosion risks, protecting mine staff and infrastructure

- Fewer coal production shutdowns or slowdowns
- Maintain or increase production capacity



- Skilled job training and creation
- Direct and indirect cost savings for the mine

- Safe utilization of otherwise wasted gas resources
- Energy recovery
- GHG emission reductions

Opportunities to Improve Gas Drainage in a Pre-feasibility Study

In a pre-feasibility study, potential improvements to gas drainage are based on the analysis of available data and a site visit, focusing on the greatest potential impact at a high level. A pre-feasibility study is not intended to present an assessment of all options. A more detailed and comprehensive review is typically undertaken for the full feasibility study.

There are four areas where a mine operator can look for improvements to increase gas drainage at the lowest possible costs:

- Optimize gas production
- Improve recovered gas quality
- Optimize drainage system efficiency
- Minimize costs of gas production

These areas are further described on the next few slides.

How to Increase Gas Drainage at Lowest Cost

Optimize gas production

Improve recovered gas quality

Optimize drainage system efficiency

Minimize costs of gas production

- Ensure underground gas collection systems are maintained and free of water and solids accumulations.
- Ensure the system is designed to accommodate maximum expected produced gas volume (methane + air).
- Balance ventilation air with gas drainage volumes to meet methane concentration targets while effectively managing ventilation and drainage costs.

How to Increase Gas Drainage at Lowest Costs

- Optimize gas production
- **Improve recovered gas quality**
- Optimize drainage system efficiency
- Minimize costs of gas production

➢ Improve borehole standpipe installation to achieve improved seal to minimize air intrusion, particularly when operated under vacuum.

➢ Regulate gas production based on gas quality at system, district, and borehole level, if possible.

➢ Regulate vacuum pressure based on gas quality at system, district, and borehole level, if feasible, to prevent dilution of post-mine drainage methane concentration.

How to Increase Gas Drainage at Lowest Costs

- Optimize gas production
- Improve recovered gas quality
- **Optimize drainage system efficiency**
- Minimize costs of gas production

➢ Optimize the number and type of boreholes/galleries based on gas drainage experience and projections of the gas resource:

- pre-mine/post-mine
- in-mine/surface
- directionally drilled, laterally drilled, vertically drilled boreholes
- underlying/overlying galleries

➢ Ensure effective location and installation of boreholes and galleries in relation to longwall panels, longwall face, longwall district, development areas, gate roads and mains to maximize gas recovery by building on degasification experience.

How to Increase Gas Drainage at Lowest Costs

- Optimize gas production
- Improve recovered gas quality
- Optimize drainage system efficiency
- **Minimize costs of gas production**

➢ Minimize the number of boreholes and cumulative length sufficient to meet gas production targets.

➢ Adapt the most effective combination of drilling and completion techniques for coal and rock strata.

➢ Develop reasonable cost estimates for drilling and completion services (contracted vs. managed in-house).

➢ Manage system pressures based on recovered gas quality.

Overview of Methods to Improve Gas Drainage System Efficiency

Improving the efficiency of a gas drainage system will directly affect the quality and quantity of gas that is recovered. Gas drainage system efficiency can be improved through:

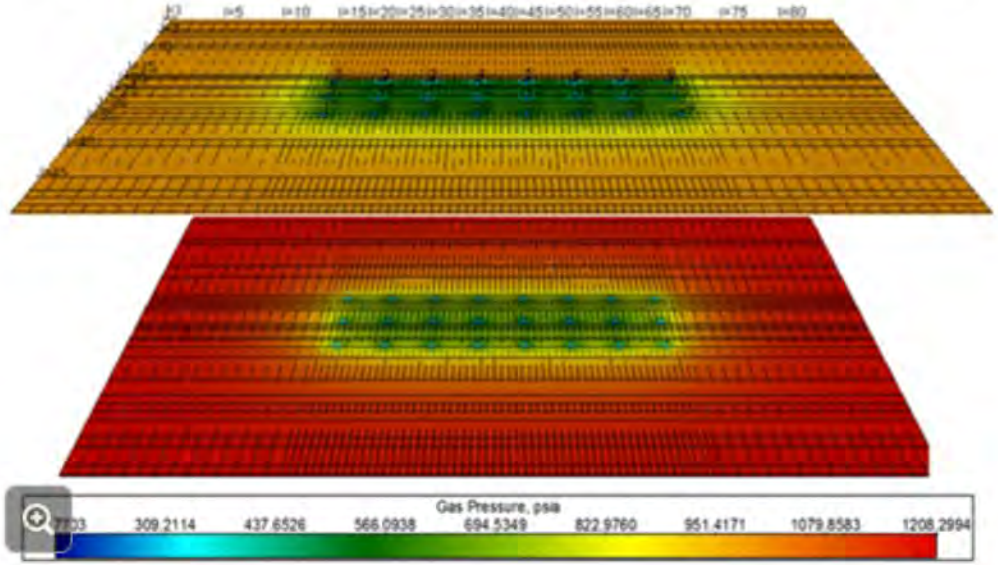
1. Pre-mine drainage: Drilling in-seam boreholes in advance of mining.
2. Post-mine drainage: Drilling boreholes (vertical gob wells, cross-measure, directional horizontal gob boreholes, or gob drainage galleries) in advance of mining so that they are in place prior to under-mining but producing gas during and after the seam is being mined.
3. Optimizing the gas collection system to capture the gas drained from pre- and post-mine boreholes.

Methods to Improve Gas Drainage System Efficiency: Assessment Tools

Regardless of the method chosen to optimize gas drainage, the project developer will need to forecast gas drainage system improvements through one of the methods described in Module 4: probabilistic methods, analytical methods, or reservoir simulation.

Reservoir simulation is an important tool in optimizing drainage efficiency. Simulations can help predict gas flow from different borehole placements, spacings, length, and diameters.

To improve confidence in the forecasting of gas drainage improvements, the project developer can correlate (history match) predicted gas production using known inputs in a reservoir simulator (see Module 4) against historic gas production as a function of time.



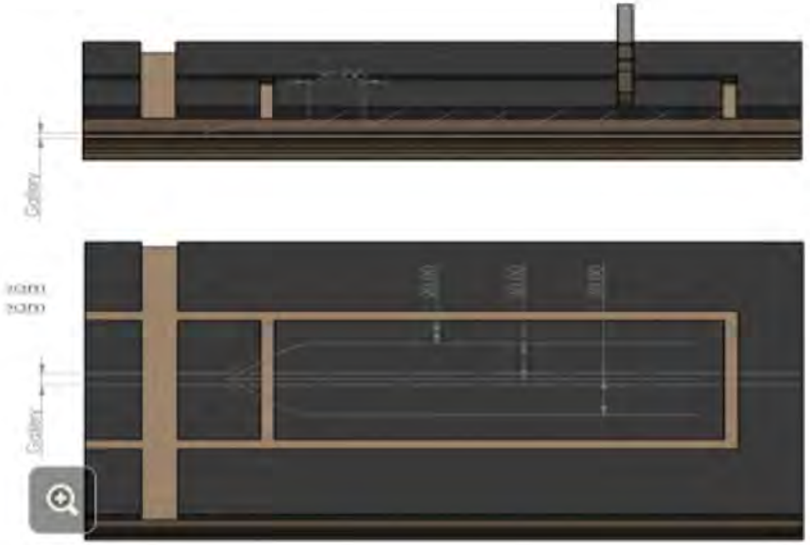
Improving Pre-mine Drainage

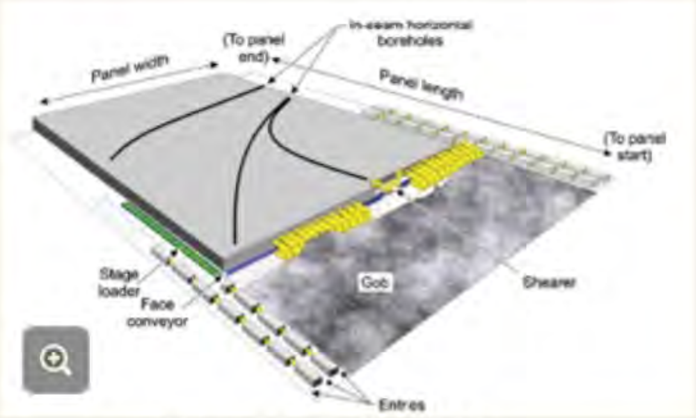
Improving Pre-Mine Gas Drainage: Planning and Designing Boreholes

Pre-mine improvements can include surface or in-mine vertical, horizontal, or directionally drilled wells.

Directionally drilled wells are becoming more common as a standard good practice, because they can:

- Enable longer reach.
- Initiate drainage with less development.
- Provide for more drainage time.





Karacan, C. Ö. 2009

The optimal solution depends on many factors:

- Legal access to extract gas from the surface or underground
- Availability of in-country or regional drilling infrastructure
- Geologic, geomechanical, stress, and mining conditions
- Regulations
- Budget
- Regional culture and common practice

Improving Pre-Mine Gas Drainage: Design Considerations for Boreholes

Geologic/ Geomechanical

- Coal seam friability
- Igneous intrusions
- *In-situ* and mining induced stresses

Reservoir

- Gas content
- Diffusion time constant
- Adsorption/gas saturation
- Permeability
- Reservoir pressure, water saturation

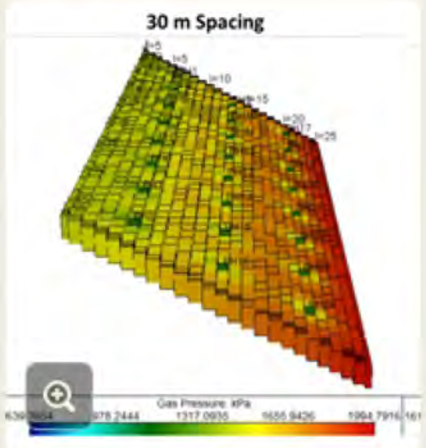
Model Simulation Outputs

- Borehole spacing vs. drainage
- Gas production projection

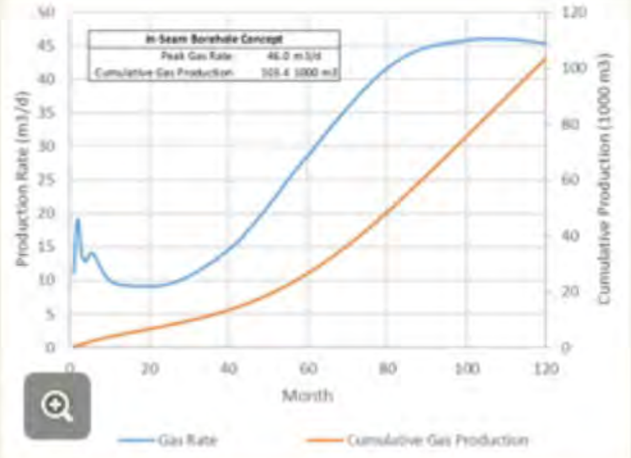
Mining

- Ensure mine operator and gas producer objectives align

Example output of *in-situ* gas content reduction using in-seam pre-mine drainage boreholes

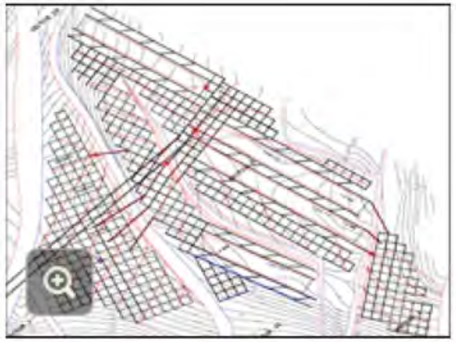


Example of gas production simulation results



Improving Pre-Mine Gas Drainage: Developing Improvement Plans

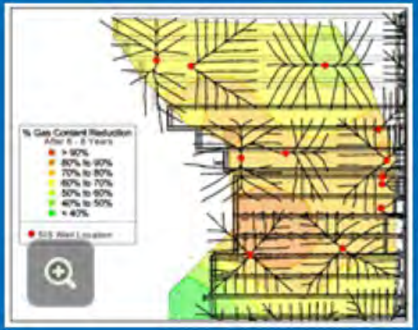
Based on the initial reservoir simulation, an initial borehole design is made and a single longwall panel is modeled. After optimizing the design for the single panel, this design is then applied to the remaining longwall districts adjusting for differences in depths/gas contents, panel widths, etc.



Project developers should prepare a design and installation schedule for the improvements, and specify the length and spacing of the boreholes, pipeline requirements, etc., to allow for preparation of cost estimates.

Considerations for Future Implementation Plans

- ✓ Align with mine layout and production plan
- ✓ Define borehole layout
- ✓ Establish implementation schedule
- ✓ Project CMM production through life of the gob boreholes/wells



Improving Gas Drainage at Different Stages: Pre-mine and Post-mine

Although pre-mine methods can be very effective at producing gas with a high methane content while also reducing the *in-situ* gas content of the mined seam, they may not always be the most effective gas drainage method.

In many of the world's coal basins, the low permeability of the coal seams (<0.1 millidarcy (mD)) and geologic characteristics of the seams (for example, soft coals and faulting) are not conducive to pre-mining techniques.

As shallow reserves are mined out and mining moves to deeper seams with complex geology and lower permeability, post-mine drainage may be necessary to remove gas from the workings.

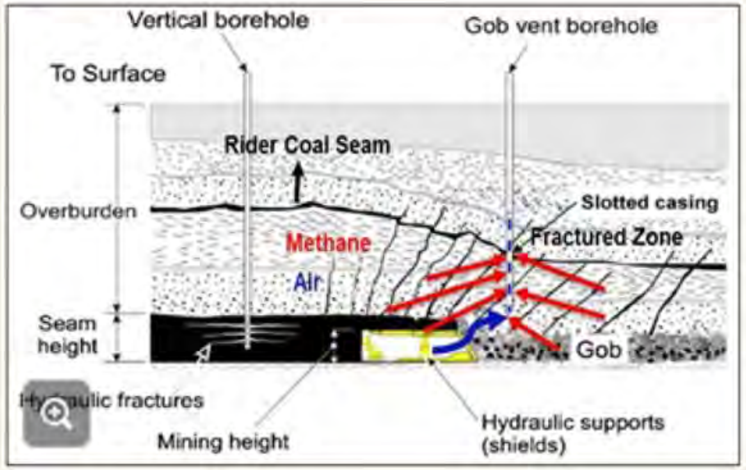
Post-Mine Drainage Methods

Overview of Post-Mine Drainage Methods

Gob (goaf) refers to the fractured, permeable ground above where coal has been extracted by longwall mining and the roof has collapsed.

Where there are one or more coal seams above or below the worked seam, emissions from these seams can contribute to methane emissions into the workings, even potentially exceeding emissions from the mined seam.

Post-mine drainage methods involve intercepting methane released into the gob area before it can enter a mine airway.



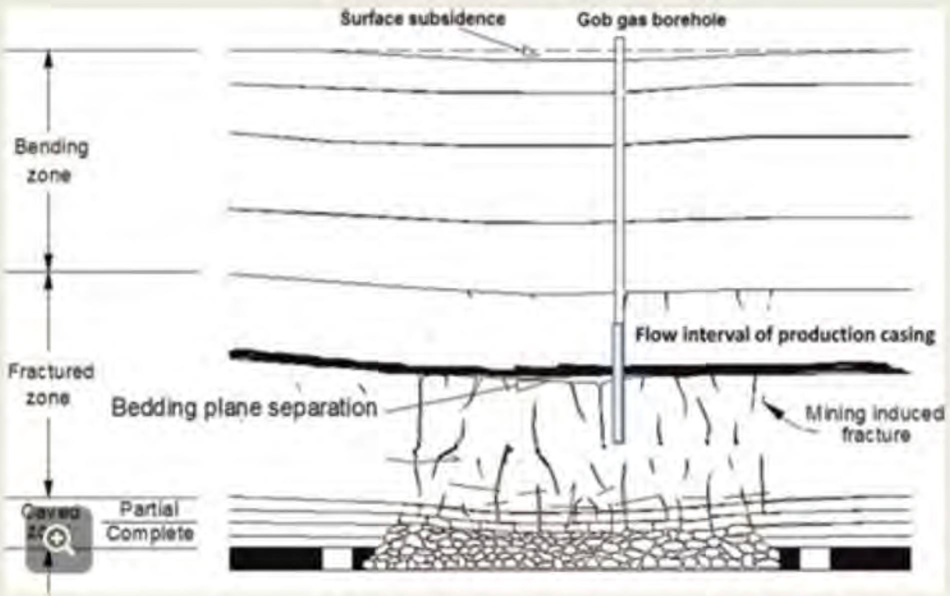
Gob gas can be extracted through vertical gob wells at the surface, cross-measure boreholes drilled at an angle above or below the working seam, through overlying or underlying horizontal gob boreholes applied from underground or the surface, or through gob gas drainage galleries. These techniques are successful when operated under vacuum.

Understanding Gob Gas Drainage Geomechanics

Understanding all of the geomechanical characteristics is not necessary for a pre-feasibility study, but, if they are available, they can inform a skilled engineer when evaluating and designing improvements to post-mine drainage systems.

Depending on the gob gas drainage method, historical gob gas flow and methane concentrations are often sufficient to estimate gob gas emissions in future areas with proposed improvements to drainage for a pre-feasibility study.

However, these characteristics, and the impact of changes to these characteristics, should be evaluated for a full-feasibility study and detailed system design.

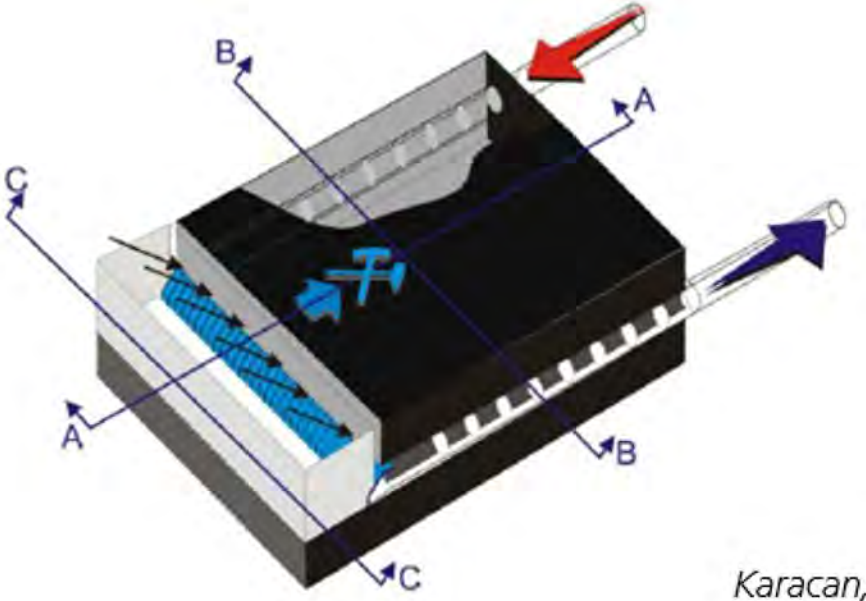


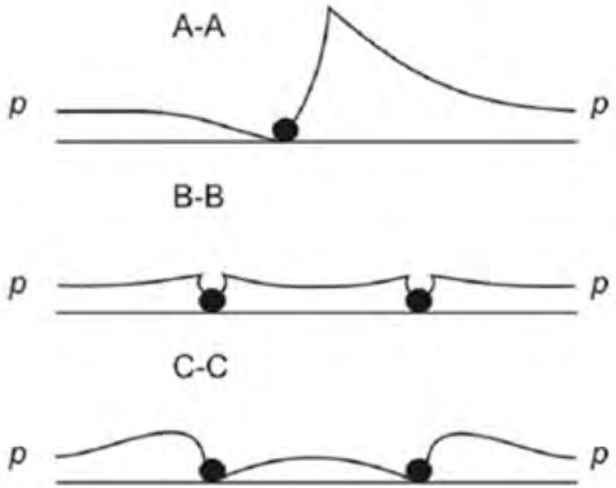
Optimizing emission control and gas production from gob gas boreholes requires an understanding of the geomechanical characteristics of the surrounding strata and how this strata is affected by mining.

Understanding Gob Zone Characteristics for Modeling Improvements

The gob zone in a mined out seam includes critical vs. sub-critical panel width, stress re-distribution, cave height, cave characteristics, and zones where strata is under tension or re-compaction. These parameters are needed for inputs for modeling post-mine drainage improvements.

Location of Gob Gas Venthole to Control Strata Gas





Karacan, C. Ö. 1997

Improving Post-Mine Gas Drainage: Optimizing Gob Gas Drainage

Available Technologies

- Gob gas drainage galleries
- Cross-measure boreholes
- Vertical gob wells

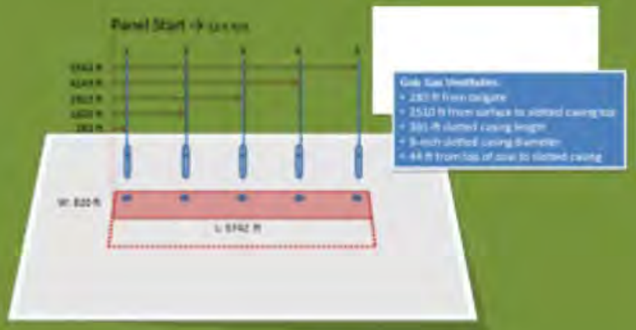
Improved Technologies

- Surface directional gob wells (angled or parabolic depending on surface access)
- Laterals over longwall panels directionally drilled from the surface
- Horizontal gob boreholes
- Directionally drilled cross-measure boreholes (modified cross-measure boreholes)

Implementation Requirements

- Surface access
- Depth from surface
- Geomechanical characteristics

Click to view a gob model layout schematic diagram.



Free software is available from the U.S. NIOSH to model gas production from surface gob vent boreholes:

https://www.cdc.gov/niosh/mining/works/coversheet1805.html

Engineering equations are also used to predict gob gas flow from boreholes.

Considerations for Gob Borehole Planning and Design

Operational constraints can be addressed to optimize gob gas drainage performance. Considerations for gob borehole planning and design include:

Physical Considerations

- Number of wells/boreholes
- Lateral and vertical placement
- Diameter
- Collar
- Casing and completion

Performance Considerations

- Wellhead vacuum
- Production projections
- Anticipated concentration
- Monitoring provisions

Click to view data on the number of Horizontal Gob Boreholes (HGB) required for 100 m^3/min methane flow (500 m length and 75% CH_4 by volume).

Borehole Diameter	Vacuum Pressure		
Diameter	50 mm Hg	100 mm Hg	150 mm Hg
96 mm	32	23	19
121 mm	18	13	11
146 mm	12	9	7
165 mm	9	6	5

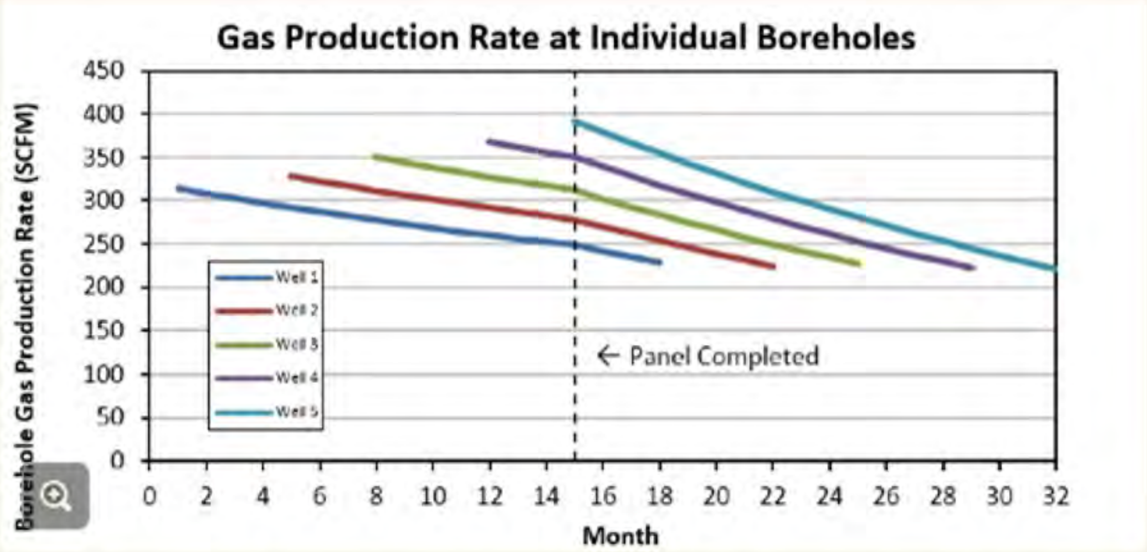
Borehole Performance Data

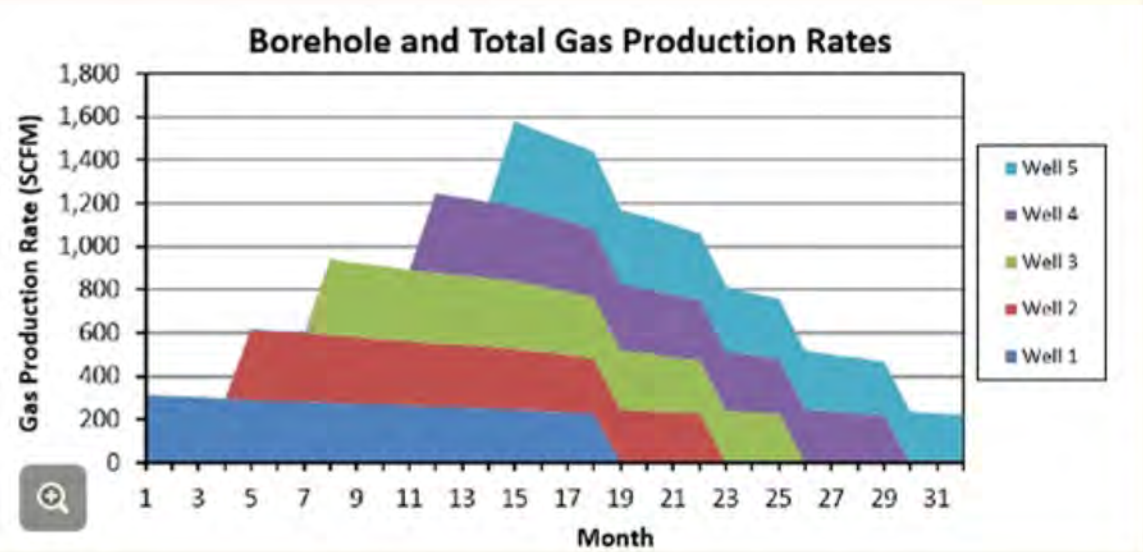
Number of HGBs required for 100m^3/min methane flow (500m length and 75% CH_4).

Borehole Diameter	Vacuum Pressure		
Diameter	50 mm Hg	100 mm Hg	150 mm Hg
96 mm	32	23	19
121 mm	18	13	11
146 mm	12	9	7
165 mm	9	6	5

Planning and Designing Gob Gas Boreholes

Gob gas production and recovered gas quality will depend on a number of factors. Proper planning and designing of gob gas recovery systems will help ensure mine safety while optimizing gob gas production rate and methane concentration.

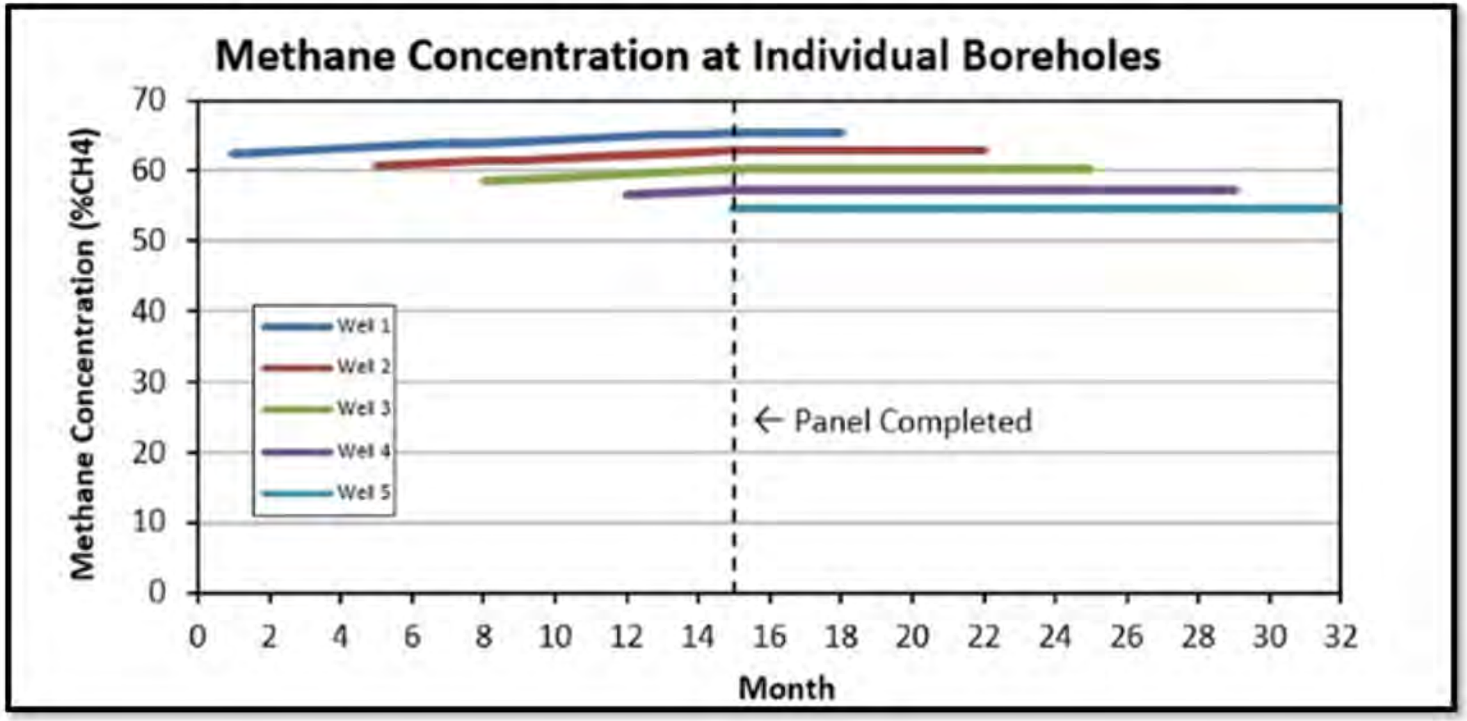




The cumulative gas production period and the total quantity of gob gas produced increases as vertical gob wells are under-mined through panel completion.

Methane Concentration of Gob Gas

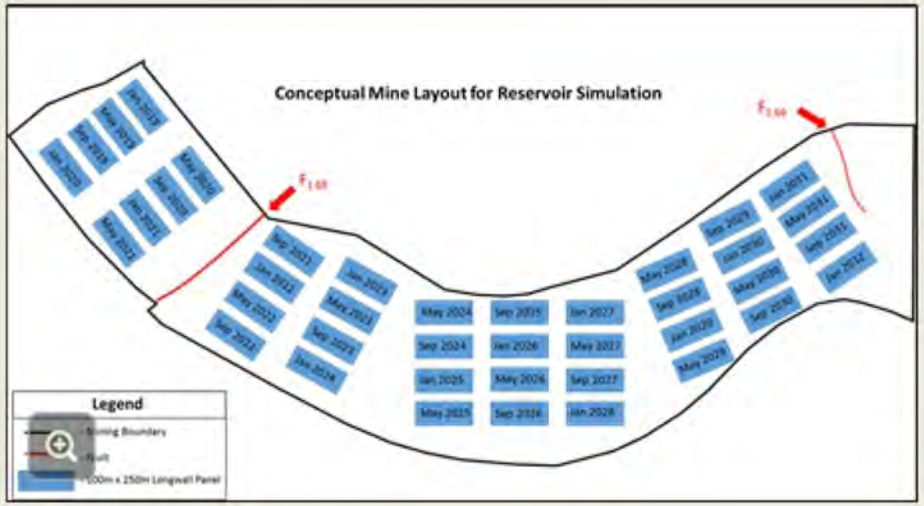
As noted on the previous slide, the cumulative gas production period and the total quantity of gob gas produced increases as vertical gob wells are under-mined through panel completion. However, the concentration of the recovered gob gas from each subsequent under-mined vertical gob well is reduced through panel completion.



Develop Plans for Future Implementation of Gob Boreholes

Similar to pre-mine drainage boreholes, gob wells or boreholes can be designed for the remaining longwall districts based on the mine's development and production plan, and differences in the gob gas resource.

This will allow project developers to prepare an initial design and schedule for the entire system, including the number, length/depth, and diameter of the boreholes/wells.



The initial design provides the basis for the developer to prepare cost estimates for improvements to drainage.

Optimizing Gas Collection

Optimizing Gas Collection Pipelines and their Operation

A gas drainage system consists of boreholes to produce the coal mine gas, a collection system of pipelines, and pumps and associated equipment to transport the gas to the surface for utilization or venting.

Optimizing the drainage collection system can lead to improved recovery of high-quality gas of commercial value.

Important considerations with respect to optimizing gas collection system are:

- Pipeline construction: materials, connections and layouts
- Monitoring and control
- Vacuum pressure and system monitoring/control
- Pipeline integrity monitoring for safety

HDPE Gas Collection Piping

Considerations for Pipeline Construction

Potential improvements and considerations for improving the gas collection system include:

Pipe Materials

- Steel – especially useful in space-restricted areas or where the pipe may be vulnerable to damage
- High density polyethylene (HDPE) – requires conductive medium to reduce risk of static discharge

Connections

- Gasketed flange
- Fused
- Victaulic to flange

Other considerations

- Handling/installation

Underground pipe systems are vulnerable to damage even when using the most optimal systems. The drainage system should be designed and operated with the premise that there is a finite risk of integrity failure.

View more details about gas collection system materials.

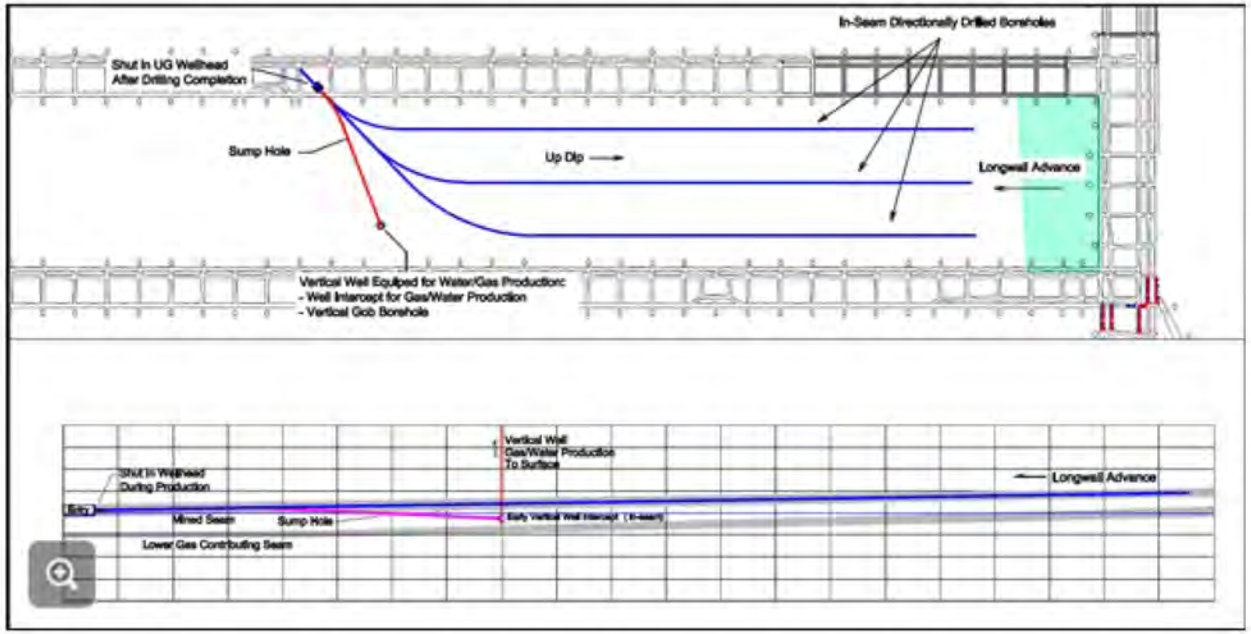
Gas Collection System Materials

Steel Pipe		High-density Polyethylene Pipe	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Superior mechanical strength	Connection can corrode and leak over time Heavy and difficult to move	Non-corrosive: resistant to H_2S, does not rust Lighter and easier to handle than steel, reducing installation and maintenance costs Connections can be fused together, minimizing leaks	Less mechanical strength than steel Some concern about static electricity issues

Pipeline Layout

The gas pipeline network acts as a gathering system to bring the produced gas to a central collection point on the surface. Gathering systems can be on the **surface or underground**.

If only surface wells are drilled (pre-mine drainage wells or gob wells), gas collection systems will be located on the surface (or buried on the surface).



Gas collected from in-mine boreholes (pre-mine drainage or post-mine drainage) will be piped to a gas collection well which leads to the surface.

Pipeline Layout Best Practices

Best Practice Principles to Follow When Designing the Pipeline Layout

- ➢ Minimize the length of pipe
- ➢ Eliminate underground pipelines as feasible. For example, use horizontal to vertical well intercepts, or localize gas collection wells to surface

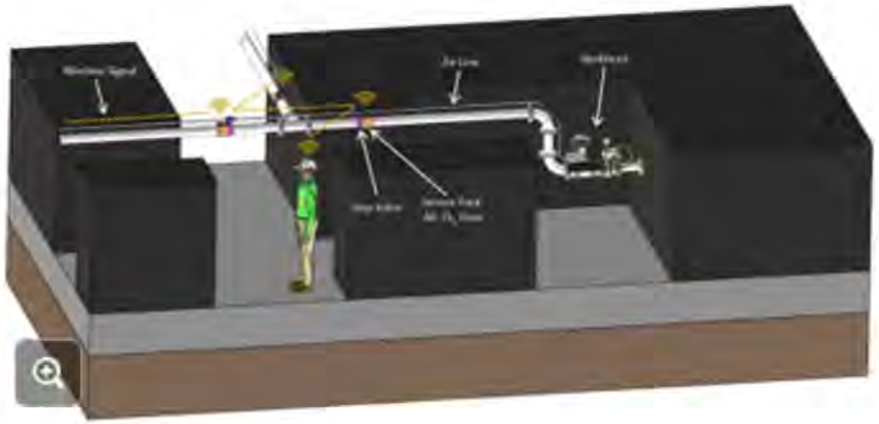
Benefits of Implementing Best Practices

- ✓ Reduces capital and operating costs
- ✓ Improves gas quality
- ✓ Reduces risk of pipeline damage from operations

Pipeline Monitoring and Control

Methane utilization efficiency and safety can be significantly enhanced if the methane concentration is accurately measured and controlled.

- Use manual or remote monitoring systems to determine the effectiveness of the gas drainage system.
- Take measurements in a consistent manner at individual wellheads as feasible, in the gas drainage pipe network, and at the surface methane extraction plant.
- Monitor gas flow rate, methane concentration (directly or indirectly), and gauge pressure. Also record barometric pressure, temperature, and moisture content of the gas at central locations to facilitate the standardization of flow data.
- Select monitoring equipment that is capable of correcting for non-methane hydrocarbons to ensure accurate measurements.



Pipeline Vacuum Pressure Estimation

Generally, for a pre-feasibility study, the project developer does not prepare a detailed design of the gas collection system other than identifying pipeline length, diameter and the location of pipeline intercepts.

Wellhead vacuum pressures should be estimated when gob boreholes/wells are used to determine capacity and cost of vacuum plants/blowers.

For a pre-feasibility study, estimates are sufficient, but more detailed engineering designs are required for full feasibility studies and future project implementation.

Additional Pipeline Monitoring for System Performance

Conducting systematic monitoring of other gas collection system components is good practice.

- Manage the underground gas pipeline.
- Maintain water separation equipment and ensure that the pipeline is not entrained with water or solids.
- Check operation of the pipeline safety integrity monitoring system, including all sectioning valves.
- Clean and check all sensing/monitoring and actuating equipment on a regular basis.

Vacuum plant operators can perform routine manual measurements or implement permissible remote monitoring and control systems.

Maintaining Vacuum Station

Vacuum is the primary means of moving gas from pre-mine drainage and post-mine drainage underground boreholes to the surface. The gas collection system is normally under suction induced by a vacuum pump, which is controlled by a vacuum station.

Gas flow rate, methane concentration, pressure and temperature should be measured at the vacuum station to ensure safe operation and to prevent the transport of explosive mixtures of methane from the vacuum station to CMM utilization plants, such as power plants, flares and natural gas pipelines.

Module 5 Summary

This module described methods and tools that can be used to improve mine gas drainage.

Improving mine gas drainage can not only make the mining operation safer, but it can also increase coal production and result in the production of higher quality gas.

It is important to note that the drainage system design may need to be adjusted on a continual basis to ensure that gas production is optimized as the mine develops over time.

Looking Ahead

Module 6 will discuss how to quantify the benefits of improvements to methane drainage systems.

Thank you!

You have completed Module 5.