CMM Resource Assessments and their Impact on Project Development

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4 June 2015

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Outline of Presentation

- CMM and CBM Resources Assessments and Coal Mine Development
- Elements of Resource Assessment
- Classification Schemes and Methods of Resource Estimation
- Example Resource Assessment: CMM/CBM Occurrences and the Potential for Development in Mongolia
- Coal Mine Development and the Impact on Resource Assessment
- Including the Economic and Social Dimensions in Resource Assessments

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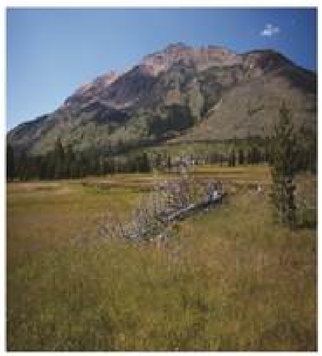
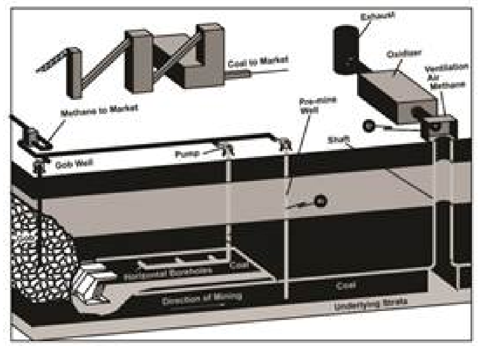
CMM and CBM Resources Assessments and Coal Mine Development

Types of Resources Assessments Discussed in this Presentation

- Coal
- Coalbed Methane (CBM)
- Coal Mine Methane (CMM)
  - Underground coal mines
  - Surface/Open cast mines
- Abandoned Mine Methane (AMM)

Gas Resources and the Coal Mining Life Cycle

Coal Mining Life Cycle

Mine Planning	*Active Mining*	*Mine Closed*
Undeveloped Coal Reserves	**Developed Coal Reserves**	**Depleted Coal Reserves**
		
Gas Resources Evaluated and Production Plan Adopted	**Gas Produced and Sold During Mining**	**Enhanced CH_4 Recovery and CO_2 Sequestration**
Exploration	*Pre-mine and Gob Drainage*	*Post-mining Gas Production*

Gas Production Life Cycle

Pilcher, 2013

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Elements of Resource Assessment

Input Considerations for Resource Assessments

- <u>Coal</u>: extensive drilling/coring,(or mining) and borehole logging.
- <u>CBM</u>: utilizes coal resource information, but needs additional testing to determine gas content, permeability, water saturation, and gas composition gas content data can come from core or cuttings.
- <u>CMM</u> integrates knowledge gained from coal resource exploration and coal mine development; generally requires experience in region to reliably forecast resource and producibility.

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Input Considerations for Resource Assessments

- CMM
  - SMM integrates knowledge gained from coal resource exploration and coal mine development; generally requires experience in region to reliably forecast resource and producibility and is reliant on coal mine timing.
  - AMM utilizes historical information regarding size and extent of mining, methane emission during active mining, and time since closure to estimate potential resource. Forecasting is unreliable without AMM gas production reliability.
  - VAM resources largely determined by volume of ventilation air and exposure of coal in mine workings; safety considerations establish limits on methane and ventilation air.

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Sources of Uncertainty Embedded in CMM/CBM Resource Estimates

Data-type and associated uncertainty

- Coal thickness data — continuous, variable with gaps caused by sparse data — often modeled which may obscure uncertainty
- Coal quality data — variability related to geologic setting and sampling density
- Depth and area of occurrence — function of geologic setting and sampling density
- Variation in data density — required for evaluation of resource class — subjective to some extent
- Sorption data — desorbed gas content can be highly variable determined by coal type and geologic setting, may be necessary to model gas potential based on adsorption isotherm

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Resources Classifications

- Resources classifications should:
  - Facilitate and organize exploration and development information and data so that the magnitude of a potentially valuable resource is reliably reported
  - Capture the uncertainty of the discovery and the potential for commercial development
  - May incorporate legally defined categories
- Resources classifications are used to assess the relative value of the resource base
- The basis on which resources are publicly reported may be strictly regulated

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What External Factors Can/Should be Considered When Estimating and Reporting Resources and Reserves?

- economic
- environmental
- market
- legal
- political
- social

Classification Schemes and Methods of Resource Estimation

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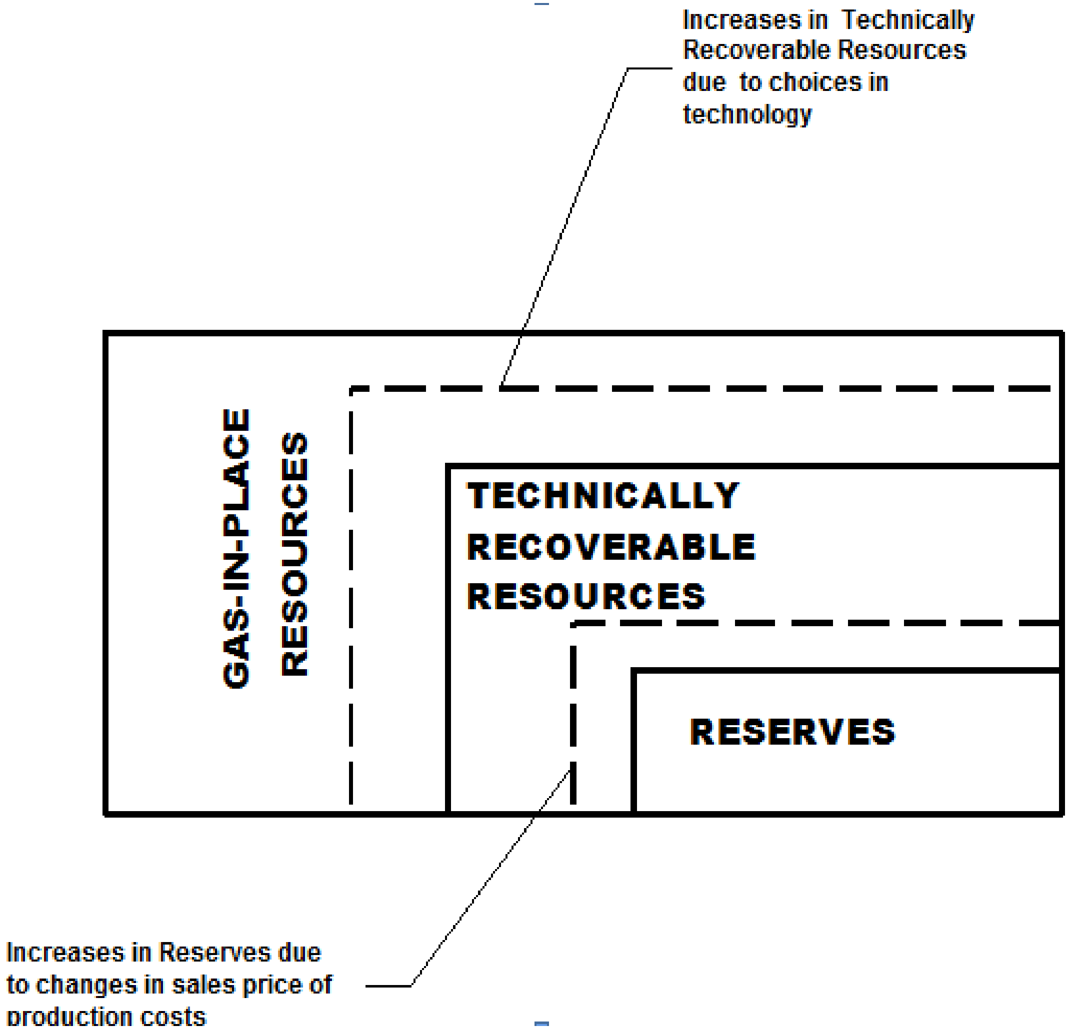
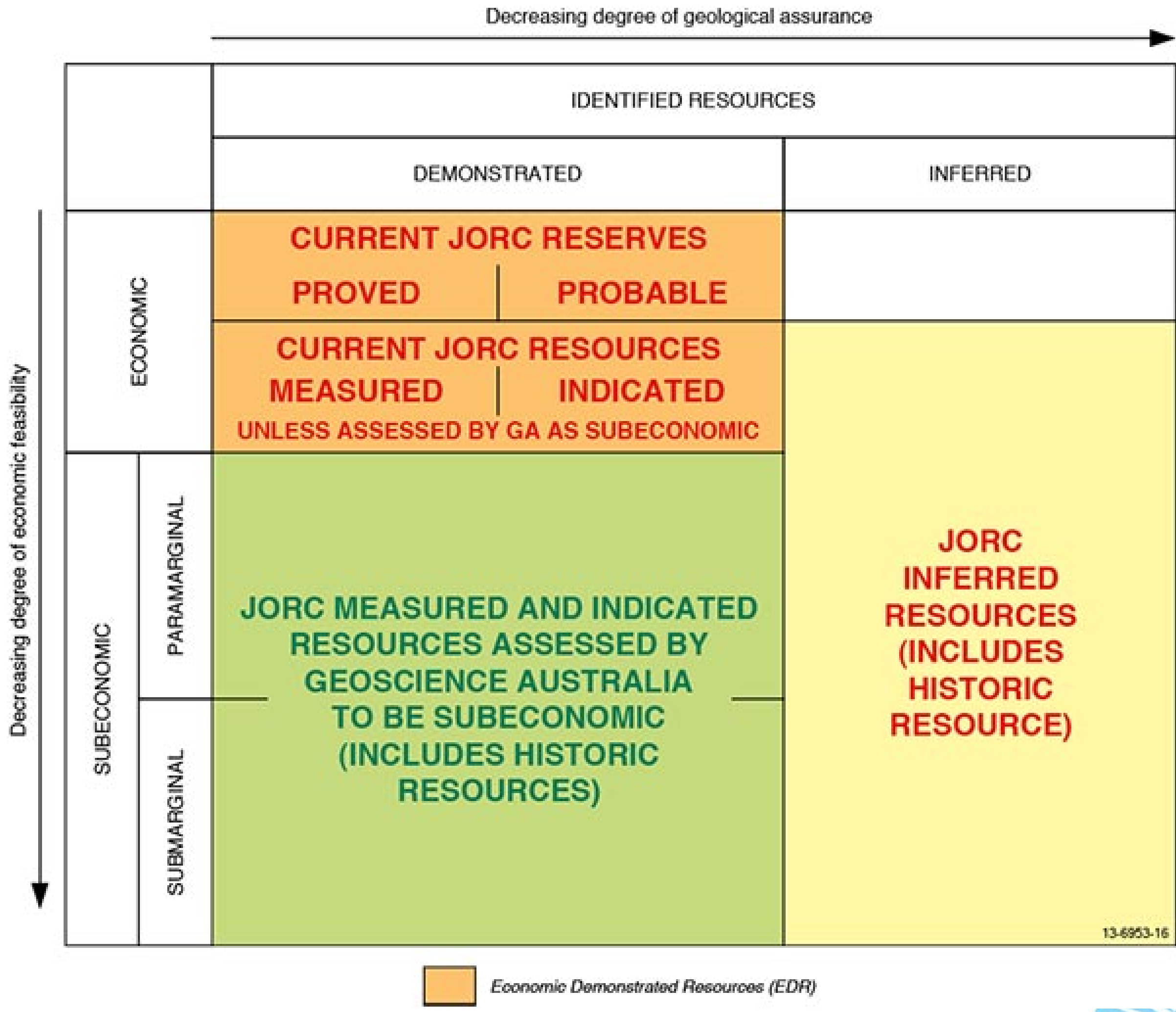
McKelvey (1972) Diagram Implies Relative Commercial Potential of Resources By Mapping Uncertainty

Cumulative Production	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES	
	Demonstrated		Inferred	Probability Range (or)	
	Measured	Indicated		Hypothetical	Speculative
ECONOMIC	Reserves		Inferred Reserves		
MARGINALLY ECONOMIC	Marginal Reserves		Inferred Marginal Reserves		
SUB-ECONOMIC	Demonstrated Subeconomic Resources		Inferred Subeconomic Resources		
Other Occurrences	Includes nonconventional and low-grade materials				

Converting Resources to Reserves — What Determines the Commercial Potential?



Joint Ore Reserves Committee Mineral Resources Classification



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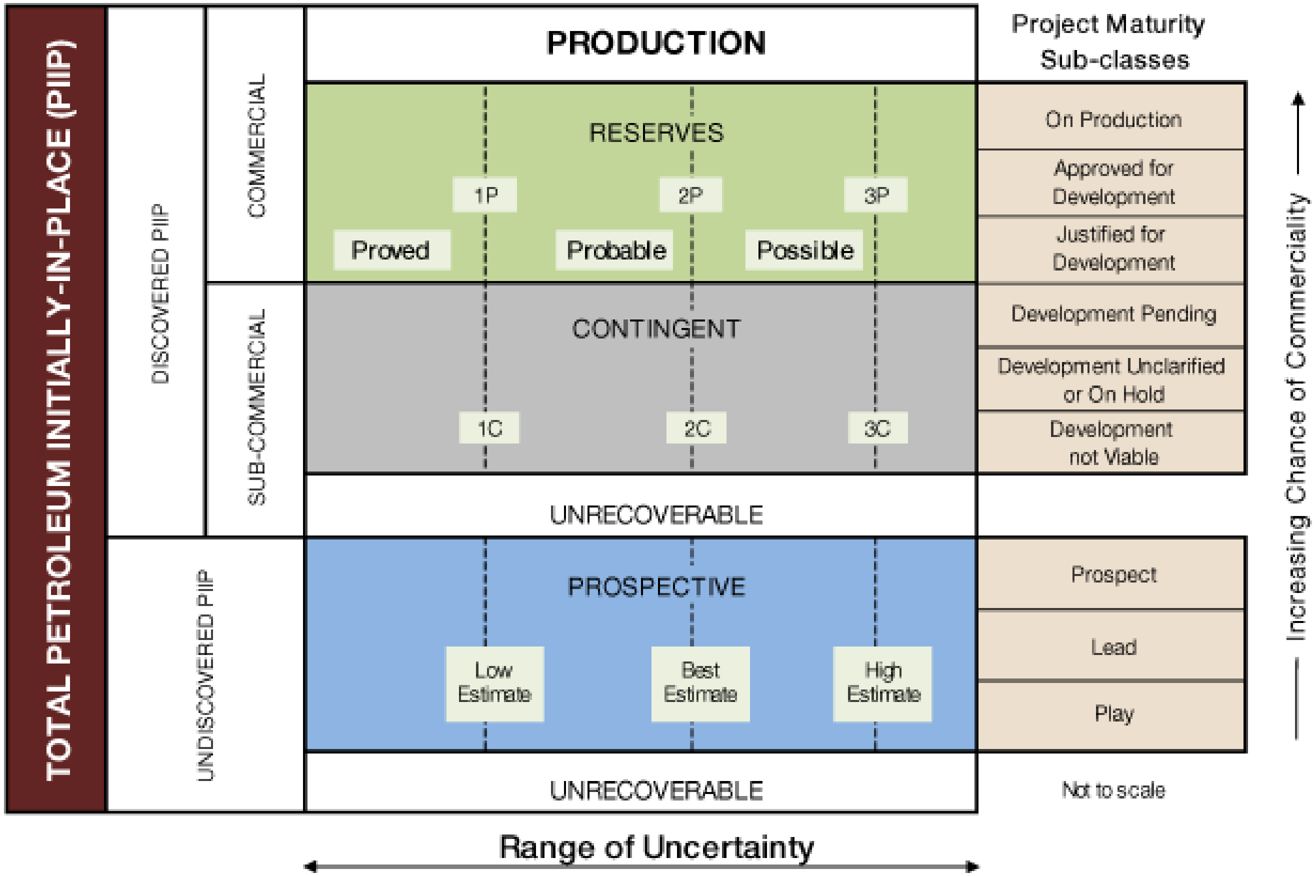
The Petroleum Resources Management System (SPE, WPC, AAPG)



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Approaches to Estimating (Assessing) CMM Resources

- Commonly a volumetric calculation:
  - multiply mass of coal (tonnes) by gas content (cubic meters of methane per ton of coal) = volume of gas in place (equivalent to OGIP or PIIP)
- Two accepted approaches to calculate estimate:
  - Use low, high, and mid range single values for all parameters; result is a resource estimate ranging from low to high forecasts
  - Stochastic estimate using probability functions developed for each parameter yielding a probabilistic forecast of resources

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Example Resource Assessment:

CMM/CBM Occurrences and the Potential for Development in Mongolia

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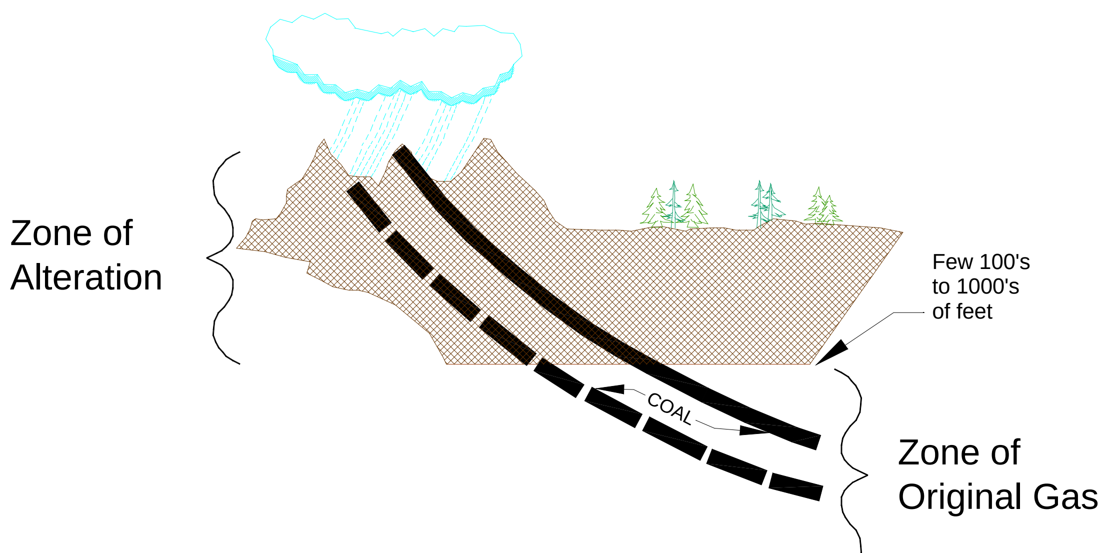
Map of Mongolia Coal Basins

Model of Methane Occurrence and Enrichment in Coal

Zone of Alteration

- Dry gas with isotopically light methane
- Gas composition controlled by (1) mixing of biogenic methane and/or (2) oxidation of heavy gases
- Located in margins and shallow central parts of basins.



Zone of Original Gas

- Wetter gas with isotopically heavier methane
- Gas composition controlled by rank and composition of associated coal
- Located in deep and central parts of basins

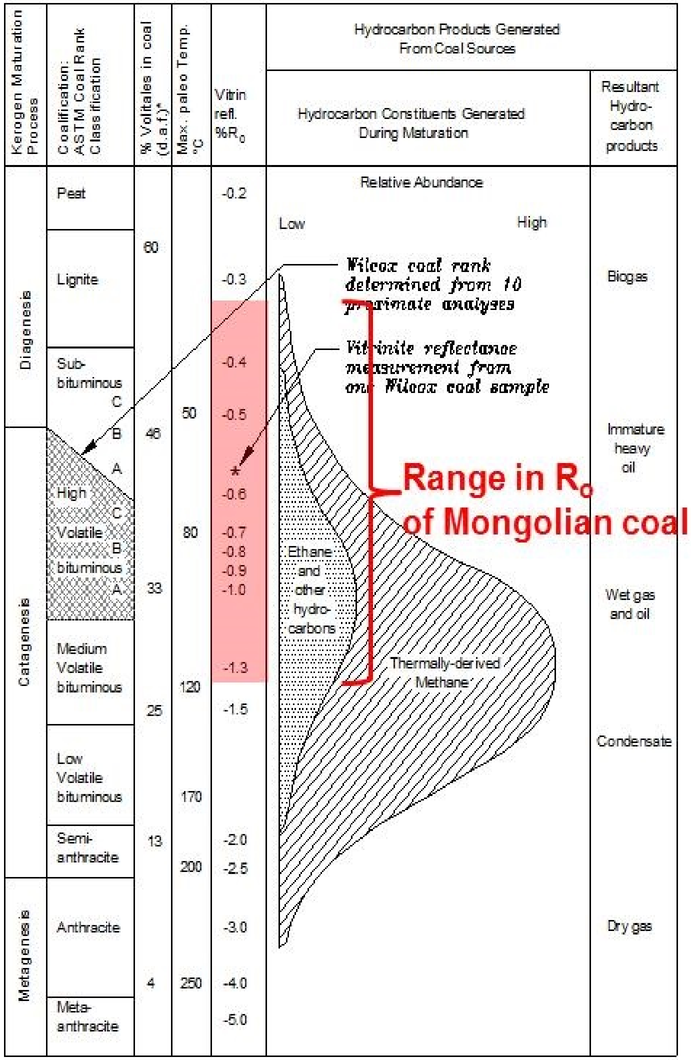
After Rice, 1993

Rank of Mongolian Coal and Hydrocarbon Generation Potential

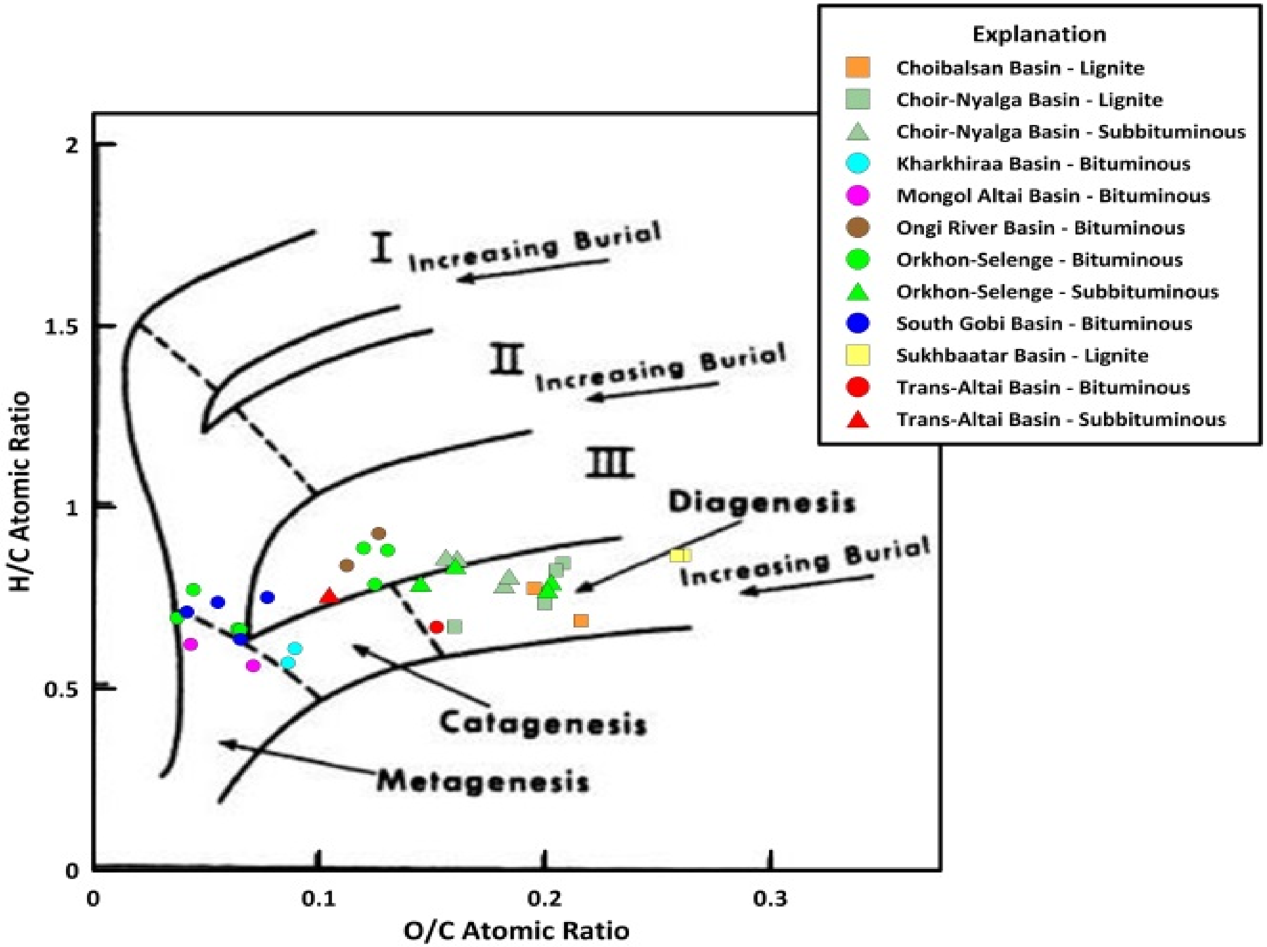
Powder River (subB)

San Juan and Raton Basins

(hvBb - mvb)



Kerogen Types of Known Coal Occurrences in Mongolian Coal Basins



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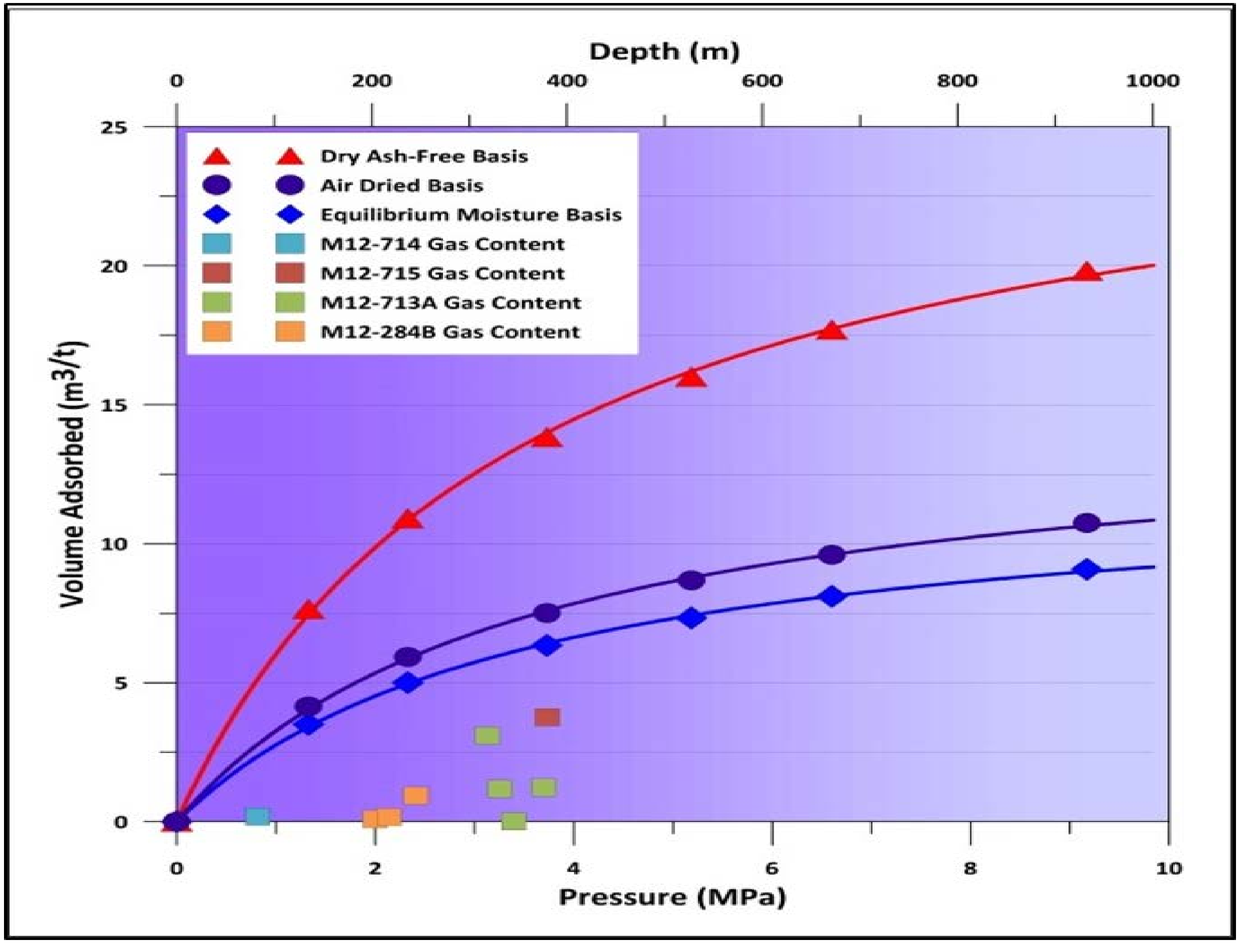
Comparison of CBM Producing Basins in USA to Coal Basins in Mongolia

	San Juan	Raton	Powder River	Tavan-tolgoi	Nariin-sukhait	Nuurstk-hotgor
Coal Rank	hvBb-mvb	hvBb-mvb	subB	hvBb-mvB	hvBb	hvBb-c
Gas Content m^3/tonne	3-14	6-14	<3	?	?	?
Max. Coal Thk.	8-14m	<3.5m	30-50m	1-73m	1-54m	1-38m
Cum. Coal Thk.	13-20m	13-22m	75-105m	?	?	?
Sorption Time	>52 days	>8 days	>7 days	?	?	?
Depth of Completion	~800m	~650m	~150m	?	?	?

Desorption Test Results at Naryn Sukhait

Sample Name	Borehole Name	Analysis Date	Sample Depth (m)	Gas Content	
				S&W (m^3/t) (raw)	S&W (m^3/t) (DAF)
CANISTER №1 29 October 2012	M12-714	11-Dec-12	83	0.184	0.193
CANISTER №2 09 November 2012	M12-715		379.7	3.758	3.758
CANISTER №3 15 November 2012	M12-713A	11-Dec-12	318.2	3.093	3.453
CANISTER №4 18 November 2012	M12-713A	11-Dec-12	331.2	1.185	1.573
CANISTER №5 22 November 2012	M12-713A	11-Dec-12	345.2	0.015	0.016
CANISTER №6 25 November 2012	M12-713A	11-Dec-12	376.2	1.231	1.334
CANISTER 1 - 524	M12-284B	17-Jun-12	203	0.09	0.168
CANISTER 2 - 525	M12-284B	17-Jun-12	217.4	0.172	0.0192
CANISTER 3 BTM - 526	M12-284B	17-Jun-12	245	0.941	1.753

Adsorption Testing Results



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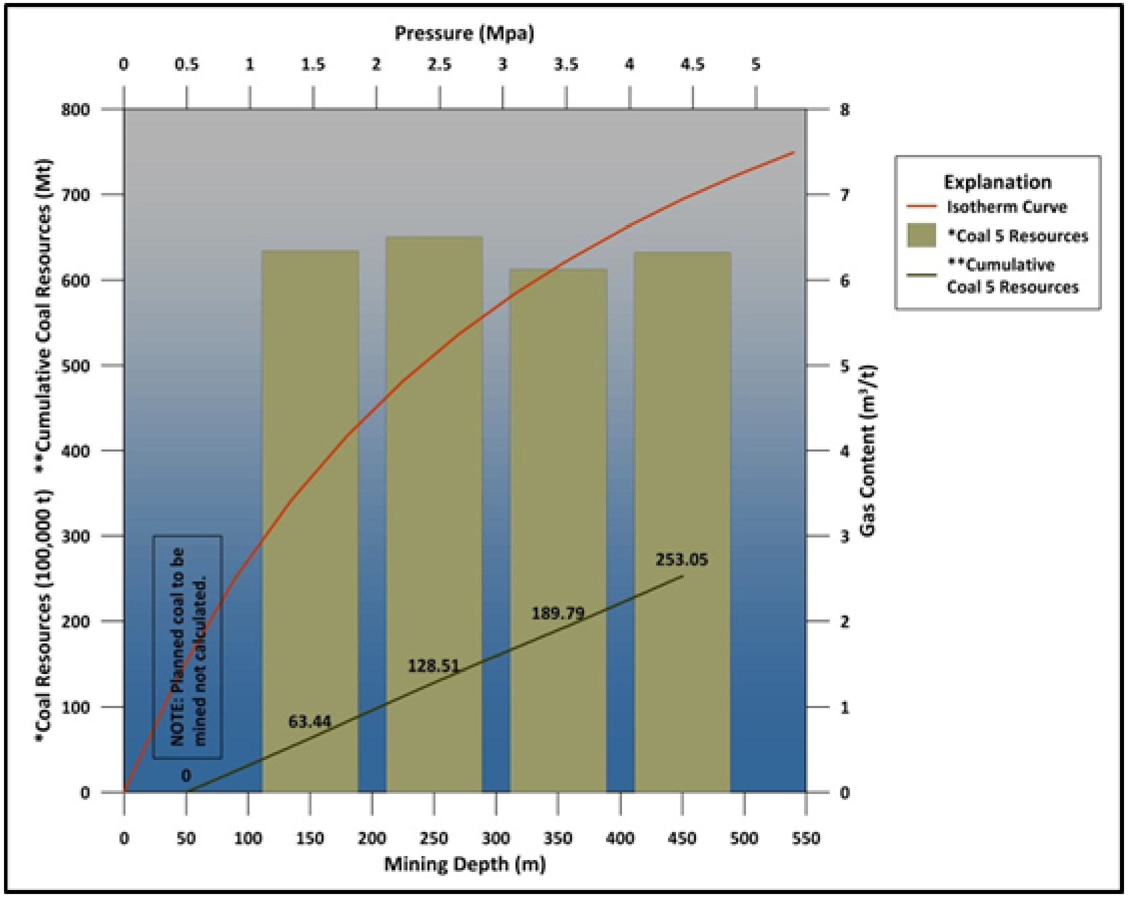
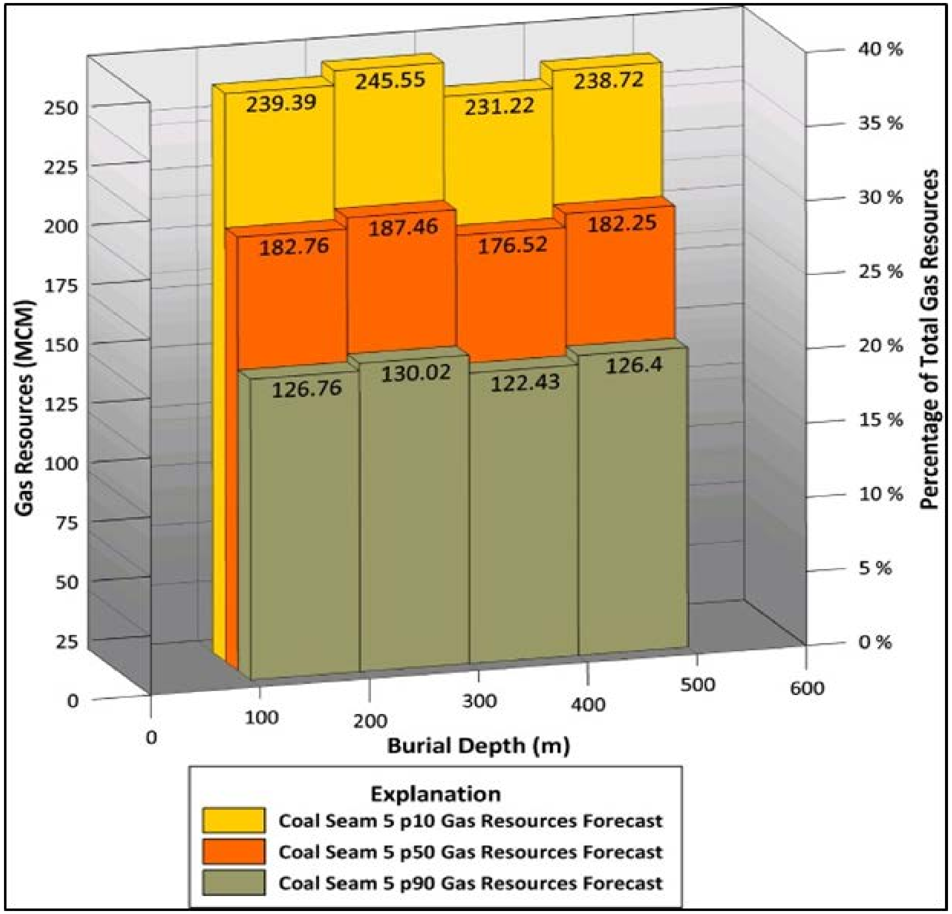
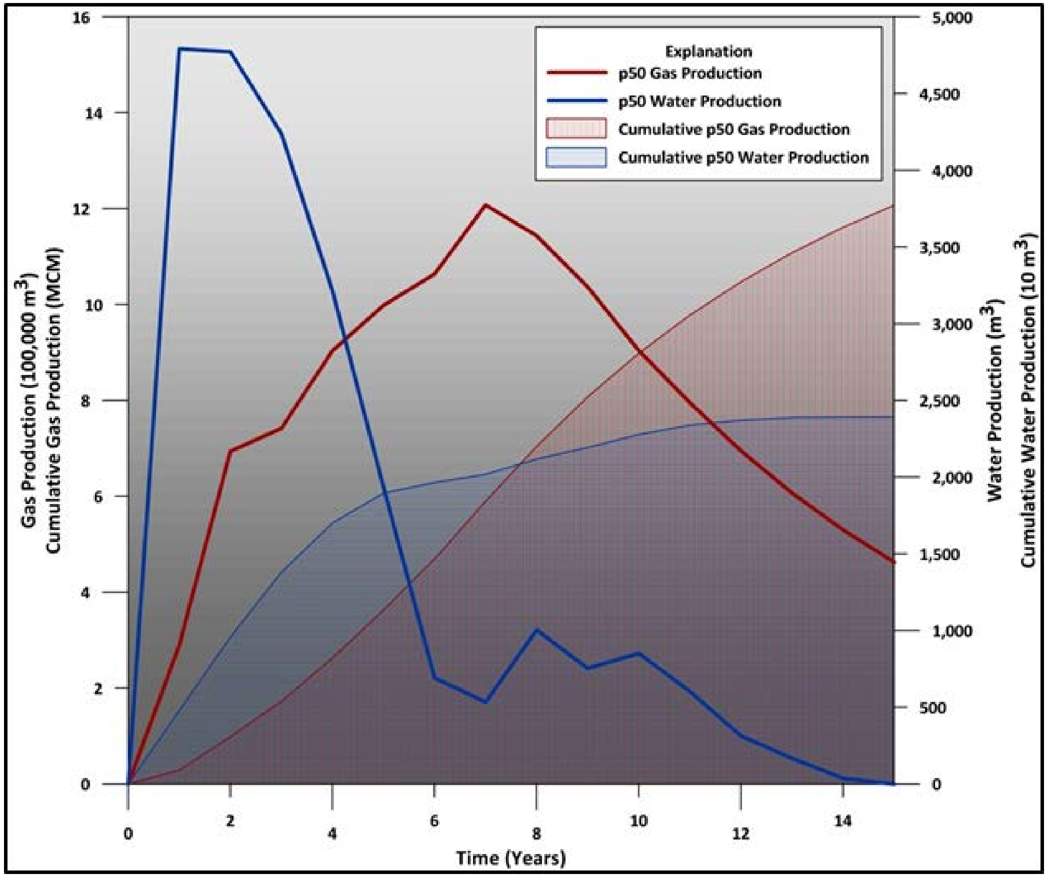
Calculated Coal Resources Shown by Depth, with Equilibrium Moisture Adsorption Isotherm



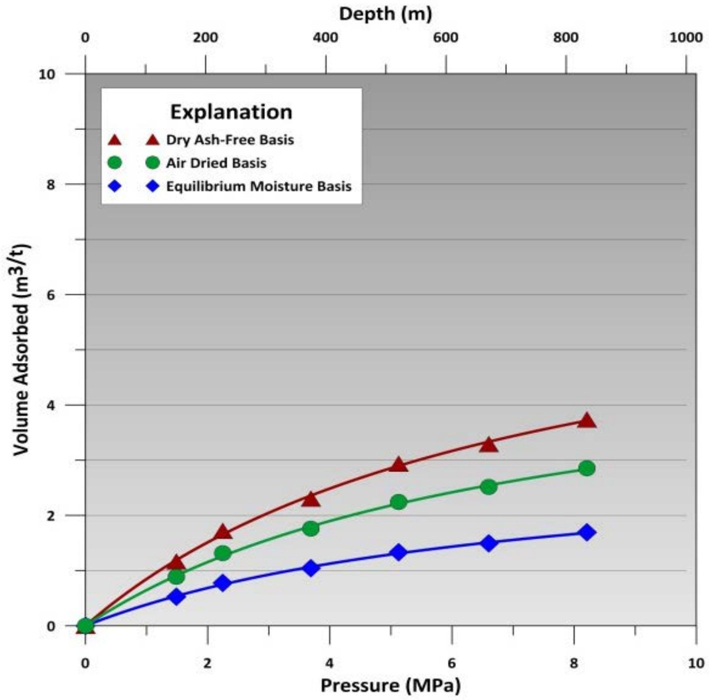
Probability Based Estimate of GIP by Depth Interval, Coal Seam 5 Naryn Sukhait

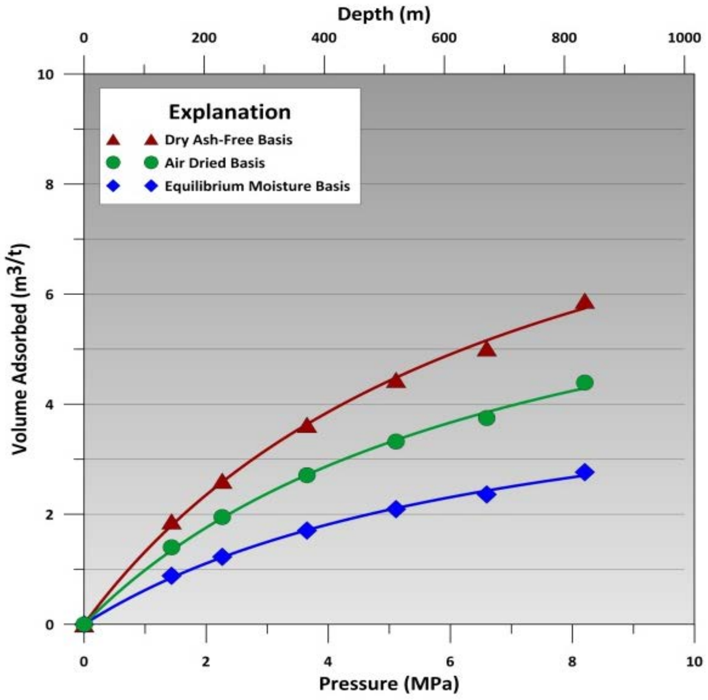


Gas and Water Production Forecast Based on p50 Decline Model

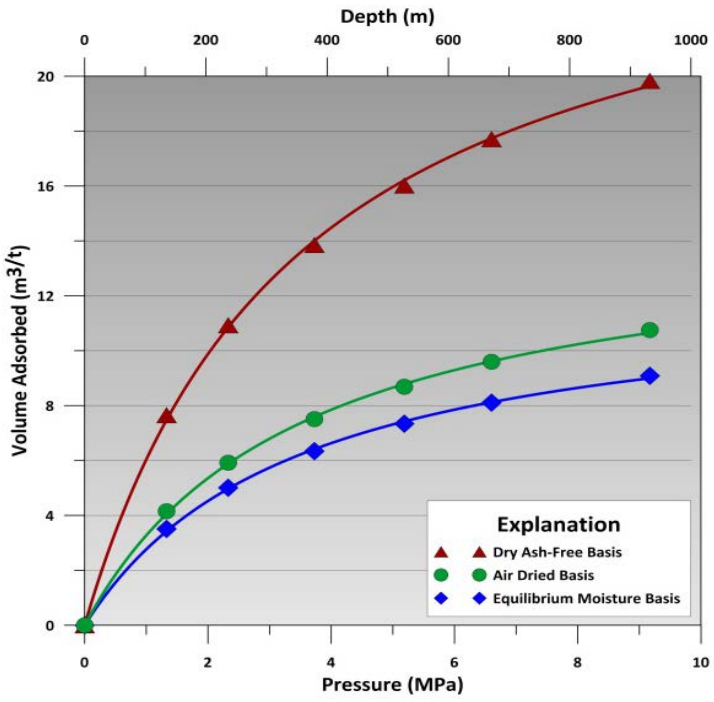


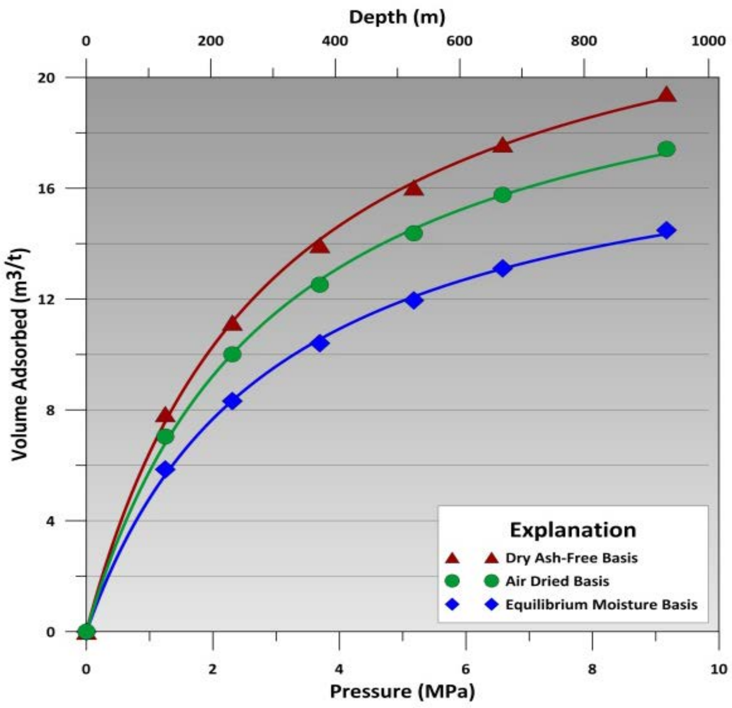
Methane Isotherms from Samples Collected at the Khotgor Deposit, Kharkhiraa Coal Basin





Methane Isotherms from Samples Collected at East and Central Gobi Coal Basins





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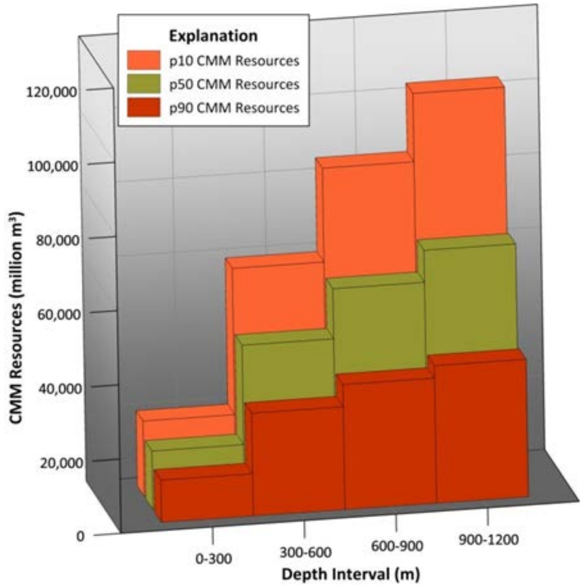
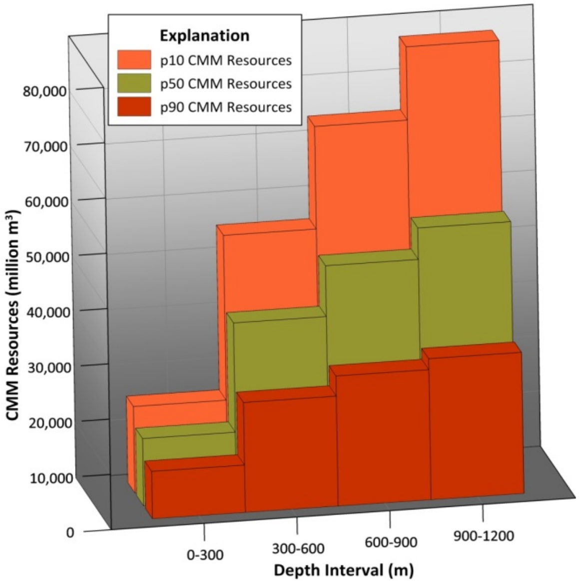
Stochastic (probability based) Resource Estimate for the Central Gobi Coal Basin





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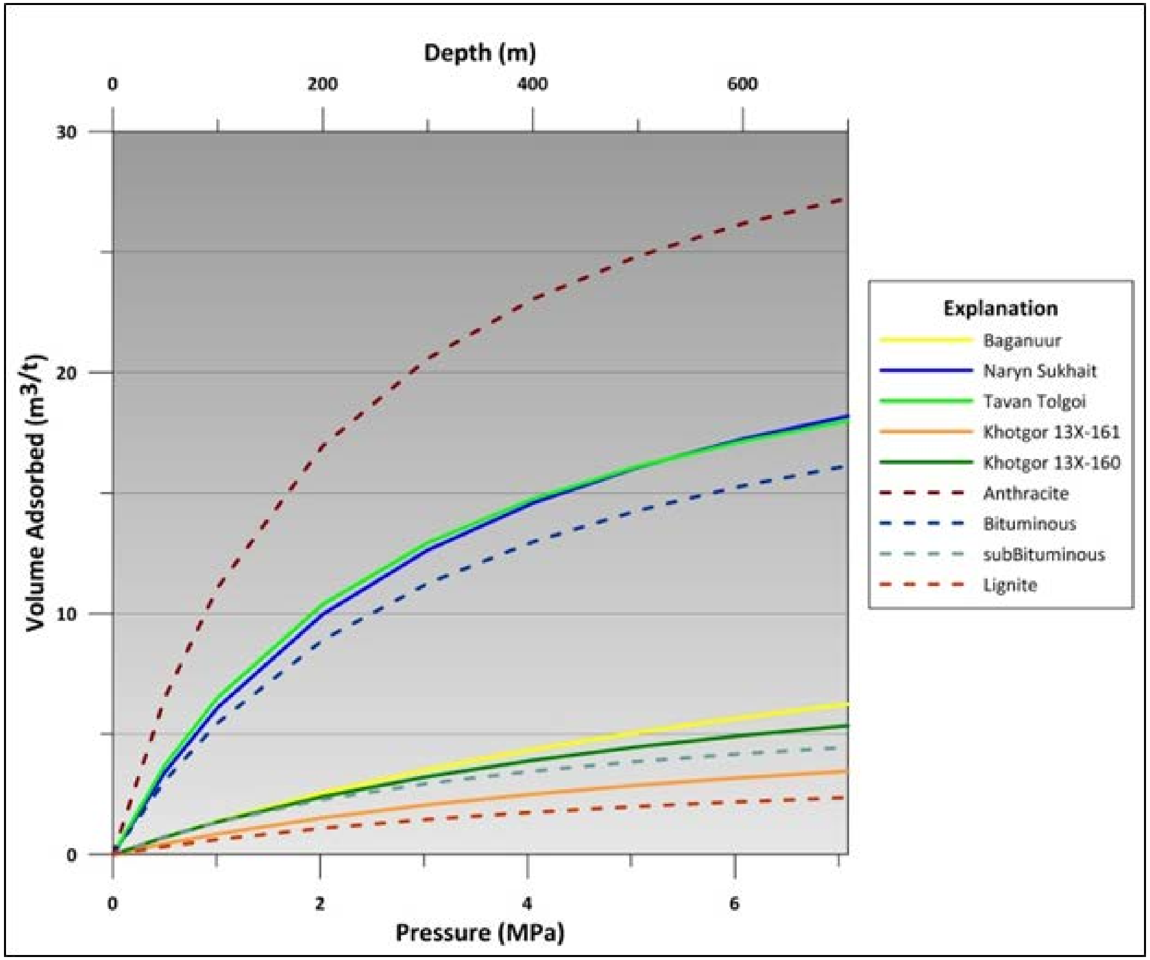
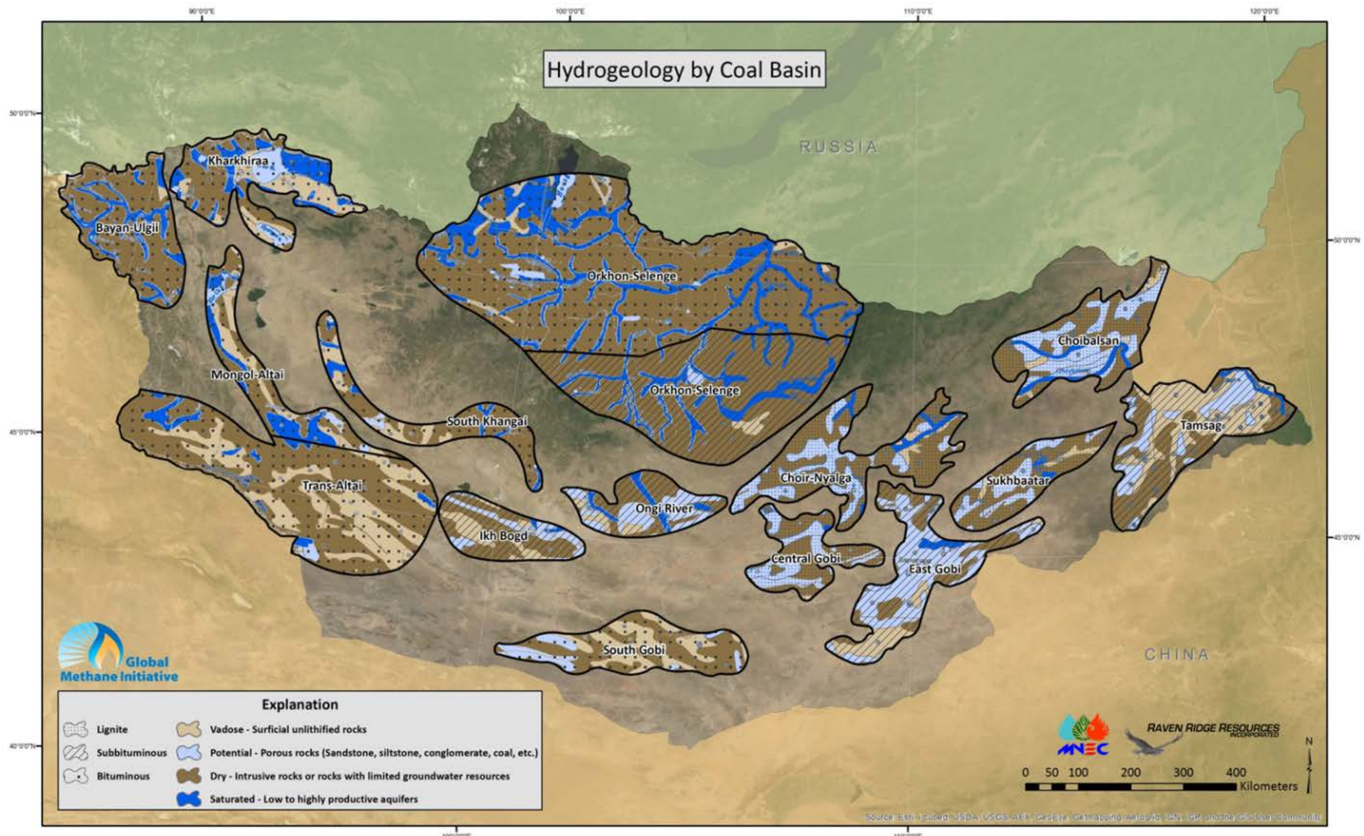
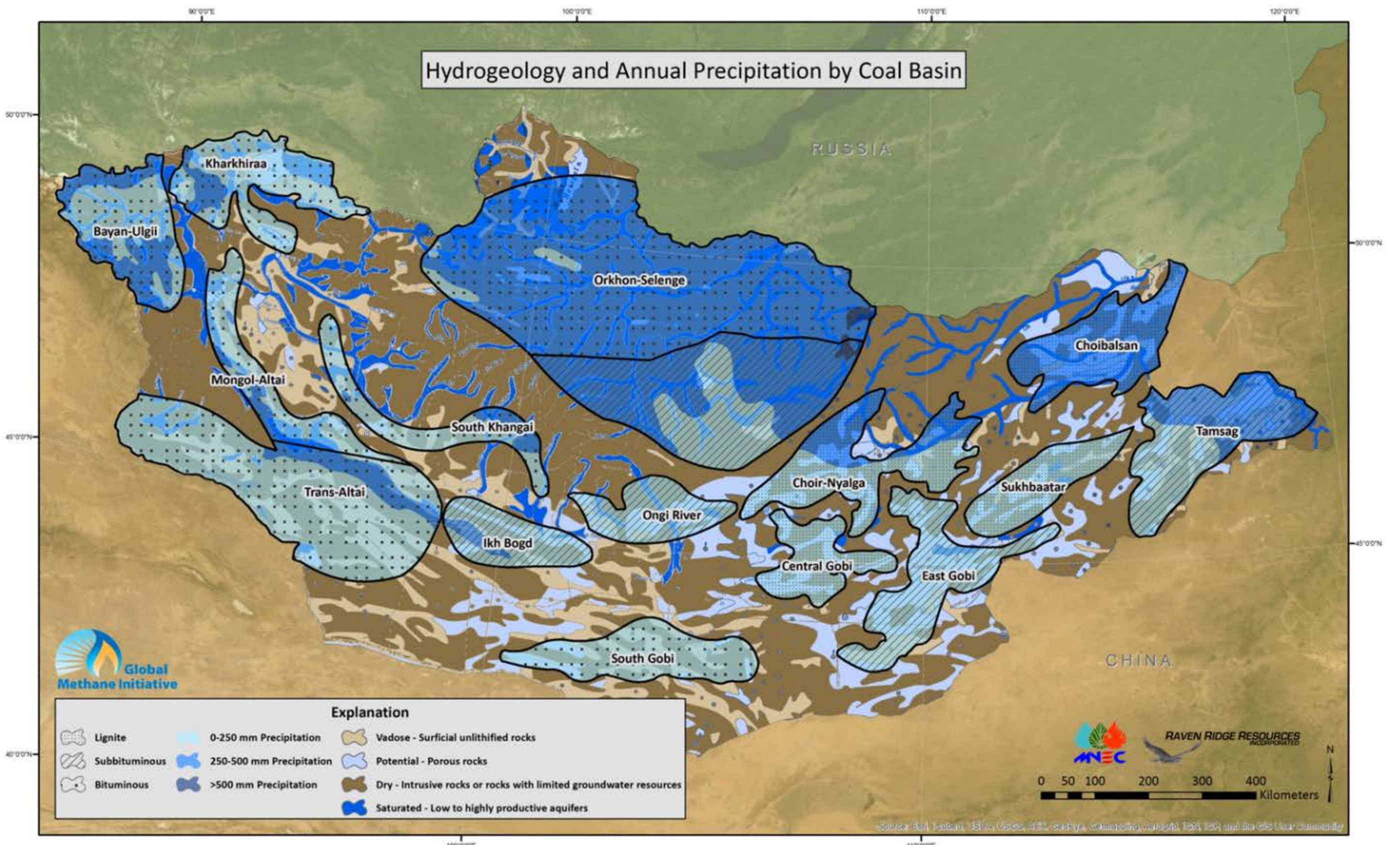
Comparison of Methane Isotherms from Mongolia to p50 Isotherms from Database of US Isotherms



Hydrology of Mongolian Coal Basins



Hydrology Overlain with Annual Precipitation



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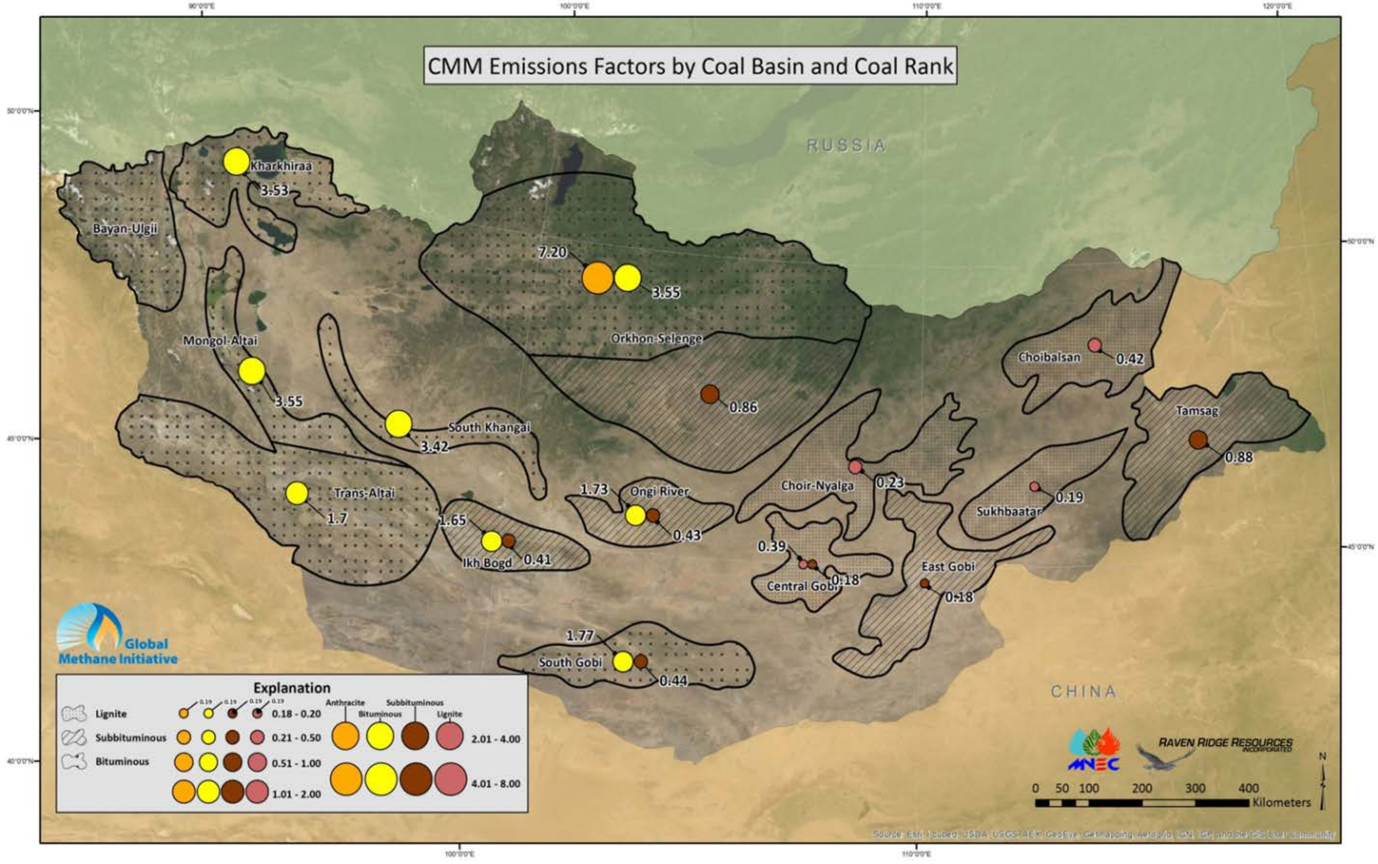
Estimated Emissions Factors for Mongolian Coal Basins



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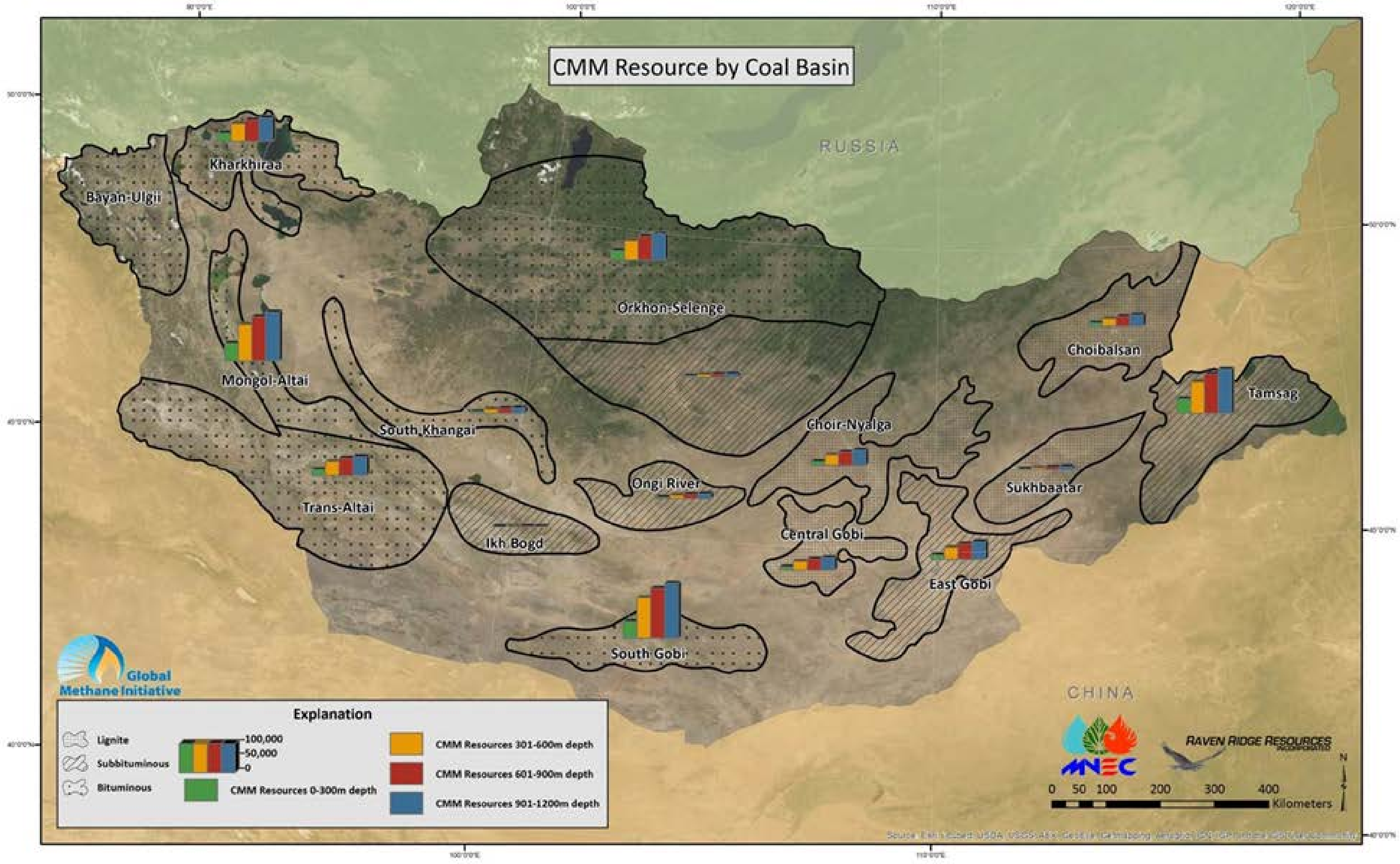
Estimated CMM Resources by Coal Basin In Mongolia



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Estimate of CMM Resources by Coal basin in Mongolia

Coal Basin	p50 CMM Resources 0 – 300 m (billion m^3)	p50 CMM Resources 300 – 600 m (billion m^3)	p50 CMM Resources 600 – 900 m (billion m^3)	p50 CMM Resources 900 – 1200 m (billion m^3)
Bayan-Ulgii	-	-	-	-
Central Gobi	12.2	31.9	41.1	46.8
Choibalsan	11.8	26.9	35.5	41.0
Choir-Nyalga	14.1	36.7	48.4	55.8
East Gobi	15.7	42.5	56.0	64.6
Ikh Bogd	0.7	1.7	2.1	2.3
Kharkhiraa	30.8	63.7	77.8	85.8
Mongol-Altai	64.3	132.8	162.2	178.8
Ongi River	5.2	12.6	15.5	17.2
Orkhon-Selenge (North)	34.0	69.9	85.1	93.7
Orkhon-Selenge (South)	4.2	9.2	11.6	13.0
Southern Khangai	7.6	15.9	19.5	21.5
South Gobi	61.8	148.6	181.8	200.7
Sukhbaatar	2.9	7.8	10.2	11.8
Tamsag	52.5	113.8	143.3	160.8
Trans-Altai	20.9	50.5	61.6	68.0
TOTAL	338.7	764.5	951.8	1,061.9

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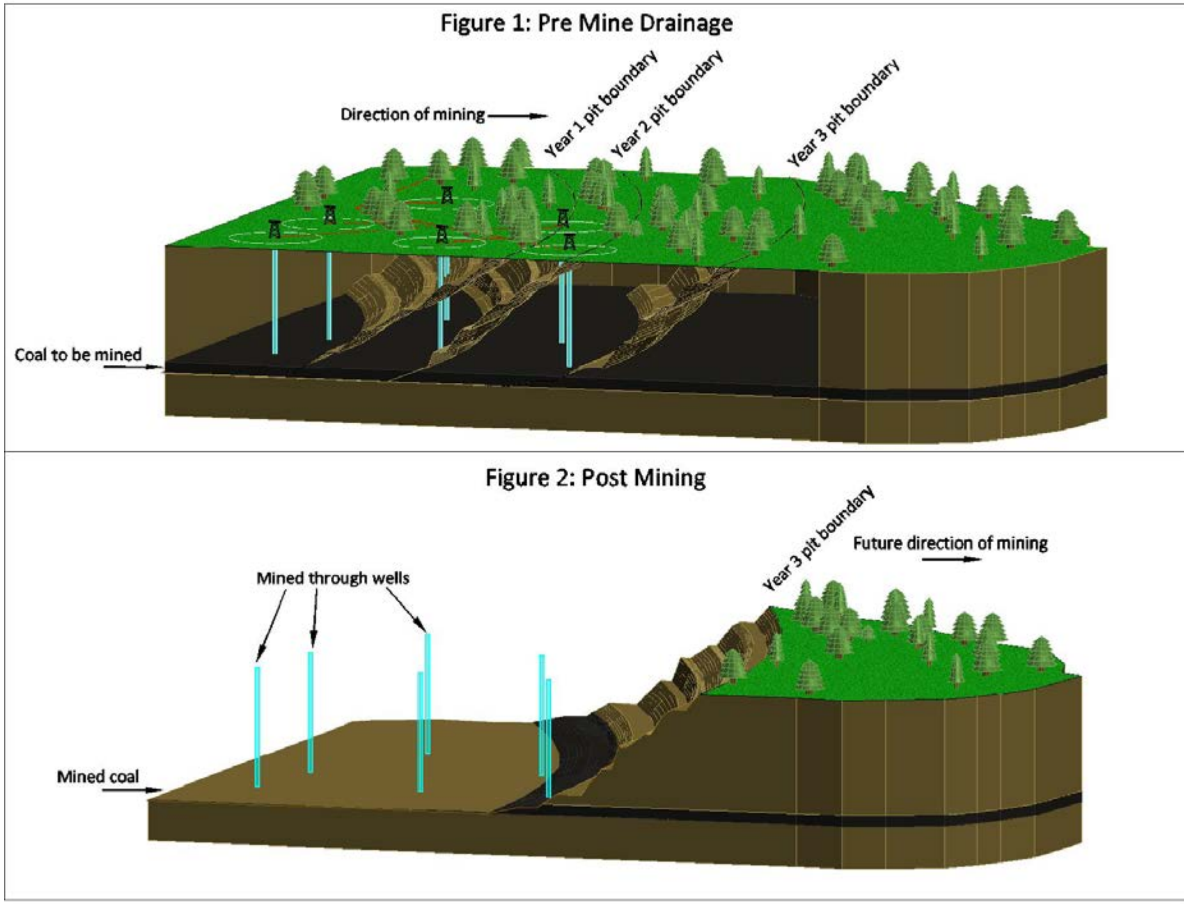
Coal Mine Development and the Impact on Resource Assessment

Vertically Drilled Boreholes



Overburden Removal Increases Permeability

- Permeability increases exponentially with decreasing effective stress.
- Effective stress is diminished as overburden is removed during mining.
- Permeable pathways occurring in geologic structures such as breached folds or faults are enhanced as overburden is removed.
- Matrix and fracture permeability is enhanced as a function of the stiffness of the rock mass, density of fracturing and thickness of overburden removed.

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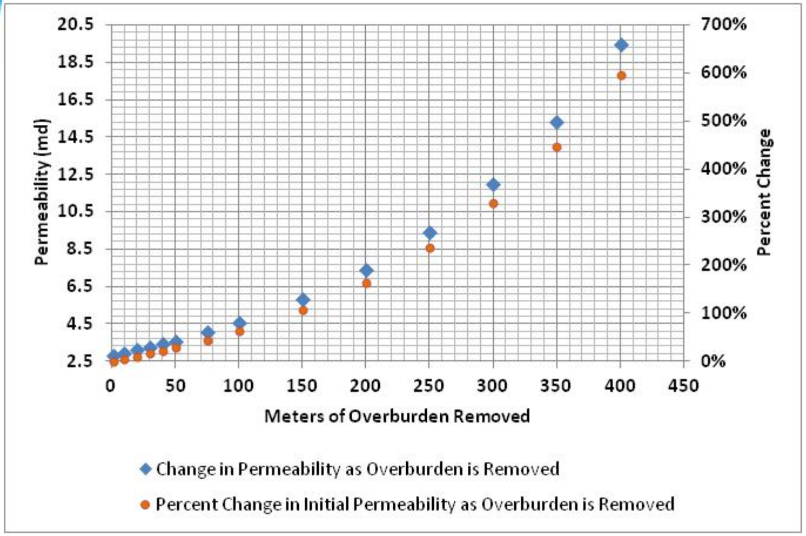
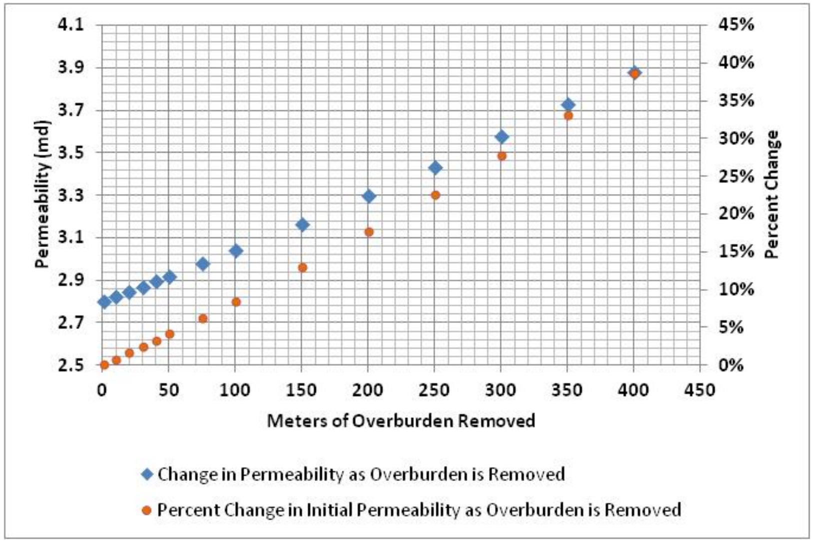
Impact of Rock Stiffness on Increases in Permeability as Overburden is Removed

Medium-Volatile Bituminous Coal



Sub-bituminous Coal



Fracture compressibility for bituminous coal from *A New Coal-Permeability Model: Internal Swelling Stress and Fracture-Matrix Interaction* by Hui-Hai Liu and Jonny Rutqvist, Transp Porous Med (2020) 82: 157-171.
Fracture compressibility for sub-bitumious coal, high volatile bituminous and equation for relationship between overburden removal and permeability increase from *Improvements in Measuring Sorption-Induced Strain and Permeability in Coal* by E.P. Robertson, SPE 116259, 2008 SPE Eastern Regional/AAPG Eastern Section Joint Meeting held in Pittsburgh, Pennsylvania.

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Effects Caused by Relaxation of Stresses in Coal Bearing Strata

- Void spaces remain after coal removal that allows surrounding strata to relax and create zones of increased permeability
- Fluids can use these zones as pathways during migration from higher to lower pressure regimes
- Zones of increased permeability are gas drainage targets
- Voids and zones of increased permeability may also become productive targets for gas production after mine closure, they may also be the pathway for water influx

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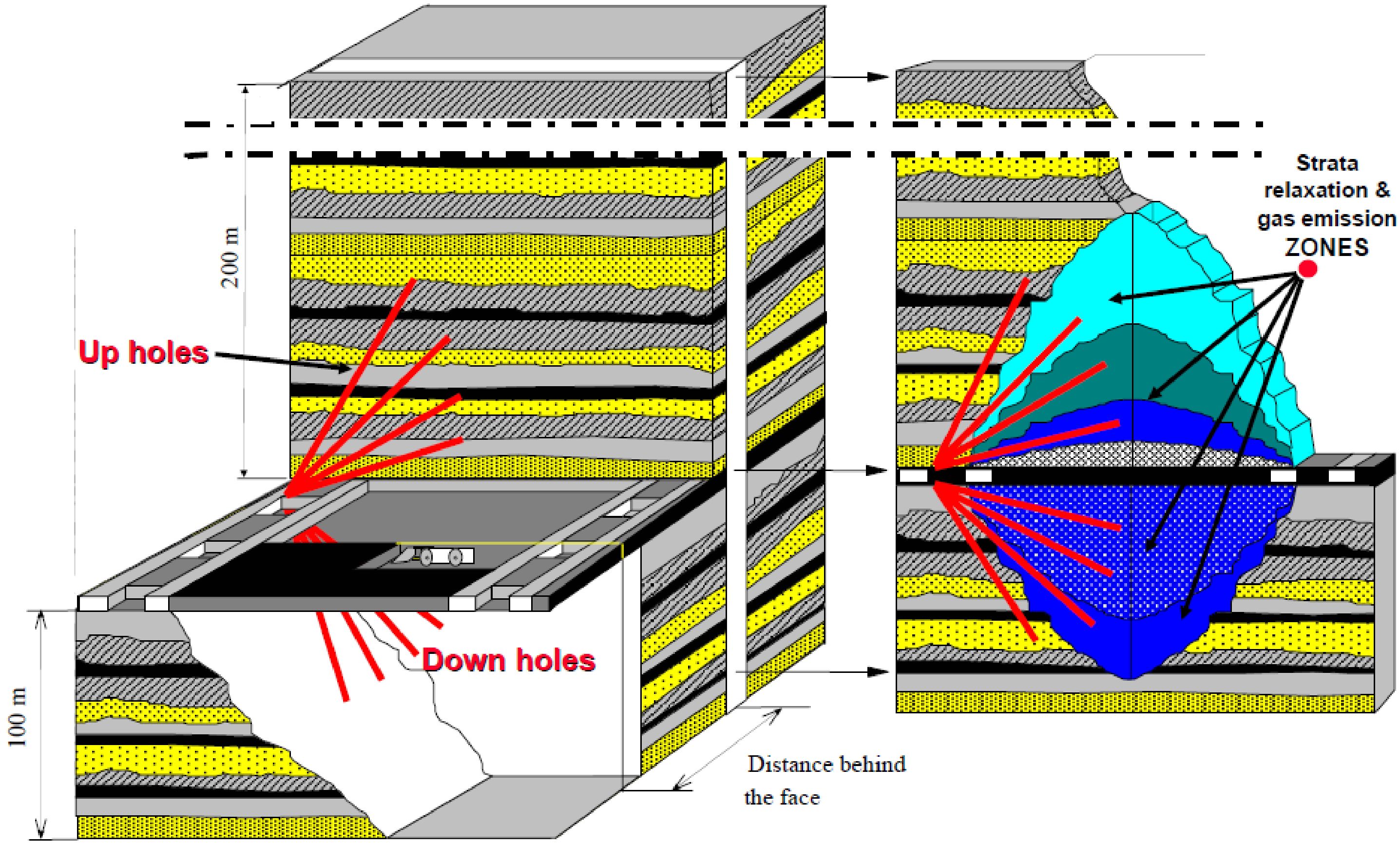
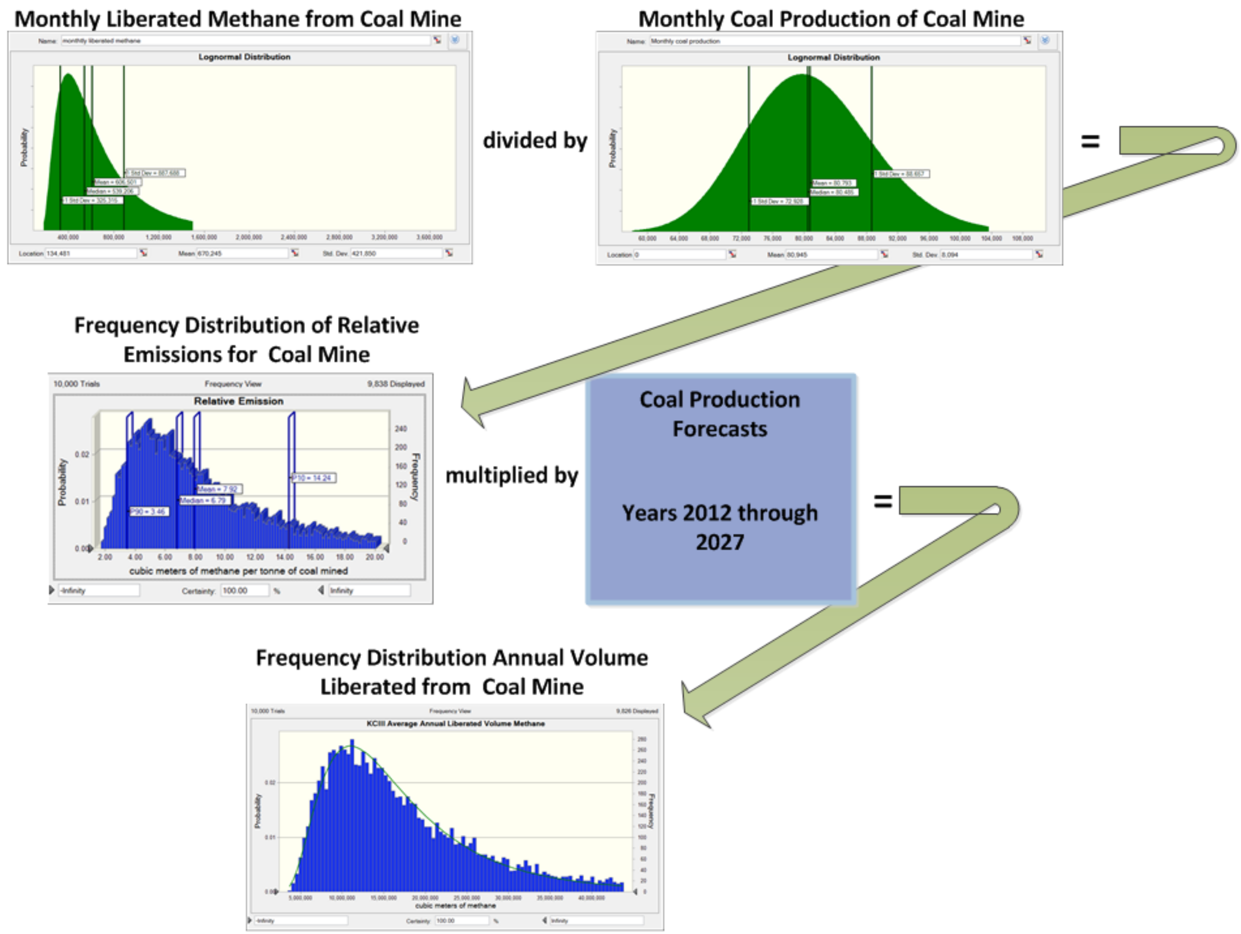
Impact of Mining on Gas Release



Method of Calculating Gas Resources at an Underground Coal Mine



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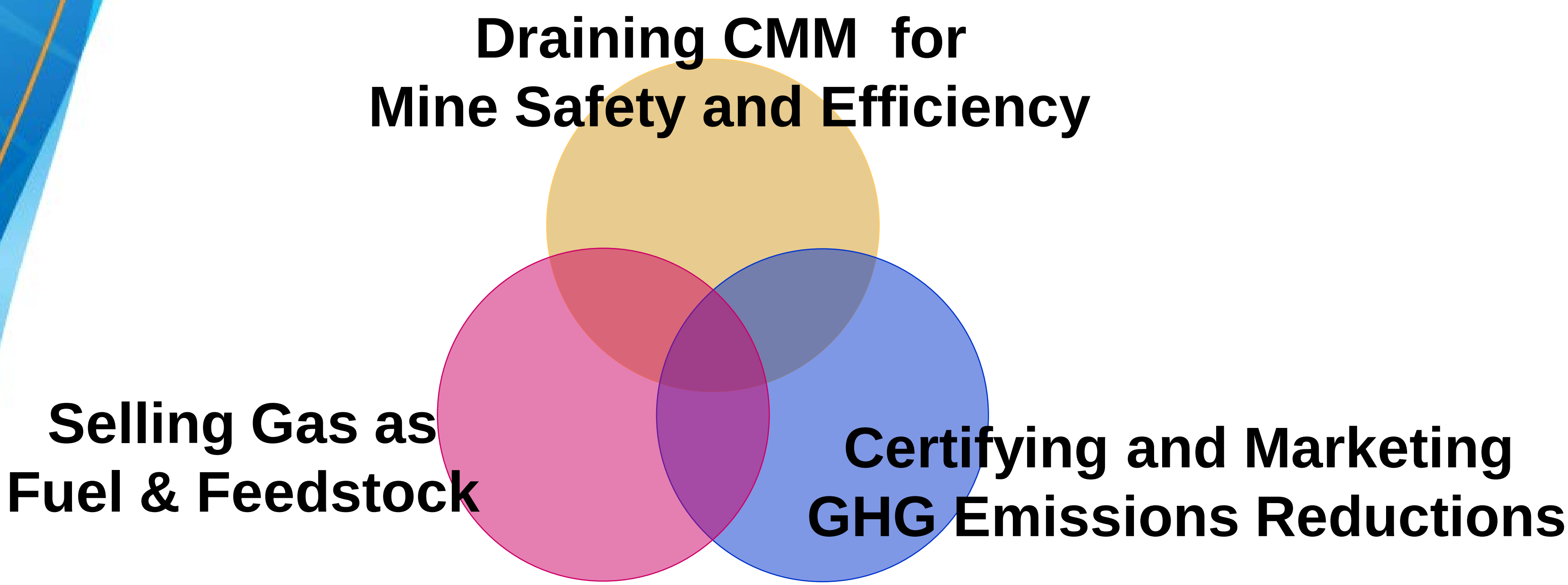
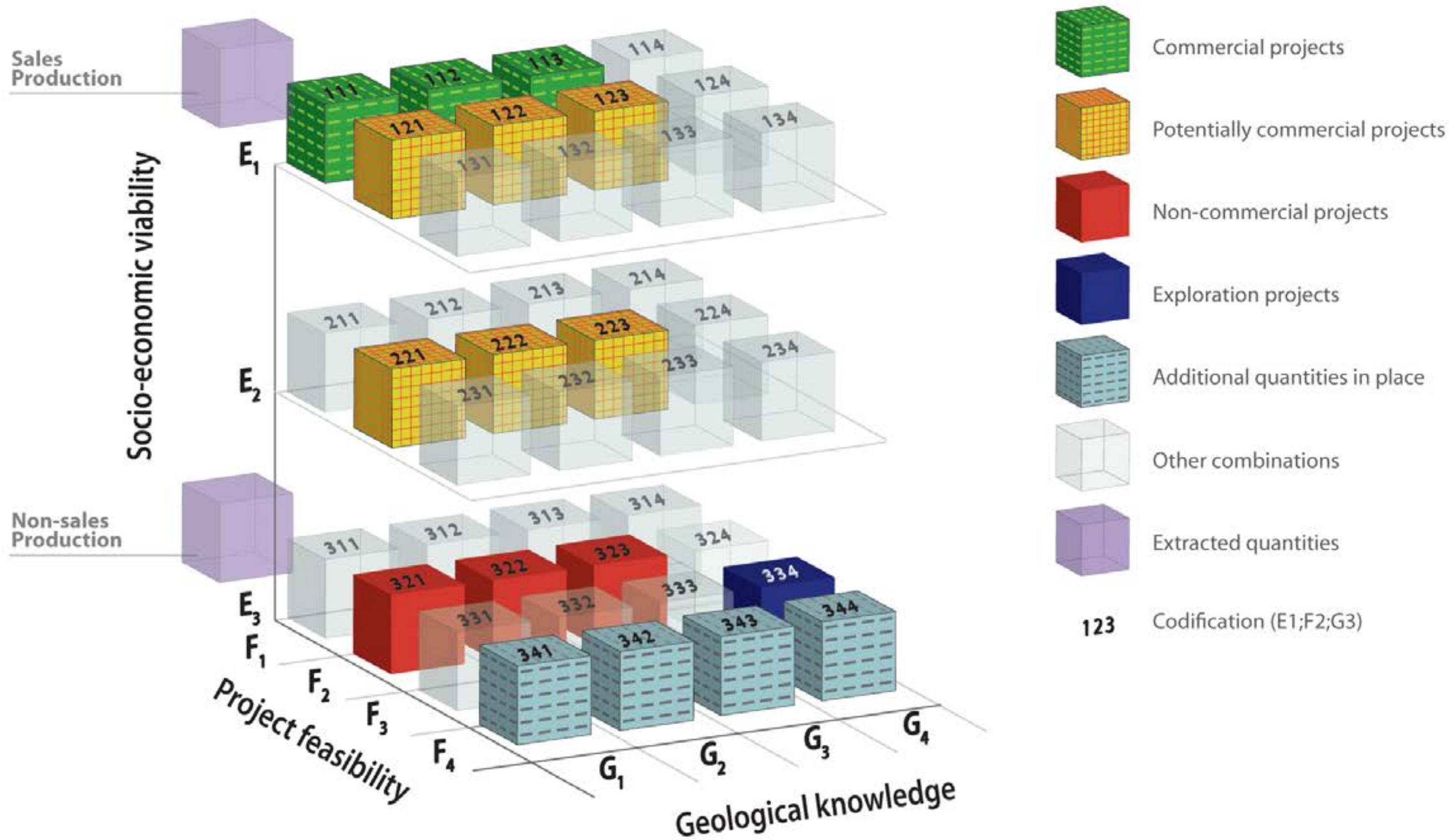
Including the Economic and Social Dimensions in Resource Assessments

Understanding the Issues that Drive the Economics and Operation of a CMM Project



UNFC Resource Classification and the Socio-Economic Dimension



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Muchas gracias!

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