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 introduced general approach 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

GMI Partner Countries

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 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 4

Forecasting Methane Production from Gas Drainage Systems

What You Will Learn

After completing this module, you will:

- Be familiar with methods for forecasting gas drainage production.
- Understand how the forecast analysis depends on the quality and quantity of available data.

Time needed to complete this module:

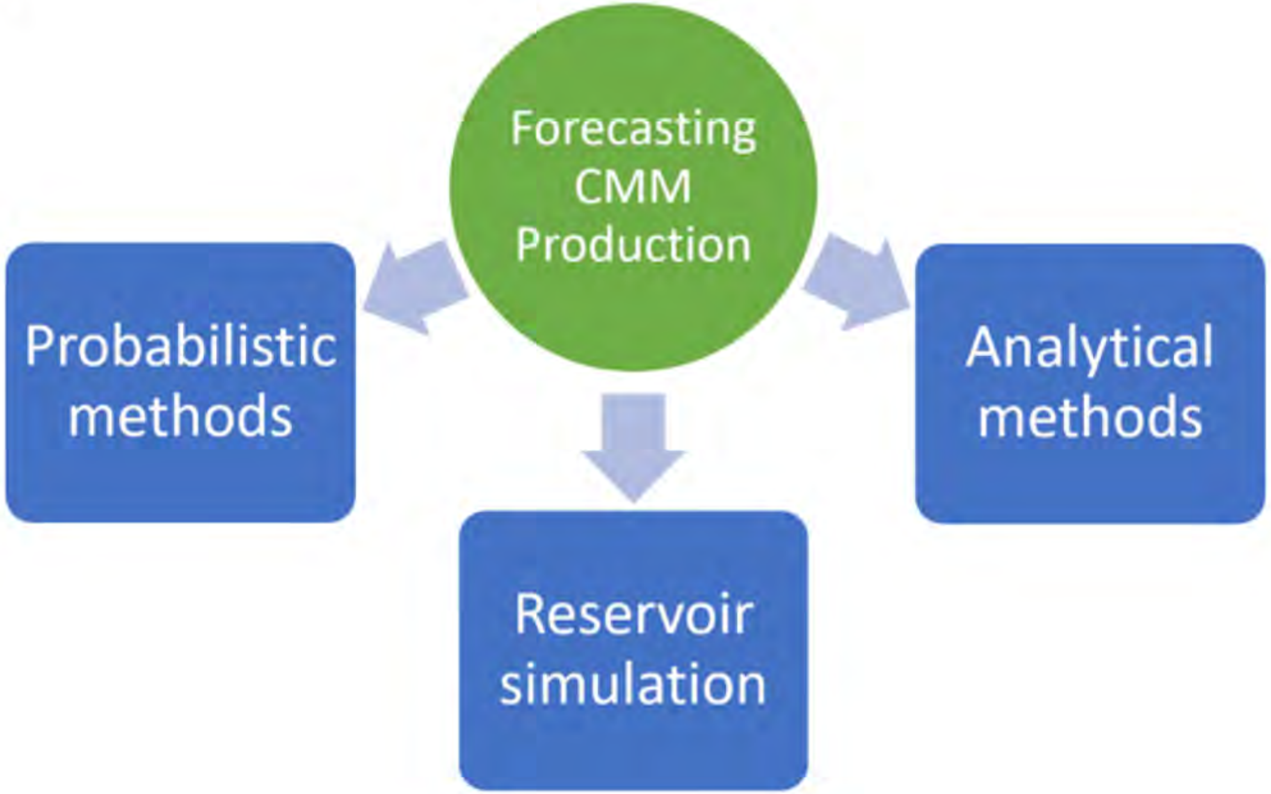
Approximately 30 minutes

Forecasting CMM Production from Methane Drainage Systems

Project developers can rely on several types of approaches to forecast CMM production from methane drainage systems. The best approach depends on the amount and types of data available.

Methods to forecast CMM production include:

- Probabilistic methods
- Analytical methods
- Reservoir simulation



Forecasting: Probabilistic Methods

- **Probabilistic methods**
- Analytical methods
- Reservoir simulation

Used when the project developer does not have sufficient or reliable empirical data.

Probabilistic methods use a range of estimated values to predict the probability of different outcomes.

Therefore, probabilistic methods use randomness to solve problems that may be inherently deterministic (i.e., fully determined by the parameter values and initial values).

Forecasting: Analytical Methods

- Probabilistic methods
- **Analytical methods**
- Reservoir simulation

Used when the project developers have sufficient or reliable field data.

Analytical methods use a range of field data values to predict future methane production from gas drainage systems by applying analytical techniques.

These analytical techniques may include volumetrics analysis or field-derived production relationships.

Forecasting: Reservoir Simulation

- Probabilistic methods
- Analytical methods
- **Reservoir simulation**

Used when project developers have access to field and laboratory data on coal seam parameters.

Reservoir simulation provides a means to account for the complex mechanisms of coalbed methane gas desorption, diffusion, and flow.

This method allows the integration of field and laboratory data into a single geologic/reservoir model in order to evaluate pre-mining methane drainage strategies.

Selecting an Approach to Forecast CMM Production

Experts, including mining and reservoir engineers, develop models, simulations, and/or software for each of these approaches to forecast CMM production from methane drainage systems.

The amount and types of data that are available to a project developer often dictate which approach is the most appropriate.

Regardless of which approach is selected (probabilistic methods, analytical methods, or reservoir simulation), the model or software should be robust enough to tailor to a specific project. Project developers often work with technical consulting firms to decide on the appropriate approach.

Probabilistic Methods

Forecasting CMM Production through Probabilistic Methods

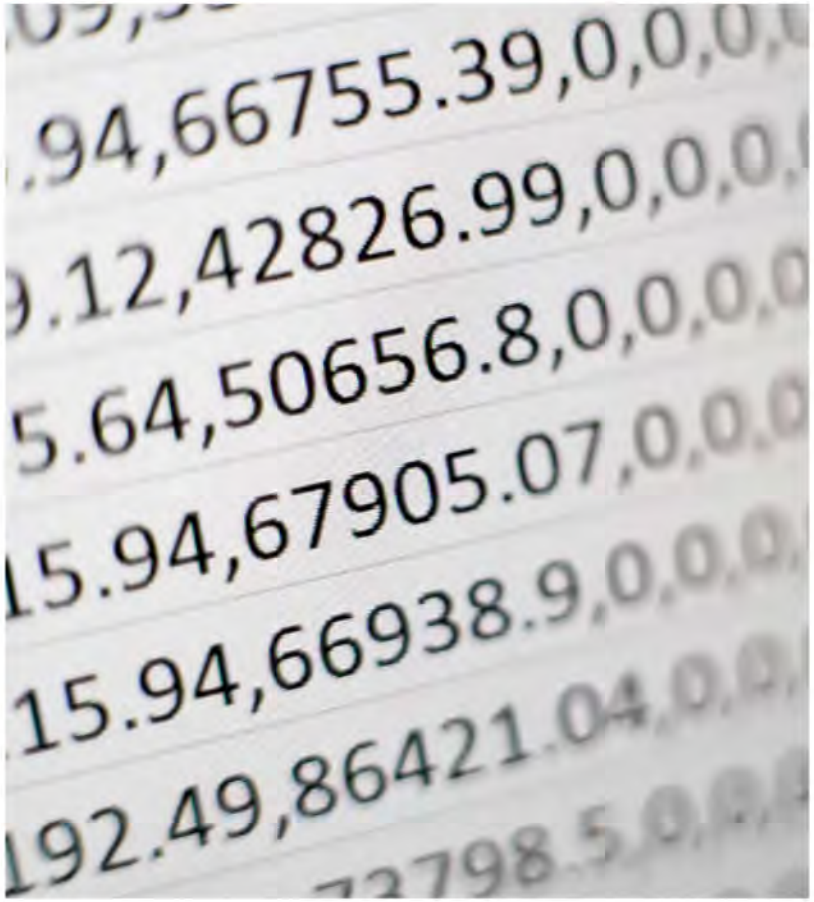
Estimating gas drainage production requires the knowledge of many variables, which may not always be available to a project developer. Therefore, project developers may need to rely on probabilistic methods, which use computational algorithms to predict the probability of certain methane drainage characteristics.

One example of a probabilistic method is the Methane Control and Prediction ("MCP") software that was developed by National Institute for Occupational Safety and Health *(Note: the software is currently being updated)*. Publicly available, the MCP software predicts mine methane emissions and estimates degasification system production rates.

Probabilistic Method Approach

Probabilistic methods, such as the MCP software, use a broad class of computational algorithms that rely on repeated random sampling to obtain numerical results.

- The underlying concept is to use randomness to solve problems that might be deterministic in principle.
- These simulations are used to predict the probability of different outcomes when the intervention of random variables is present.
- This method helps explain the impact of risk and uncertainty in prediction and forecasting models.



When to Use Probabilistic Methods

Developers use probabilistic methods when the available data are limited.

This approach can provide upper and lower limits for forecasted CMM production from gas drainage, but it is not as accurate as analytical techniques that are based on mining and coal reservoir characteristics.

For example, probabilistic analysis can be applied to forecast gas production from the drainage of gob gas, which is methane released from mined-out areas. In this example, the analysis would utilize a range of data, including mining parameters and coal production forecasts.

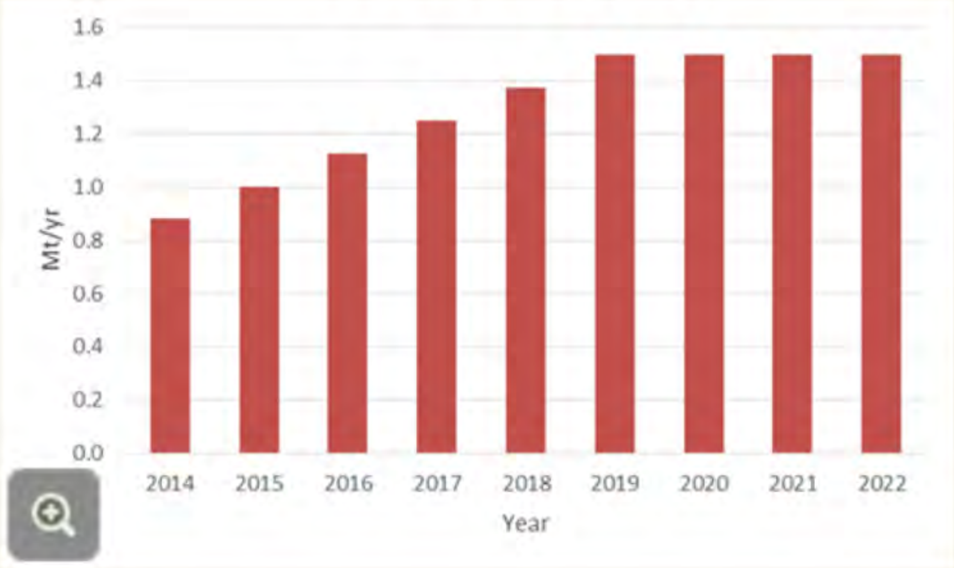
Parameters may include:

- Slotted casing length
- Distance (from surface) to slotted casing top
- Slotted casing diameter
- Slotted casing distance from top of coal
- Distance of gob gas borehole to tailgate
- Distance of gob gas borehole from start of panel
- Average exhauster vacuum

Examples of Probabilistic Method Outputs

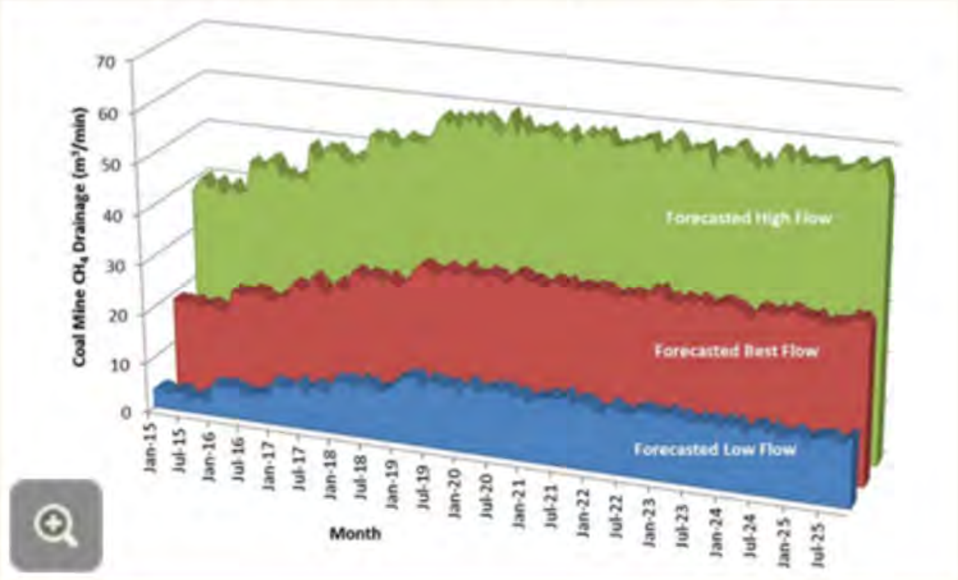
In addition to forecasting gob gas drainage, probabilistic methods can also be applied to in-seam boreholes, cross-measure boreholes, or any other methane drainage techniques. Example forecasts using probabilistic methods are presented below.

Coal Production



An example of an 8-year coal production forecast provided by a mine

Forecasted CMM Drainage



An example of forecasted CMM drainage for a 10-year period showing high, low, and

Analytical Methods

Forecasting CMM Production through Analytical Methods

To estimate the rates of gas production from methane drainage systems, project developers can use analytical techniques when adequate data are available.

These analytical techniques may include volumetric analysis or numerical calculations. Developers can use these techniques to forecast methane production for different scenarios, such as:

- The volume of gas in strata potentially affected by mining.
- Mine ventilation methane emissions.

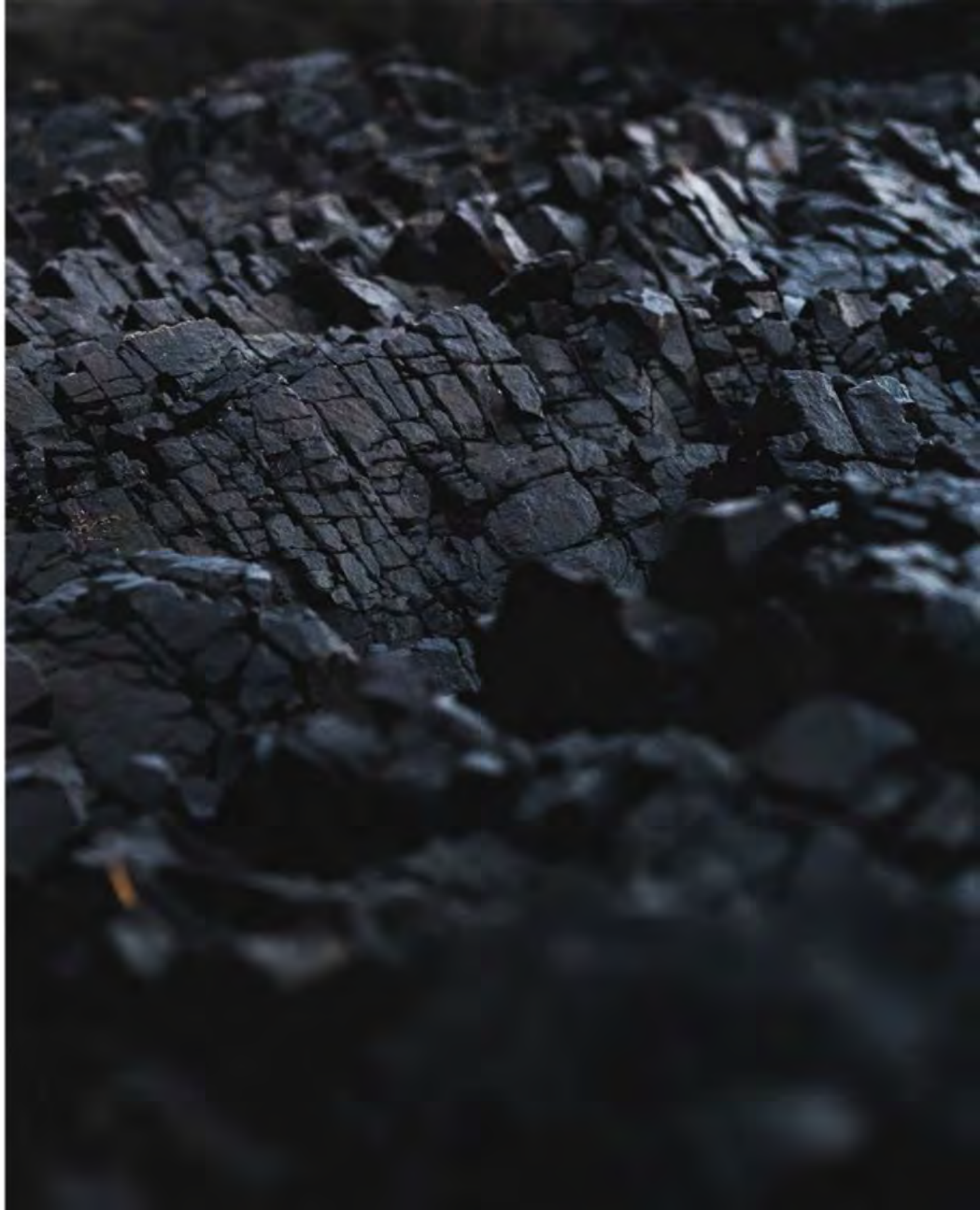
After using analytical methods to forecast the variables above, project developers can then use these variables to forecast CMM production as they continue to plan further mine development.

Volumetric Analysis

Volumetric analysis is a technique used to estimate the volume of gas stored within a specific bulk reservoir rock volume (gas-in-place).

This method employs geological observations and relevant production information to predict the volume of methane adsorbed on coal surfaces as well as trapped in the pore spaces.

This technique often relies on data from core samples, wireline logs (continuous measurements using electrically powered geologic instruments), and geological maps.



Volumetric Gob Gas Prediction Models

One example of analytical methods are volumetric gob gas prediction models. Gob gas prediction models typically simulate the gas present in the mined-out area of a mine, also known as the gob area, and take into consideration the affected gas bearing strata.

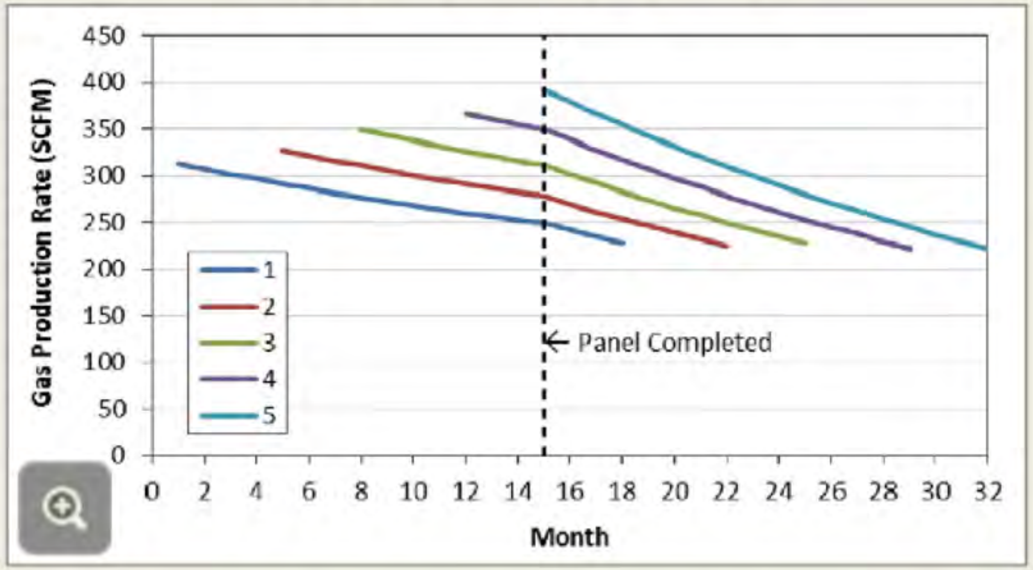
Input requirements include:

- Depth below surface
- Geomechanical properties of the adjacent strata
- Gas content and reservoir properties of the adjacent strata
- Proximity of the adjacent strata to mining
- Panel length
- Panel width
- Mining height and rate

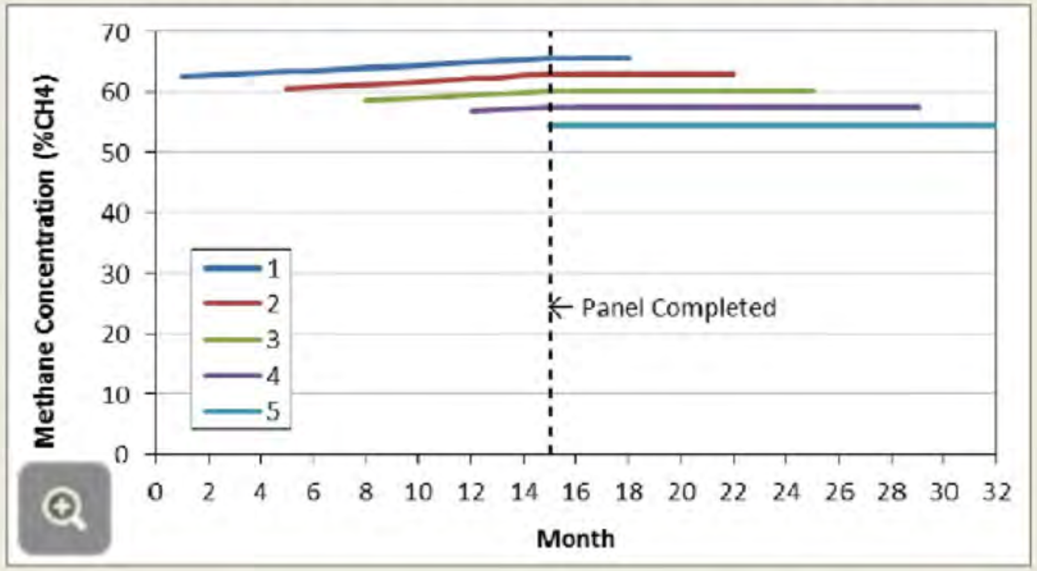
Volumetric Gob Gas Prediction Model Example

The graphs below show example outputs from forecasting the production performances of gob gas boreholes using intelligent computing methods for optimum methane control in longwall coal mines. They show initial high rates of gas production and methane concentration for gob gas wells during the mining of a single longwall panel. As time increases, gas production and methane concentration decrease. The first boreholes in each panel typically produce the highest methane percentage, and subsequent boreholes produce lower quantities of methane.

Gas Production vs Time



Methane Concentration vs Time



Numerical Calculations

Numerical calculations are another analytical method used to study the interaction of multiple parameters in a complex system.

These simulations employ numerical modeling to predict and provide analytical solutions using empirical data and measurements when they are available to the project developer.

One way to apply numerical calculations is through the use of equations.

If utilizing the calculation technique, developers may use parameter relationships to estimate the gas flow rate capacity of a horizontal gob borehole as a function of:

- ✓ gas composition
- ✓ borehole diameter
- ✓ wellhead vacuum pressure

Calculation Technique

As noted on the previous slide, another approach to analytical methods is to use numerical calculations, such as calculation equations developed by geologists and engineers that are found in various technical textbooks. If the calculation technique is being used, developers may apply the below relationship to estimate the gas flow rate capacity of a horizontal gob borehole as a function of gas composition, borehole diameter, and wellhead vacuum pressure.

$$Q = 1.3303\,(10)^{-5}\left(\frac{T_b}{P_b}\right)\left[\frac{(P_1^2 - P_2^2)}{G T_f L Z f}\right]^{0.5} D^{2.5}$$

Q = gas flow rate, measured at standard conditions (liters/second)

f = coefficient of friction, dimensionless

P_b = base (standard) pressure (kilopascals)

T_b = base (standard) temperature (kelvin)

P_1 = upstream pressure (kilopascals)

P_2 = downstream pressure (kilopascals)

G = gas gravity (air = 1.0)

T_f = average gas flowing temperature (kelvin)

L = pipe length (kilometers)

D = borehole diameter

Z = gas compressibility factor

Reservoir Simulation

Forecasting CMM Production through Reservoir Simulation

Reservoir simulation is the preferred and most accurate approach to forecast CMM production, provided a project developer has adequate and reliable data.

Advantages of Using Reservoir Simulation for Pre-mine Drainage Forecasts

- ✓ Provides a means of accounting for the complex mechanisms of coalbed methane gas desorption, diffusion, and flow
- ✓ Allows integration of field and laboratory data into a single geologic/reservoir model in order to evaluate pre-mining methane drainage strategies
- ✓ Provides a basis for forecasting future production of pre-mining gas drainage systems
- ✓ Helps diagnose in-situ gas content reduction and drainage time as a function of pre-mining borehole spacing
- ✓ Predicts gas recovery from pre-mining degasification over time considering underground mining plans

Reservoir Simulation Parameters

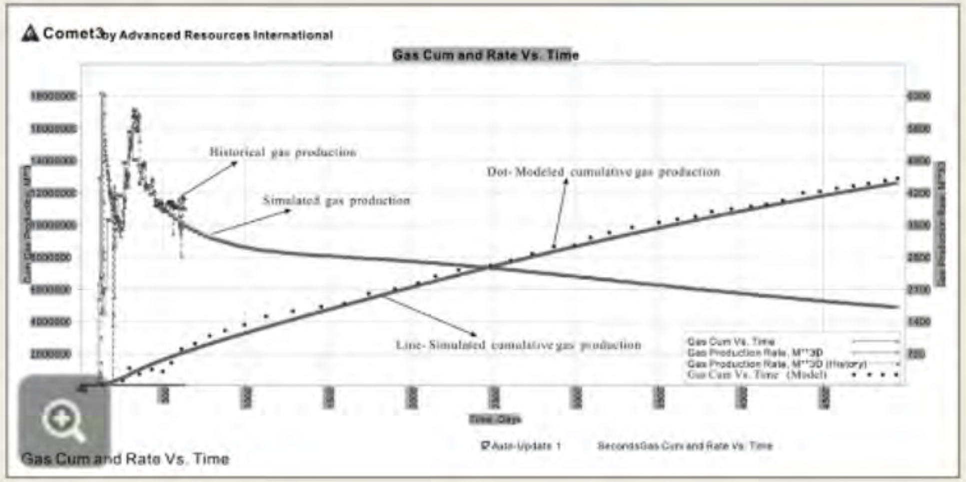
Reservoir simulation requires knowledge of the characteristics of the coalbed reservoir, including the following parameters:

- Cleat permeability and orientation
- Porosity
- Initial gas content
- Adsorption isotherm
- Desorption pressure
- Diffusion coefficient
- Cleat spacing
- Pore volume compressibility
- Gas composition, gravity, and viscosity
- Depth
- Net coal thickness
- Stratification (layers)
- Ash content
- Drainage area
- Reservoir pressure
- Water saturation
- Gas-water relative permeability

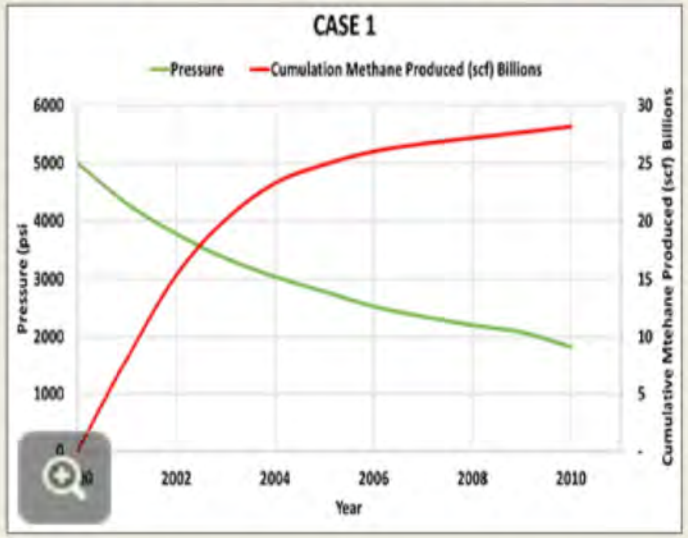
Reservoir Simulation Examples

Developers can use reservoir simulation to derive pre-mining methane drainage plans based on mine plans and reservoir parameters that are available or estimated. Examples of commercially available software that are commonly used in the United States are COMET3 and GEM.

Example Output from COMET3



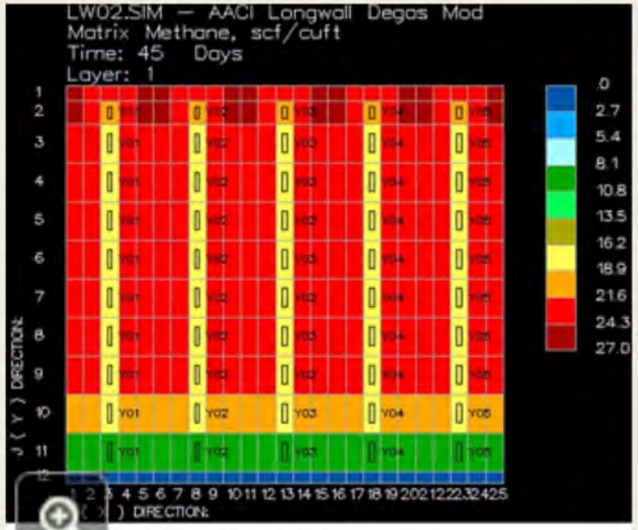
Example Output from GEM



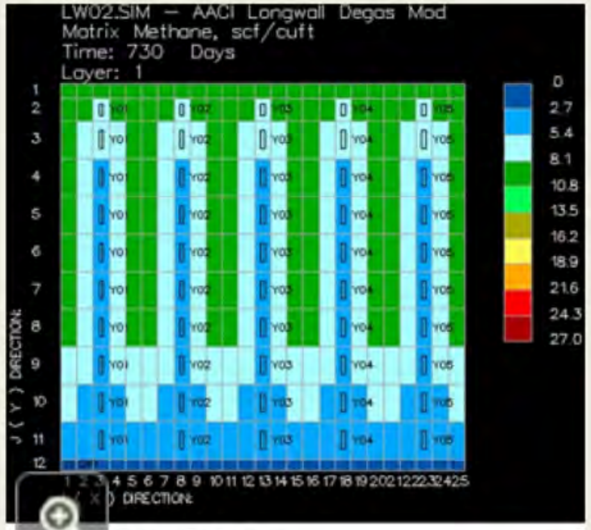
Reservoir Simulation Confidence

Reservoir simulation requires a significant amount of data, and the applicability of reservoir modeling for gas drainage system design depends on the availability and quality of such data.

Confidence in reservoir simulation results can be improved by comparing historical production or gas content reduction data against the outputs of the simulation.



- GC_I = 15 m³/t, Spacing 20 m



- GC_R = 6 m³/t , 2 Years

These images illustrate the reduction in gas content after 2 years with borehole spacing of 20 m in a low permeability coal seam.

Applying the Approaches in Practice

The availability and quality of data are the primary factors in determining and choosing an appropriate forecasting method.

While reservoir simulation is the preferred and most accurate approach, it also requires more work associated with gathering necessary data.

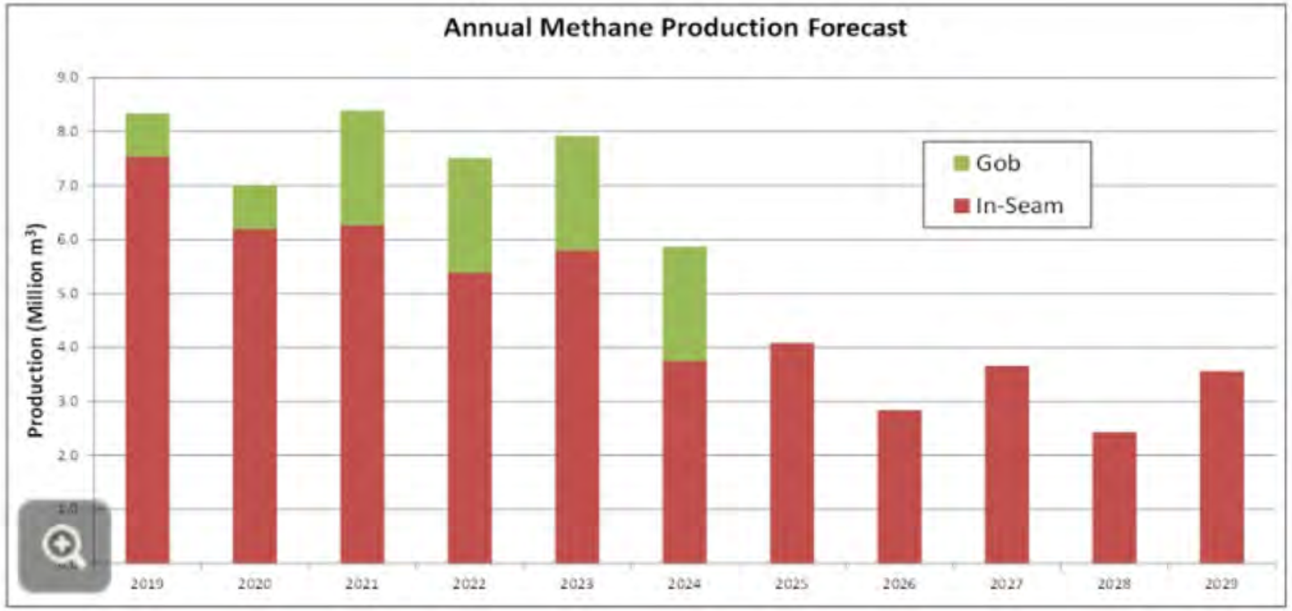
- Acquiring reservoir information requires drilling, coring, and testing wells, as well as laboratory work.
- Constructing reservoir simulations requires considerable time to assemble the data, construct the model, run the simulations, and interpret the results.

As a result, reservoir simulations are more expensive to complete than a probabilistic method, which relies on a range of data.

Importance of Forecasting Approaches

The forecasting approaches discussed in this module can be used to improve confidence in estimated gas drainage resulting from improvements to a gas drainage system (covered in Module 5). Having an accurate forecast for gas production can help select/justify the chosen approach to optimize gas production, improve gas recovery, optimize drainage efficiency, and minimize the costs of production.

Forecasting methane production is important because it forms the basis of the financial and economic analysis of the project.



Module 4 Summary

In this module, you learned:

- About the different methods that are available to predict methane drainage production, which include:
  - Probabilistic methods
  - Analytical methods
  - Reservoir simulation
- The quality and quantity of data will dictate the most appropriate method for predicting mine methane emissions and forecasting methane drainage production.

In Module 5, you will learn about the different methods and tools that are used to improve mine gas drainage. Improving mine drainage not only makes mining operations safer, but it can also increase coal production and result in the production of higher quality gas.

Thank you!

You have completed Module 4.