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 3

Resource Assessment

What You Will Learn

In this module, you will learn about:

- The purpose and role of a resource assessment in a pre-feasibility study.
- The procedures and techniques for conducting project-specific assessments.
- How to identify the data necessary for conducting a pre-feasibility resource assessment.
- How these data are acquired, analyzed, and interpreted to support development of a CMM project pre-feasibility study.

Time needed to complete this module:

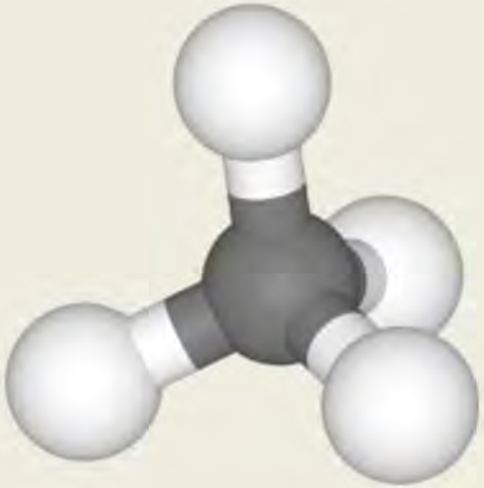
Approximately 45 minutes

Resource Assessment Overview

A gas resource assessment for a CMM project refers to the estimation of coal and gas resources, including extractable gas reserves, within and near a coal mine complex.

Resource assessments are critical to evaluating prospects for pre-mine and post-mine gas drainage for a pre-feasibility study.

An accurate resource assessment can help mine owners and operators and project developers understand the volume of gas-in-place (GIP) and the potential gas production capacity of a mine.



Methane resources are initially estimated based on physical properties of coal such as:

- Gas content
- Thickness
- Density

Pre-feasibility vs Feasibility Studies

The table below presents a comparison of data required for a pre-feasibility study versus a full feasibility study.

Pre-feasibility Study	Feasibility Study
It is generally acceptable to rely on and interpret existing data, typically obtained from the mine owner or operator, a public agency, or other sources. Such data can be supplemented by field or laboratory data, if possible.	Requires a more robust and comprehensive assessment based on existing data and new data obtained from core holes, geological surveys, engineering assessments, and reservoir modeling.

Benefits of Resource Assessments

The benefits of conducting resource assessments include the following:

- Reducing project risk
- Helping to accurately forecast ventilation emissions
- Improving mine safety
- Providing critical data inputs used in financial models

Click on each of the benefits to learn more.

Benefits of Resource Assessments

The benefits of conducting resource assessments include the following:

Reducing project risk

Project risk is reduced through the accurate estimation of GIP.

Helping to accurately forecast ventilation emissions

Ventilation emissions and the possible need for pre-mine/post-mine methane drainage can be accurately forecasted because GIP estimates resulting from resource assessments can be used to predict gas emissions into the mine workings.

Improving mine safety

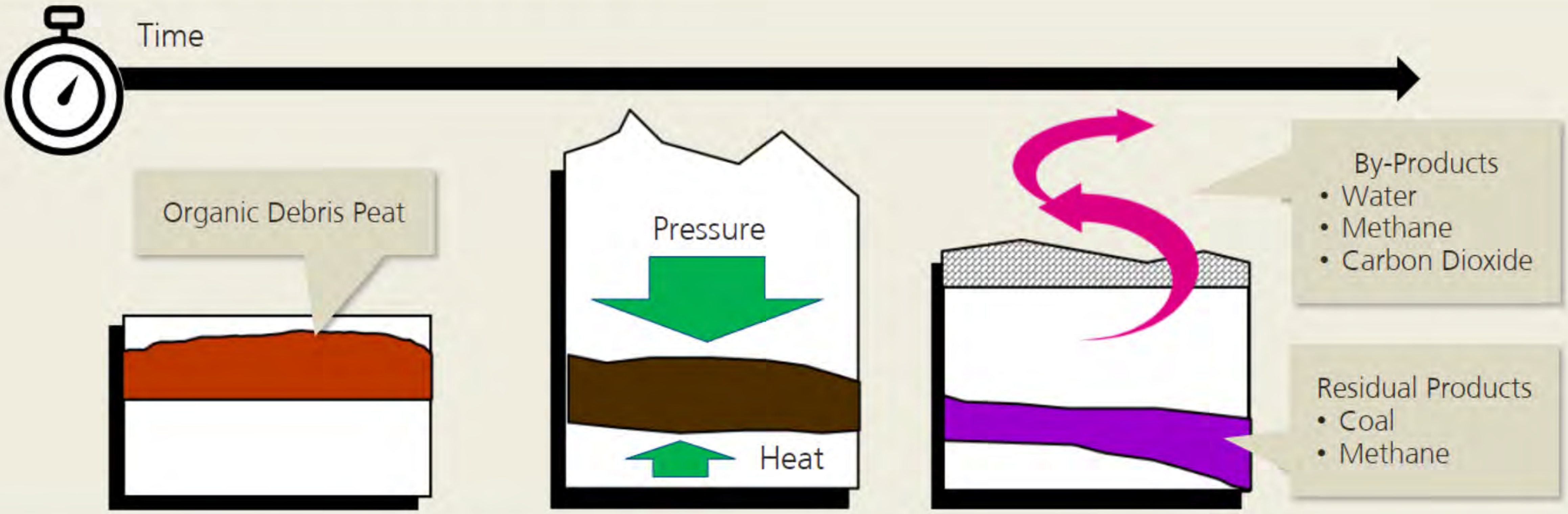
Mine safety is improved because the data and knowledge obtained support the development of more effective gas drainage and ventilation systems.

Providing critical data inputs used in financial models

Critical data inputs are obtained that are used in financial models to determine the economic feasibility and the anticipated cost savings of a methane drainage project.

Click on each of the benefits to learn more.

The Origin of Gas in Coal



The naturally-occurring gases found in coal seams generally consist of methane (typically 80% to 95%) with lower percentages of heavier hydrocarbon gases, nitrogen, and carbon dioxide. Methane was formed as a result of chemical reactions as organic matter was buried at depth and subjected to increased heat and pressure and transformed into coal.

The Origin of Gas in Coal (Continued)

The greater the temperature, pressure, and duration of coal burial, the higher the coal maturity and the greater the amount of gas generated. Today, the gas is adsorbed onto organic matter and is found in the pore space of coal and rock layers in the subsurface.

During a resource assessment, CMM project developers gather geologic data to determine the volume and composition of gases present in the coal. Subsequently, the mine's coal production plan is applied to predict potential gas releases into the mine workings.

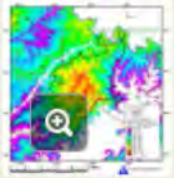
Steps in a Resource Assessment

The resource assessment steps and the order in which they are conducted depend on data availability, level of detail, and confidence in the obtained data.

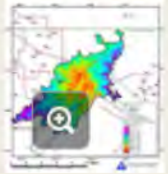
This module presents a logical workflow that is normally undertaken for gas resource assessments:

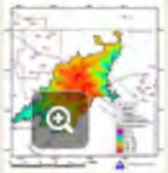
- Gather coal reservoir properties (depth, thickness, gas content, etc.).
- Develop a geographic information system (GIS) database of the area.
- Compute coal and gas in-place resources, subtracting out non-producible areas (village, local mines, etc.).
- Use GIS to estimate CMM resources for each panel/area.

Maps of Coal Reservoir Properties


Depth and Thickness Screen


Coal Resources


Depth and Reservoir Pressure


Gas Content


GIP

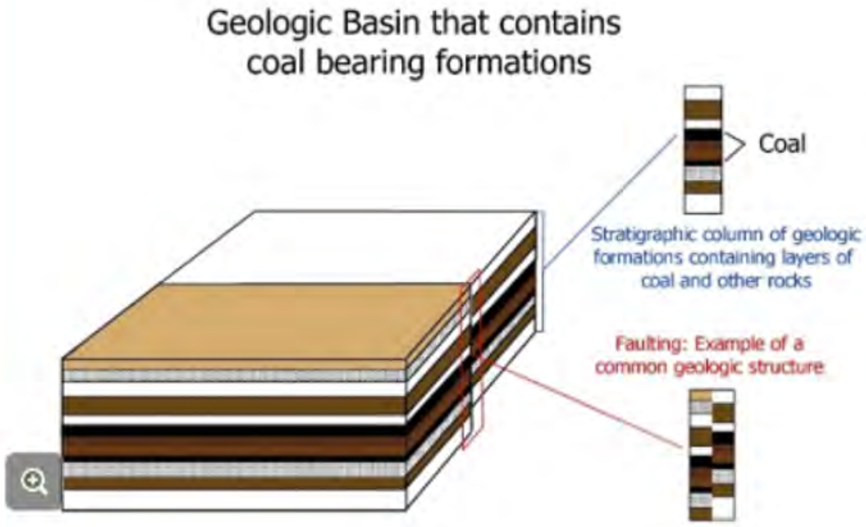
Data for Resource Assessments

Conducting an accurate gas resource assessment requires the following categories of geologic data:

Geologic Basin Data

Stratigraphic Data

Structural Data



Click on each of the categories and the image to learn more.

Data for Resource Assessments

Conducting an accurate gas resource assessment requires the following categories of geologic data:

Geologic Basin Data

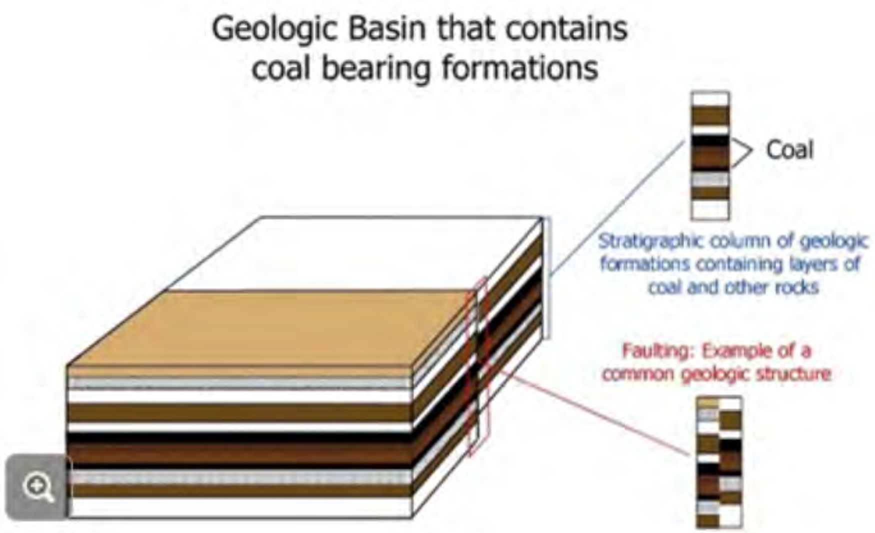
Provides information on the deposition and maturity of the coal formations in the basin.

Stratigraphic Data

Provides information on thickness and depths of rock and coal layers in the gas producing formations.

Structural Data

Provides information on geological structures below ground that may affect mining processes.



Click on each of the categories and the image to learn more.

Data Considerations

Uncertainty of available gas resources increases CMM project risk. Existing data from public sources or from the mine owner or operator should be sufficient for a pre-feasibility study. When data are unavailable for the target location, proxy data can be used as long as this is noted in the study.

Although it is not typical for a pre-feasibility study, the project developer may undertake geologic exploratory work, rather than relying on existing data (which can be of uncertain quality), to obtain direct measurements of the gas-bearing strata.

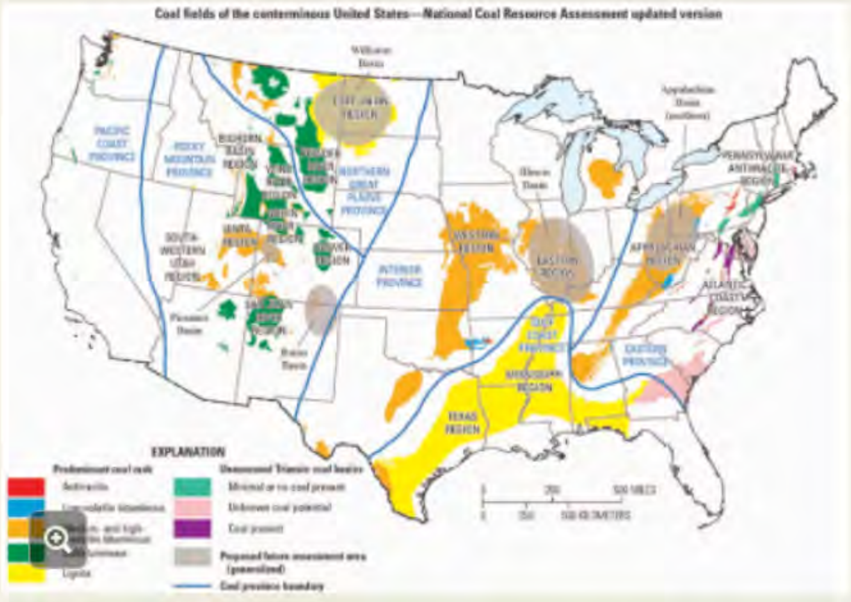
The following slides highlight how geologic, stratigraphic, and structural data can be used by project developers to prepare the assessment of gas resources for a CMM project.

Geologic Data Inputs: Basin Geology

Coal is found in sedimentary basins. A basin's characteristics control the gas resources in the coal formations. Understanding the basin geology is, therefore, fundamental to developing an accurate picture of the gas resources that may be available for recovery and use at a coal mine.

Relevant basin geology factors to consider include:

- Tectonic setting (faulting, intrusions, etc).
- Basin development
- Depositional history
- Adjacent strata
- Coal seam thickness
- Coal seam geometry
- Coal seam depth



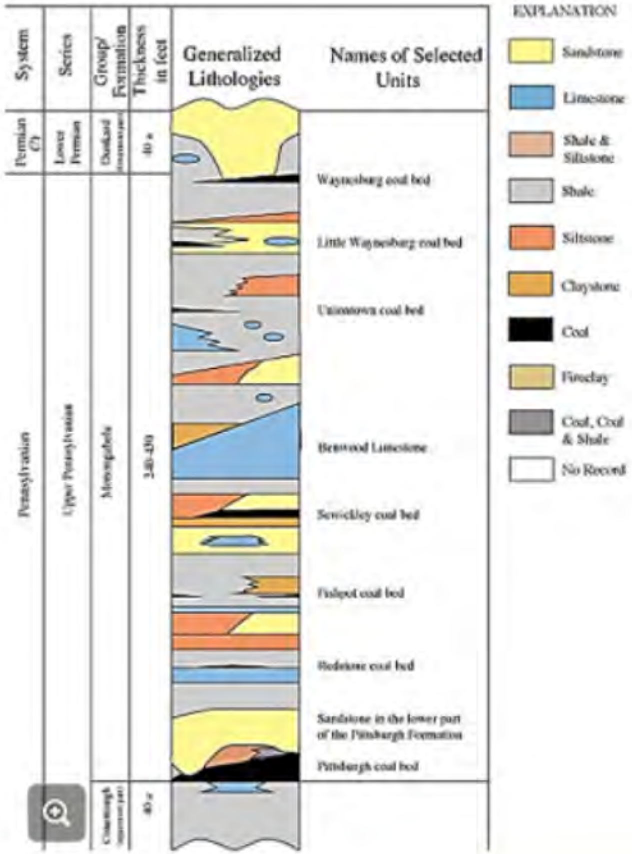
Coal Fields of the Conterminous United States

Geologic Data Inputs: Regional Stratigraphy

Stratigraphy organizes bodies of rock spatially and chronologically according to their common characteristics. Classification, correlation, and mapping of sedimentary rocks in the subsurface allows for effective evaluation of seam thickness, depth, system continuity, and trend directions of the coal resources and gas-bearing formations.

A pre-feasibility or feasibility study includes **a review and analysis of existing stratigraphic data** in the mining area.

Stratigraphic surveys, typically conducted by geologists, define rock and coal strata thickness, depth, and type. These surveys also describe the potential influence of un-mined gas-bearing strata on mined coal seams.



Click to learn more about stratigraphic data that can be used to help interpret regional stratigraphy.

Stratigraphic Data

Stratigraphic data that help interpret regional stratigraphy include:

- **Representative core logs**
  - Mined seams
  - Surrounding strata
- **Coal characteristics**
  - Proximate analyses
  - Rank
  - Mineral matter content
- **Geophysical logs**

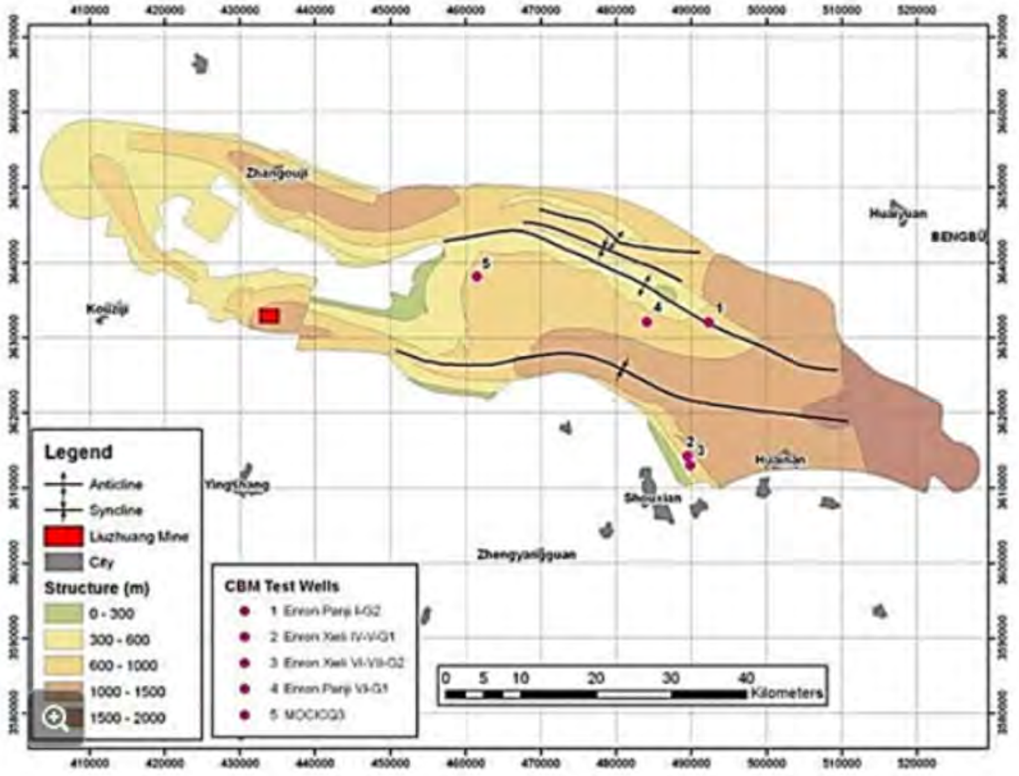
Geologic Data Inputs: Subsurface Structure

The subsurface is rarely uniform due to structures that affect the position, orientation, and presence of strata. These structures can include faults, channels, folds, and other features.

The location and type of structure can impact **gas availability** and **gas flow**, as well as the **location and design of boreholes** in the gas drainage plan.

Structural assessment of the regional geology is needed to:

- Anticipate geological structures below surface and their impact on mining and gas production.
- Help develop a safe, effective plan to work around the geological features.



Pre-feasibility Studies and Geologic Structures

A **pre-feasibility study** should identify any known geological structures based on existing data, maps, and guidance provided by the mine owner or operator, or other knowledgeable party. The potential impact on gas availability and the gas drainage plan should also be explained.

A **full feasibility study** will include a more thorough assessment of subsurface structures with a detailed plan to mitigate the impact of those structures on the gas drainage plan.

View examples of common structures encountered in mining that impact gas management.

Examples of Subsurface Structures

- **Faults**
  - Affects coal production characteristics of nearby boreholes
  - Can direct or cut gas flow; gas can migrate along faults
  - Can make directional in-seam drilling difficult
- **Channels**
  - Creates preferential paths for gas flow
- **Splits**
  - Wedge: shaped rock bodies that cause formations to split
  - Can direct or cut gas flow from the permanent lateral barriers caused by splits
  - Thinned out seams will contain less gas
- **Karst structures**

Examples of Geologic Data

- ✓ Descriptive logs
- ✓ Geophysical logs
- ✓ Oriented logs from exploration drilling
- ✓ Geophysical data from seismic surveys and lineament mapping

Geologic Data Inputs: Geologic Exploration

To reduce CMM project risks, the party undertaking the resource assessment (for example, the project developer, or mine owner or operator) **may obtain and analyze relevant geologic data** available through exploration activities that include core wells and geophysical surveys.

Geologic data compiled from exploration activities will improve the accuracy and confidence in the resource assessment.

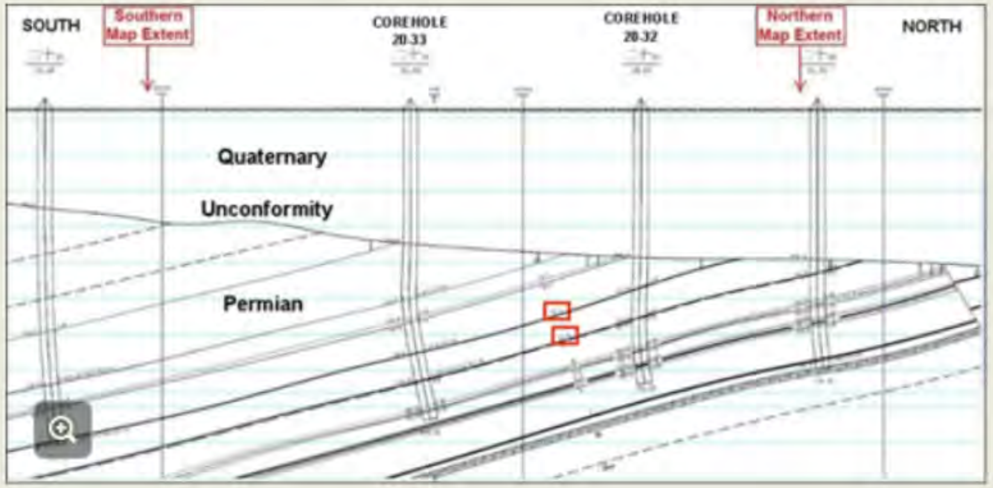
Data from Geologic Exploration

Exploration activities are rarely undertaken for pre-feasibility studies due to cost, timing, and lack of an exploration license.

Exploration is more common for a full feasibility study and may be necessary to secure project financing.

Project developers can use data from geological surveys to:

- Accurately plan locations for wells
- Reduce the probability of drilling dry wells
- Determine the need for further drilling
- Minimize the environmental impact of the exploration



Estimating Gas-in-Place

Estimating GIP is the primary objective of the resource assessment because it provides an estimate of the total volume of gas potentially available for recovery and use.

GIP estimates not only provide input data for reservoir models and gas prediction models used for CMM pre-feasibility/feasibility studies, but also more broadly for mine planning and operations including:

- Mine layout
- Mine ventilation plan
- Gas drainage plan
- Impact on coal production due to de-pressurization of the gas reservoir
- Residual gas content and impact on management of mined-out areas

GIP Estimates and CMM Projects

A CMM project may not be viable if the total GIP is too small, even if other factors such as permeability and porosity are favorable.

With a GIP estimate, the project developer can make an informed decision to continue or stop a pre-feasibility or feasibility study.

GIP Equation

Project developers calculate GIP using four basic parameters:

- Area
- Seam thickness
- Coal density
- *In-situ* gas content

Gas-in-place Equation

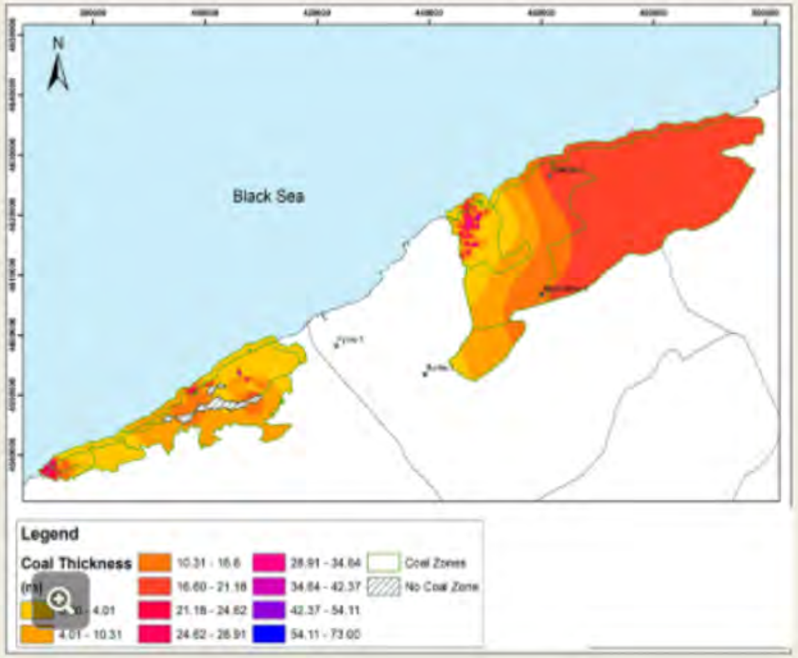
$$GIP = H \times (1 - (a + m)) \times GC \times D \times A$$

H = Completable coal thickness (ft or m)
a = Ash content (%)
m = Moisture content (%)
GC = Gas content (ft^3/ton or m^3/ton)
D = Coal density (g/cc)
A = Area (acres or hectares)

GIP Calculation: Defining Seam Thickness

Geologic data inputs, including **well log data** and **stratigraphic data**, are used to construct **coal isopach maps** that show the thickness of the coal seam(s) throughout the target production area.

When calculating GIP, the **density of the coal** needs to be considered. This is because ash and other mineral matter that does not hold gas will increase the tonnage of coal calculated and potentially overstate the GIP if a density correction is not applied.



Coal density is generally derived from proximate/ultimate analyses that determine ash, moisture content, and other coal properties.

GIP Calculation: Ash Content

Ash is the non-combustible residue formed from the inorganic or mineral components of the coal.

Ash may be incorporated from the original swamp environment or washed or blown into the coal seam during accumulation.

Ash content is often considered to be the main parameter affecting methane adsorption capacity.

As ash content increases, pore space capacity decreases

Methane adsorption decreases

GIP Calculation: Moisture Content

Most coals have some amount of moisture associated with them, ranging from 2% to 70%.

Moisture is an **undesirable constituent** within coal as it reduces the heating value, reduces the amount of pore space available for gas, and its weight adds to the transportation costs of coal.

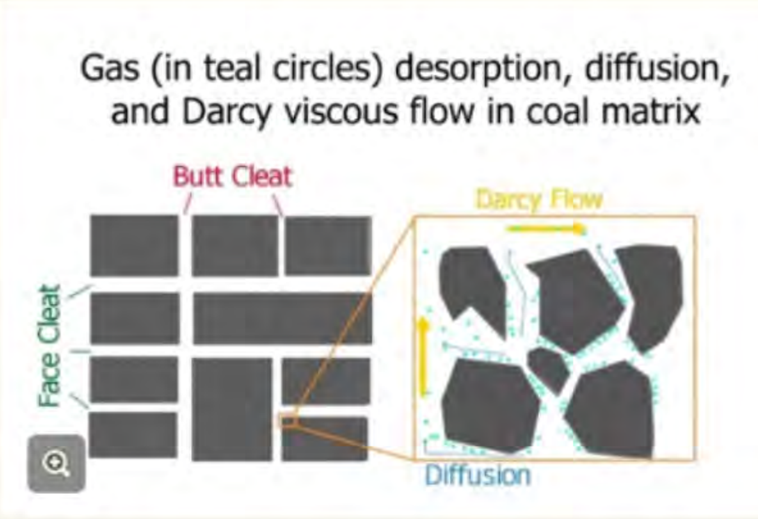
GIP Calculation: Assessing Gas Content

Gas content is important because it defines the **quantity of gas** in a ton of coal **before** disturbance *in-situ*. The volume of gas can then be extrapolated over the mining area to determine the total GIP.

Gas content is usually expressed in cubic meters of methane per ton of coal (m^3 CH_4/metric tonne of coal) or cubic feet per ton of coal (ft^3/ton of coal).

For a pre-feasibility or full feasibility study, the project developer may obtain gas content data from the mine owner or operator, a geologic survey, or from another source. The developer may also take core samples for lab analysis.

If relying on existing data, the project developer should confirm how the results were determined and the reliability of the results.



Assessing Gas Content: Overview of Methods

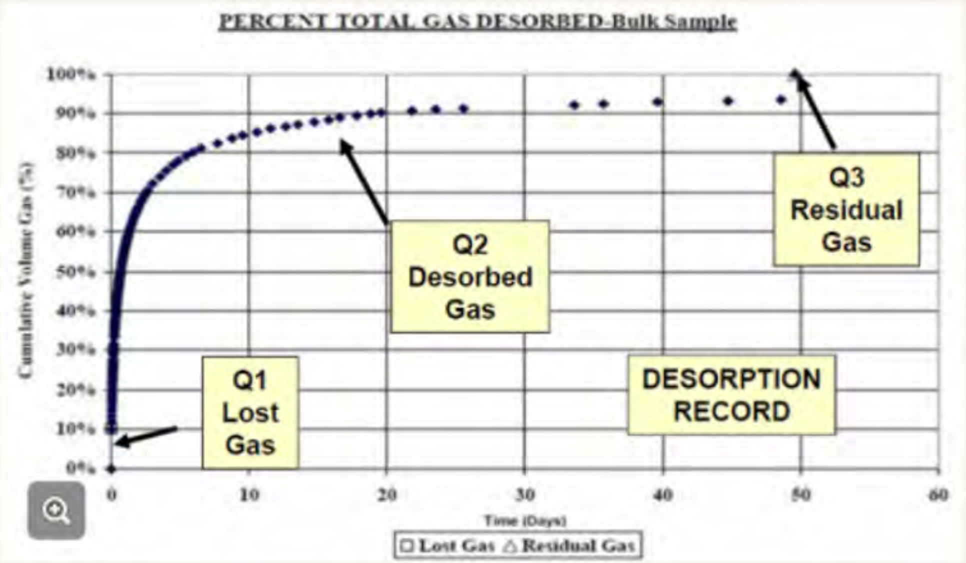
The differences between direct and indirect methods of assessing gas content are described in the table below.

Direct Method	Indirect Method
• Core desorption measurements ➢ most accurate, widely used • Drill cutting desorption measurements	• Adsorption isotherm/pressure • Analogous study ➢ Gas content/depth relationships ➢ Geophysical logs

Assessing Gas Content: Direct Method

If the project developer decides to measure gas content rather than rely on existing sources, the most widely practiced and accepted approach is to obtain **coal cores from exploration boreholes** in undisturbed areas and seal coal samples in gas-tight canisters.

Desorption Record Example



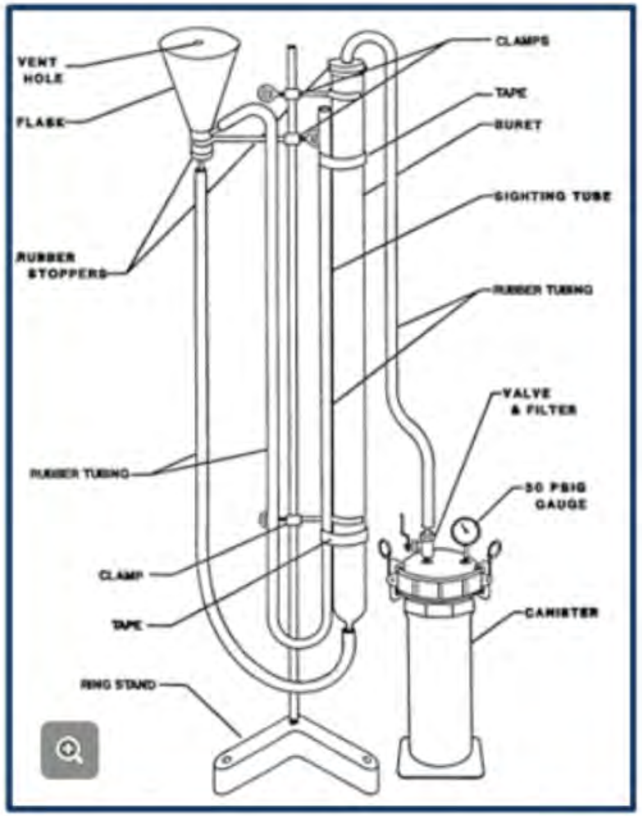
These samples are maintained at near-reservoir temperature while gas is allowed to desorb. The measured release rate allows estimation of the gas lost prior to sampling. Periodically, the gas in the canister is allowed to flow into the measuring cylinder and the volume of gas is measured and recorded.

Assessing Gas Content: Direct Method (Continued)

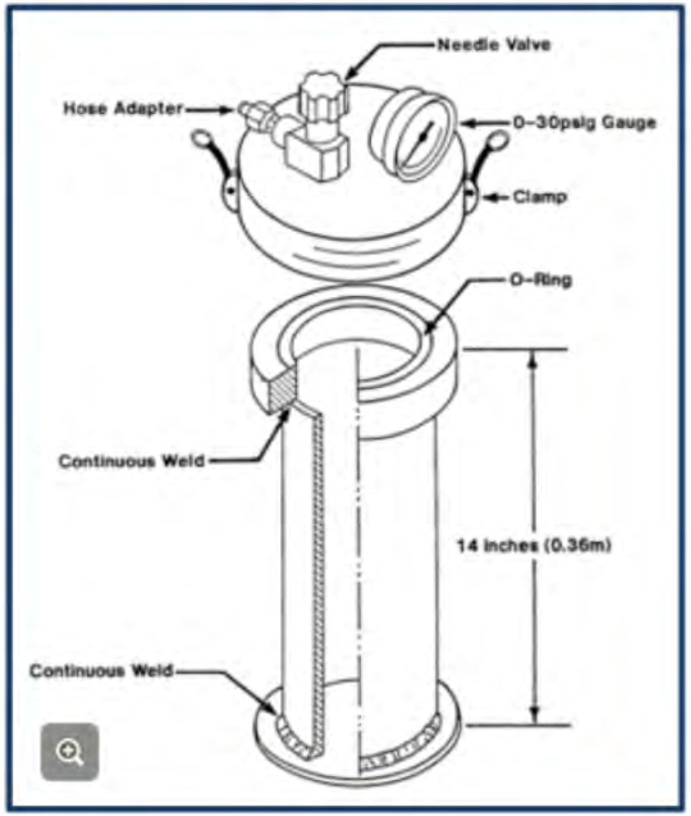
The composition of the gas may be analyzed by capturing a sample and submitting it for chemical analysis.

Important data collected from desorption testing include gas content, desorption characteristics, and diffusion coefficient.

Equipment for Desorption Testing of Coal Samples



Manometric Set-up



Canister Diagram

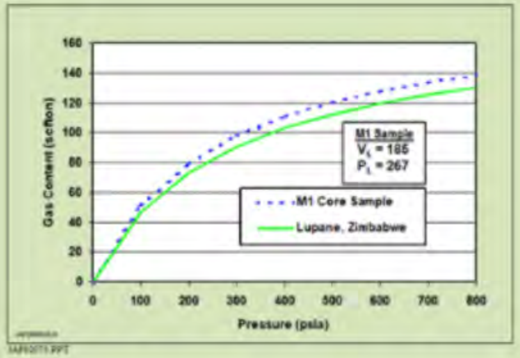
Assessing Gas Content: Indirect Method

While the most accurate way to measure *in-situ* gas content is by obtaining **coal cores from areas of interest**, this method is expensive and time consuming.

Coal seam gas content can be estimated through adsorption isotherms constructed in a lab. This method requires collecting coal samples and sending them to a lab.

- Lab pulverizes coal, allows to reach equilibrium moisture.
- Lab injects methane and allows coal to adsorb. Lab measures methane volume at different pressure increments.
- Lab typically injects methane at 6 to 8 different pressures to fit Langmuir curve.
- Lab tries to run various coal ranks and maceral content combinations to bracket reservoir variability.
- Lab determines Langmuir Volume and Langmuir Pressure.

Click to view an example coal seam gas content graph



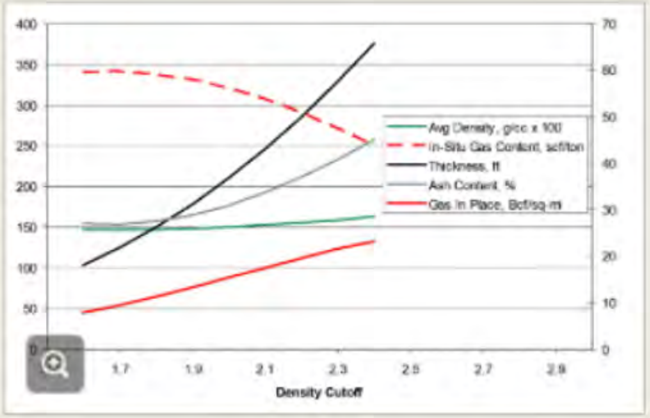
Implications of Coal Density

Density used to define coal rank, typically referred to as pay cutoff density, influences seam thickness and the GIP calculations. Coal thickness cutoff criteria (logs):

- Include ash, moisture, adsorbed gas, porosity, and fluids in porosity.
- Typically use density cut-offs in the range of 1.5 to 1.6 g/cc, although some companies use higher values.

As density cut-off increases, thickness and ash content increase

Example Coal Density Chart



GIP Calculation: Area

Area, or drillable area, represents the aerial extent (surface extent) in acres or hectares of the *in-situ* coal seams that have the potential to store gas.

Area can easily be calculated using GIS, or if GIS is unavailable, then this can be assessed manually using traditional surveying techniques.

Non-producible areas are subtracted from the total calculated area.

Putting it All Together

Once all of the data have been gathered and collated, it can either be calculated in GIS or calculated manually to determine the GIP.

In the next module, you will learn how a GIP assessment is combined with mining and drainage plans to determine a more accurate estimation of potential drainage volume and methane quality.

Module 3 Summary

This module described the gas and coal resource assessment process and the tools used to develop that assessment. Data on regional geology and coal properties serve critical roles in understanding the potential gas production capacity of a mine. Project developers can begin estimating methane emissions and determining CMM project feasibility from the resource assessment analyses.

It is appropriate for project developers to rely on existing and proxy data from the mine owner or operator (or from other sources) for a pre-feasibility study report, but it should be stated in the report when such data are used, and the uncertainties and limitations of the data should be noted. For a full feasibility study, the project developer may wish to obtain field or laboratory data to develop a more accurate resource assessment.

Data collected and evaluated (as discussed in Modules 2 and 3) provide the basis for identifying improvements to gas drainage, which will be presented in Module 5.

Thank you!

You have completed Module 3.