U.S. EPA
Coalbed Methane
OUTREACH PROGRAM

Pre-feasibility Study for Coal Mine Methane Recovery at the Sawang Colliery, East Bokaro Coal Field, India

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

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

Prepared by:
Advanced Resources International, Inc.

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Acknowledgements

This publication was developed at the request of the USEPA, in support of the Global Methane Initiative (GMI). In collaboration with the Coalbed Methane Outreach Program (CMOP), Advanced Resources International, Inc. (ARI) authored this report based on information obtained from the coal mine partner, Central Coalfields Ltd. (CCL).

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Acronyms/Abbreviations

ac	Acre
ARI	Advanced Resources International, Inc.
Bcf	Billion Cubic Feet
Bcm	Billion cubic meters
CBM	Coalbed Methane
CCL	Central Coalfields Ltd.
CGD	City Gas Distribution
CGS	Central Generating Station
CH_4	Methane
CIMFR	Central Institute of Mining and Fuel Research
CMM	Coal Mine Methane
CMOP	Coalbed Methane Outreach Program
CMPDI	Central Mine Planning and Design Institute
CO_2	Carbon Dioxide
DGH	Directorate General of Hydrocarbons
DVC	Damodar Valley Corporation
EIA	Energy Information Administration
FEED	Front End Engineering & Design
FID	Final Investment Decision
ft	Feet
ft^3/min	Cubic feet per minute
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GJ	Gigajoule
gm/cc	Grams per cubic centimeter
GMI	Global Methane Initiative
hp	Horsepower
IPPs	Independent Power Producers

IRR	Internal Rate of Return
km	Kilometers
km^2	Square kilometer
kW	Kilowatt
kWh	Kilowatt-hour
LNG	Liquefied Natural Gas
m	Meter
m^3/min	Cubic meters per minute
m^3/t	Cubic meters per tonne
mD	Millidarcy
mm	Millimeter
MMBtu	Million British thermal units
MMscfd	Million standard cubic feet per day
MMscmd	Million standard cubic meters per day
Mscfd	Thousand standard cubic feet per day
MW	Megawatt
MWh	Megawatt-hour
NPV	Net Present Value
ONGC	Oil and Natural Gas Corporation
P_L	Langmuir Pressure
PLP	Production-Linked Payment
PNGRB	Petroleum & Natural Gas Regulatory Board
psia	Pounds per square inch absolute
SAIL	Steel Authority of India Limited
scf/ton	Standard cubic feet per ton
Tcf	Trillion cubic feet
tCO2e	Tonnes of carbon dioxide equivalent
USEPA	United States Environmental Protection Agency
V_L	Langmuir Volume

Metric/Imperial Unit Conversions

Metric	Imperial
1 hectare	2.47 acres
1 centimeter (cm)	0.4 inches
1 meter	3.281 feet
1 cubic meter (m^3)	35.3 cubic feet (ft^3)
1 metric tonne	2,205 pounds
1 metric tonne	1,000 kilograms
1 short ton	2,000 pounds
1 short ton	907.185 kilograms
1 kilo calorie (kcal)	3.968 Btu (British Thermal Units)
252,016 kcal	1 MMBtu (million British Thermal Units)
159 liters	1 Barrel (bbl)
1 MegaPascal (MPa)	145 psi
760 mgHg	1 atmosphere or 14.696 psi

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Executive Summary

With funding from the United States Environmental Protection Agency (USEPA), under the auspices of the Global Methane Initiative (GMI), this pre-feasibility study evaluates the technical and economic viability of a coal mine methane (CMM) recovery and utilization project at the Sawang Colliery in India. Advanced Resources International, Inc. (ARI) developed the study for a pre-mine drainage program for the Sawang Colliery located in the East Bokaro coalfield. The mine, which is operated by Central Coalfields Ltd. (CCL), is situated in the Bokaro district of Jharkhand state, about 125 kilometers (km) from Ranchi.

Methane emissions from the unmined south block extension area are projected to be very high, which will impact mine safety, productivity, and ventilation requirements. To help mitigate the projected high methane emission levels, the Central Mine Planning and Design Institute (CMPDI) and CCL have expressed an interest in pursuing a pre-mine methane drainage program at the mine. The principal objective of this pre-feasibility study is to assess the technical and economic viability of using long in-mine horizontal wells drilled into the virgin seams of the southern block extension area, and using this gas to produce electricity.

The primary markets available for a CMM utilization project at the Sawang Colliery are power generation using internal combustion engines, and pipeline sales for city gas distribution or use in the fertilizer or industrial (e.g., iron and steel, aluminum, and cement) sectors. Given the relatively small CMM production volume, as well as the requirement for gas upgrading, constructing a pipeline to transport the gas to demand centers would be impractical. Additionally, discussions with CMPDI indicate power generation for local consumption is the preferred end-use option for the drained gas. Generating electricity on site is attractive because the input CMM gas stream can be utilized as is, with minimal processing and transportation. Additional generating sets can be installed relatively cheaply and infrastructure for the power plant and distribution system is already planned. Based on the gas supply forecasts generated in this pre-

feasibility study, the mine could be capable of operating as much as 4.4 megawatts (MW) of electricity capacity.

The proposed pre-drainage project focuses on mining of the Kargali Top coal seam located in the south block extension area. Based on the mine maps provided by CMPDI, a total of 22 individual longwall panels can be developed within the project area. Optimal well spacing for development of the CMM project at the Sawang Colliery is determined to be 100 feet (ft) between wells, or five wells per longwall panel. Boreholes are drilled and begin producing gas five years prior to the initiation of mining activities at each panel. Degasification and mining of the 22 longwall panels is expected to be completed over a 27 year project life.

Based on results of reservoir simulations and the use of the optimized well spacing pattern, a gas production forecast for the project was developed, which was then input into the economic model to assess the project economics. For the proposed project development scenario, discounted cash flow analysis was performed for the upstream portion (i.e., CMM production) and the downstream portion (i.e., electricity production). A breakeven gas price was calculated in the upstream segment, and used in the downstream segment to calculate the fuel cost for the power plant. A breakeven electricity price was then calculated for the downstream segment.

Based on the forecasted gas production, the breakeven cost of producing gas through in-seam drainage boreholes is estimated to be $3.00 per million British thermal units (MMBtu), and the breakeven power sales price, inclusive of the cost of methane drainage, is estimated to be $0.064 per kilowatt-hour (kWh). According to the Central Electricity Authority, as of March 2014 the electricity tariff for large industrial customers in Jharkhand is $0.081/kWh, which does not include transmission and distribution charges and associated losses. When compared to the breakeven power sales price of $0.064/kWh as calculated in the economic analysis, utilizing drained methane to produce electricity would generate a profit of at least $17 per megawatt-hour (MWh) of electricity produced, or possibly more if the fully landed cost of electricity is accounted for. Furthermore, on-site power production would provide added energy security and help insulate the mine from the electricity shortages and chronic blackouts experienced throughout the country.

The power production option appears to be economically feasible, and removing the cost of mine degasification from downstream economics, as a sunk cost, would reduce the marginal cost of electricity and improve the economics even further. In addition, net emission reductions associated with the destruction of drained methane are estimated to average just under 95,000 tonnes of carbon dioxide equivalent (tCO2e) per year.

As a pre-feasibility study, this document is intended to provide a high-level analysis of the technical feasibility and economics of a CMM project at the Sawang Colliery. The analysis performed reveals that methane drainage using long, in-seam directional drilling in association with the development of the south block extension area is feasible, and could provide the mine with additional benefits beyond the sale of gas or power, such as improved mine safety and enhanced productivity.

1.0 Introduction

Under the auspices of the GMI, the USEPA works with coal mines in the U.S. and internationally to encourage the economic use of CMM gas that is otherwise vented to the atmosphere. Methane is both the primary constituent of natural gas and a potent greenhouse gas when released to the atmosphere. Reducing emissions can yield substantial economic and environmental benefits, and the implementation of available, cost-effective methane emission reduction opportunities in the coal industry can lead to improved mine safety, greater mine productivity, and increased revenues.

The GMI is an international partnership of 42 member countries and the European Commission that focuses on cost-effective, near-term methane recovery and use as a clean energy source. USEPA, in support of the GMI, has sponsored feasibility and pre-feasibility studies in China, Kazakhstan, Mongolia, Poland, Russia, Turkey and Ukraine, among others. These studies provide the cost-effective first step to project development and implementation by identifying project opportunities through a high-level review of gas availability, end-use options, and emission reduction potential.

This pre-feasibility study evaluates the technical and economic viability of a CMM recovery and utilization project at the Sawang Colliery in India. As a major coal mining country and one with significant challenges related to methane emissions into mine workings, success in delivering CMM projects in India will contribute greatly to reducing regional and global methane emissions.

Methane emissions from the unmined south block extension area of the Sawang Colliery are projected to be very high, which will impact mine safety, productivity, and ventilation requirements. To help mitigate the projected high methane emission levels, the CMPDI and CCL have expressed an interest in pursuing a pre-mine methane drainage program at the mine. The principal objective of this pre-feasibility study is to assess the technical and economic viability of using long in-mine horizontal wells drilled into the virgin seams of the southern block extension area, and using this gas to produce electricity. A Final Investment Decision (FID) should only be made after completion of a full feasibility study based on more refined data and detailed cost estimates, completion of a detailed site investigation, implementation of well tests, and possibly completion of a Front End Engineering & Design (FEED).

2.0 Background

The Sawang Colliery, operated by CCL, is located in the East Bokaro coalfield, situated in the Bokaro district of Jharkhand state, about 125 km from Ranchi (Exhibit 1).

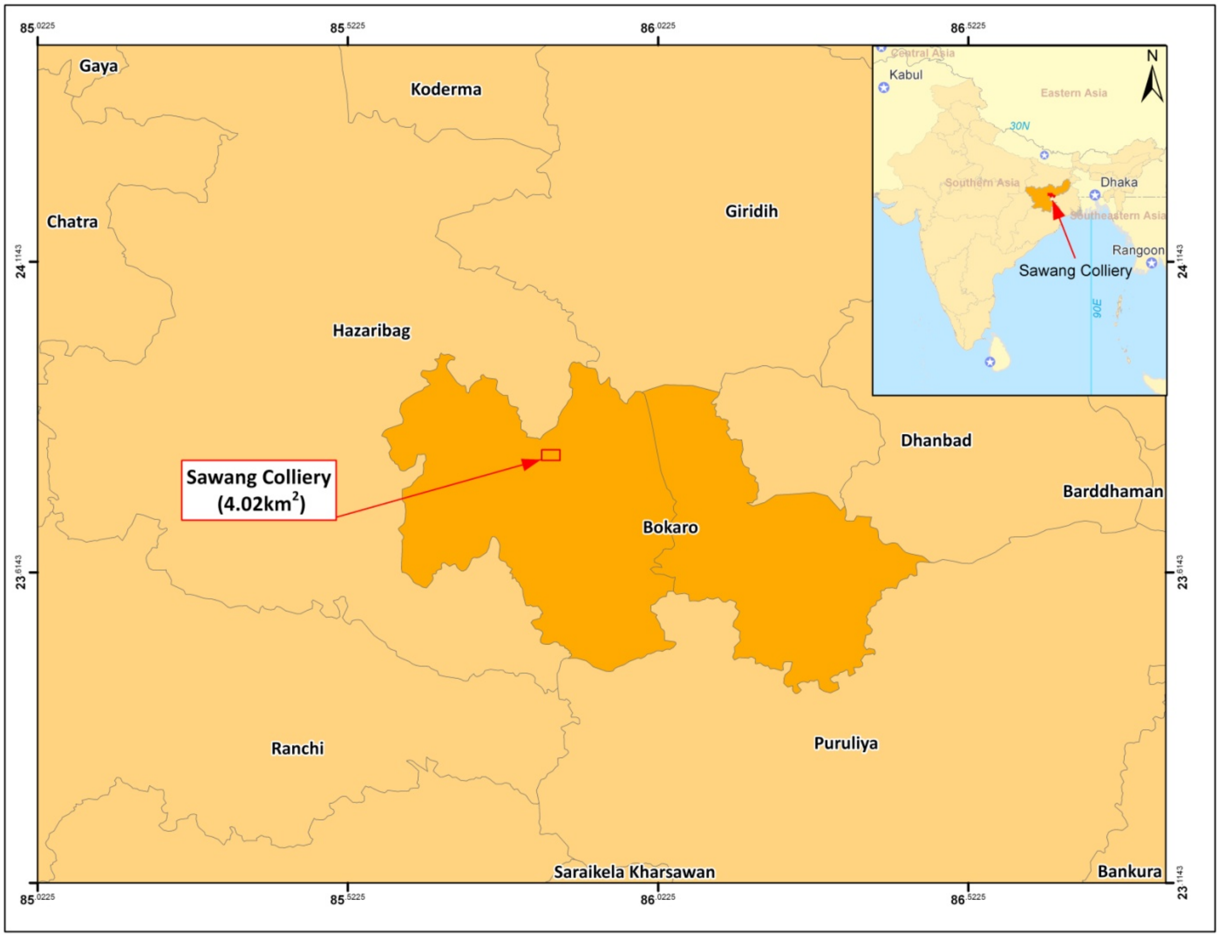


Exhibit 1: Location Map of the Sawang Colliery

The Sawang Colliery is a Degree III gassy mine, the highest classification for Indian underground mines. Exhibit 2 shows the categorization of mine gassiness based on gas concentration of air near workings and/or the gas content per tonne of coal mined.

Degree I	Percentage of inflammable gas in the general body of air near seam workings does not exceed 0.1 percent and the rate of emission per tonne of coal produced does not exceed 1 cubic meter (m^3) (35.31cubic feet, ft^3)
Degree II	Percentage of inflammable gas in the general body of air near Seam workings is more than 0.1 percent and rate of emission per tonne of coal produced does exceeds 1 m^3 (35.31 ft^3) and is less than 10 m^3 (353 ft^3)
Degree III	The rate of emission of inflammable gas per tonne of coal produced exceeds 10 m^3 (353 ft^3)

Exhibit 2: Classification of Degree Gassiness in Indian Underground Mines

The East Bokaro coalfield is one of the Gondwana-age basins of the Damodar Valley coalfields in eastern India (Exhibit 3). Situated in the northern limb of the main synclinal basin of the East Bokaro Coalfield, the 237 square kilometer (km^2) coalfield includes deposits of the Raniganj, Barakar, and Karharbari coal bearing formations. Presently, the region where the Sawang Colliery is located is host to more than a dozen coal mines overseen by CCL. Previous coalbed methane (CBM) activities have been pursued by the Oil and Natural Gas Corporation (ONGC) through a commercial development project, which is adjacent to the south block extension area (not currently mined).

CMM extraction from the Sawang Colliery is not new to the area. In the 1980s an in-seam degasification system was installed in the Kargali Top seam of zone 27. Methane emission rates from the in-mine boreholes ranged from 3.5 to 10 cubic meters per minute (m^3/min) (123 to 353 cubic feet per minute, ft^3/min).

The mine has been exploiting progressively deeper coal reserves as the mine moves down dip. Methane emissions from the unmined south block extension area are projected to be very high, which will impact mine safety, productivity, and ventilation requirements. To help mitigate the projected high methane emission levels, CMPDI and CCL have expressed an interest in pursuing long, in-seam directional drilling to drain methane in advance of mining. This technical assessment examined the feasibility of using long (4,000 ft length) in-mine horizontal wells drilled into the virgin seams of the southern block extension area.

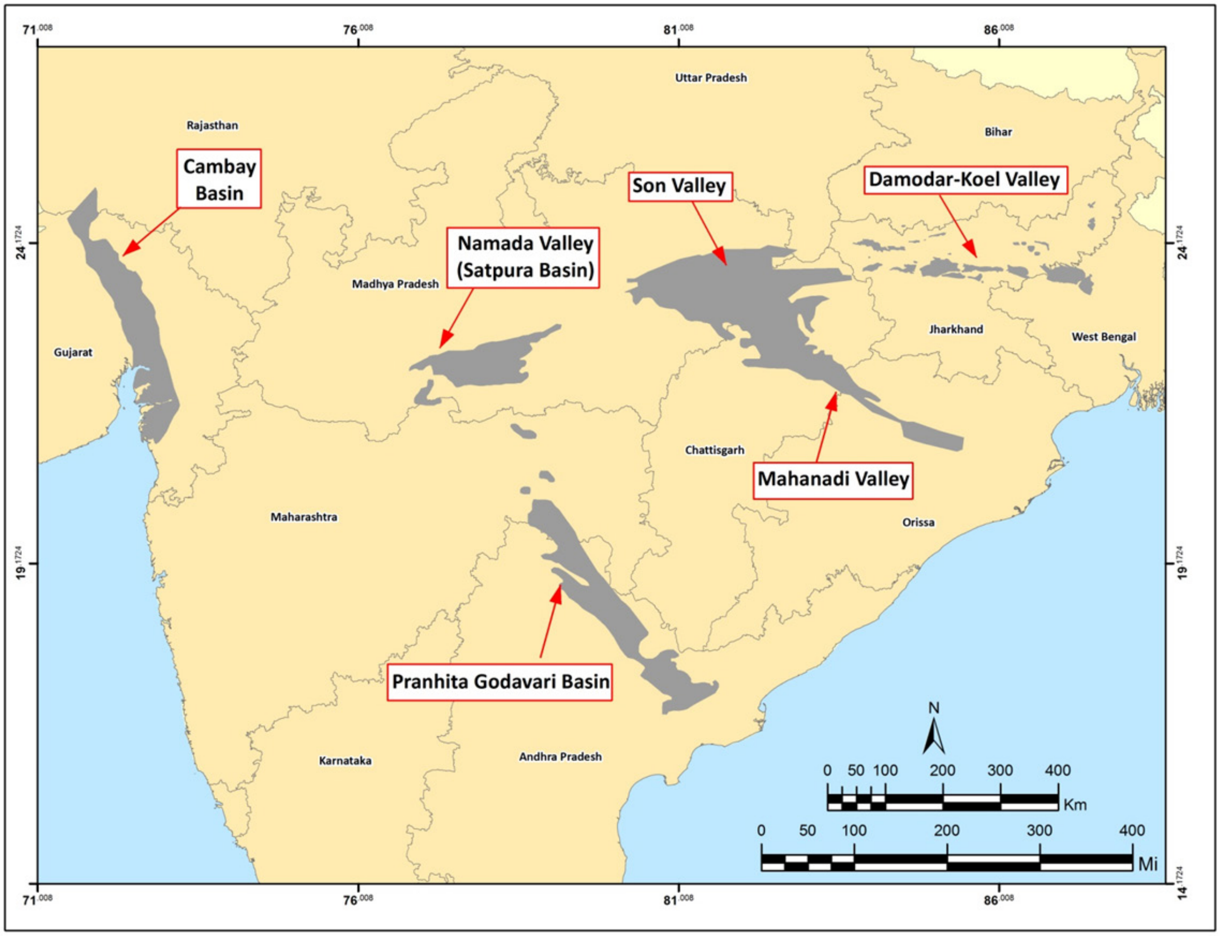
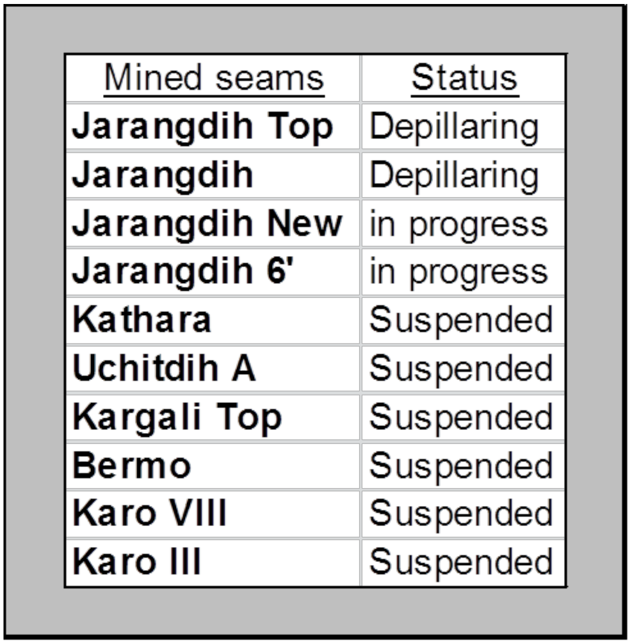


Exhibit 3: Gondwana Aged Valleys and Basins of India

3.0 Summary of Mine Characteristics

3.1 Mining Activity and Mining Characteristics at the Sawang Mine

A total of ten seams are currently being developed or have been developed to some degree at the Sawang mine as shown in Exhibit 4 below. Mining activity in the Sawang mine is currently in four seams of the Jarangdih group. Depillaring is occurring in the Jarangdih Top and Jarangdih, while the Jarangdih New and Jarangdih 6’ seams are being developed. The high emission of methane in the southeastern section of the Kargali Top seam has prevented advancement of the headings and made it unproductively slow.



Mined seams	Status
Jarangdih Top	Depillaring
Jarangdih	Depillaring
Jarangdih New	in progress
Jarangdih 6'	in progress
Kathara	Suspended
Uchitdih A	Suspended
Kargali Top	Suspended
Bermo	Suspended
Karo VIII	Suspended
Karo III	Suspended

Exhibit 4: Mining Activity at the Sawang Colliery

3.1.1 Mine Geology

The maps in Exhibit 5 and Exhibit 6 show the location and size of the Sawang block and the south extension block. Presently, there is no active mining in the south extension block, but recent developments of CBM in the area indicate that methane recovery in the area is viable. The present pre-feasibility study is focused on the viability of using long in-seam directional wells drilled from the existing mine workings into the un-mined southern extension of the block (i.e., the south extension block).

Structurally, the Sawang colliery is traversed by 19 faults that have a vertical displacement (throw) of less than 5 meters (m) to 280 m. The structure map (Exhibit 7) illustrates this complex geology in the area of the Sawang Colliery.

The strata of the formations within the mine generally strike from east to west and change in the central area to northwest to southeast and northeast to southwest. In the southeast portion of the mine the strata strikes from north to south and is a local feature. The seams dip in varying degrees and can be broken into the northern, eastern and southeastern parts. The north dips from 19 degrees to 35 degrees, the eastern strata dips from 14 degrees to 17 degrees, and the southeastern ranges from 5 degrees to 12 degrees.

Mica peridotite igneous intrusions are present in the Sawang A, Sawang B, Kargali Top and Kargali Bottom in multiple wells. More than 80 percent of the boreholes show that the Bermo seam has been cooked by intrusions to some degree.

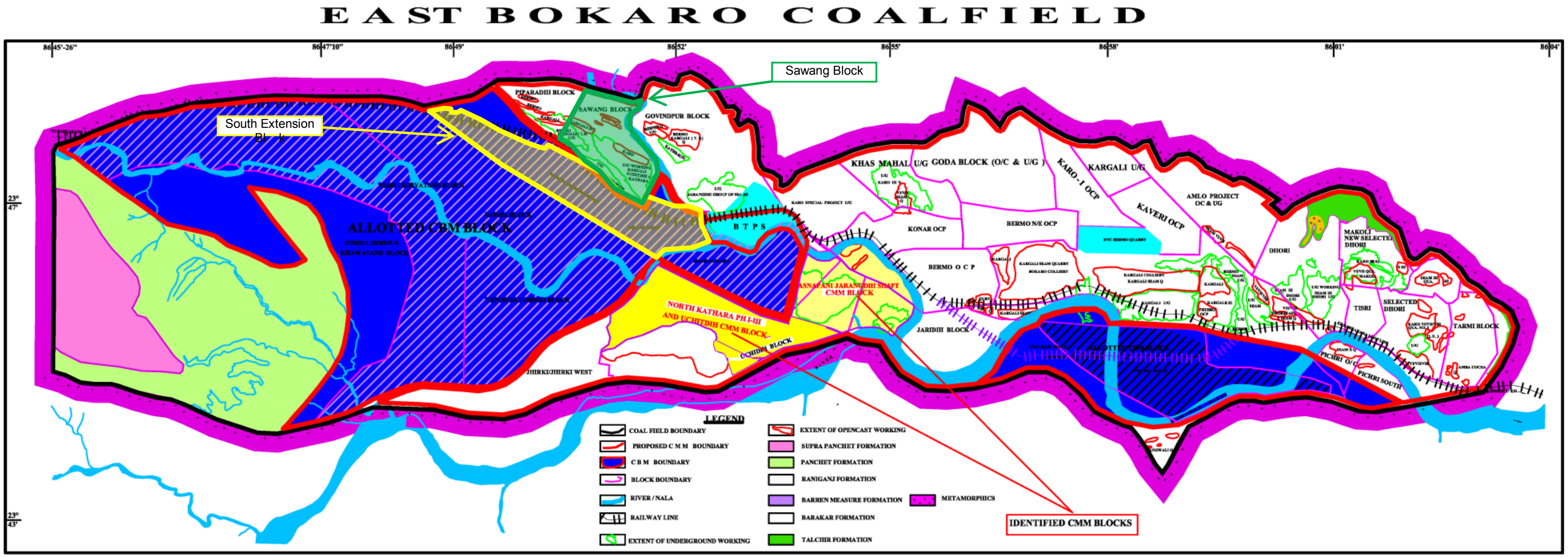
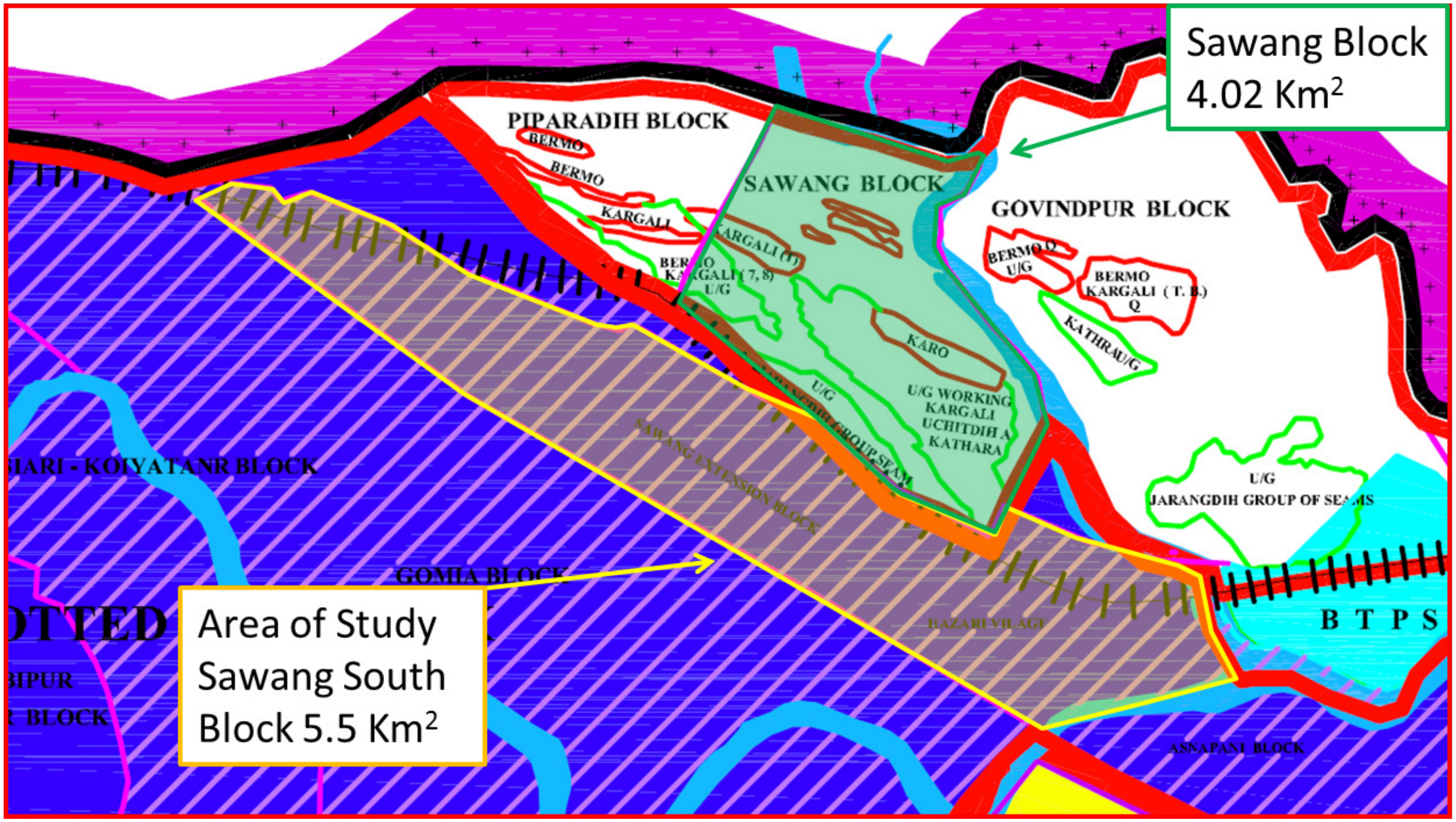


Exhibit 5: Location Map of Sawang Block and South Extension Block



Sawang Block
4.02 Km^2

Area of Study
Sawang South
Block 5.5 Km^2

Exhibit 6: Sawang Block and South Extension Block Area Comparison

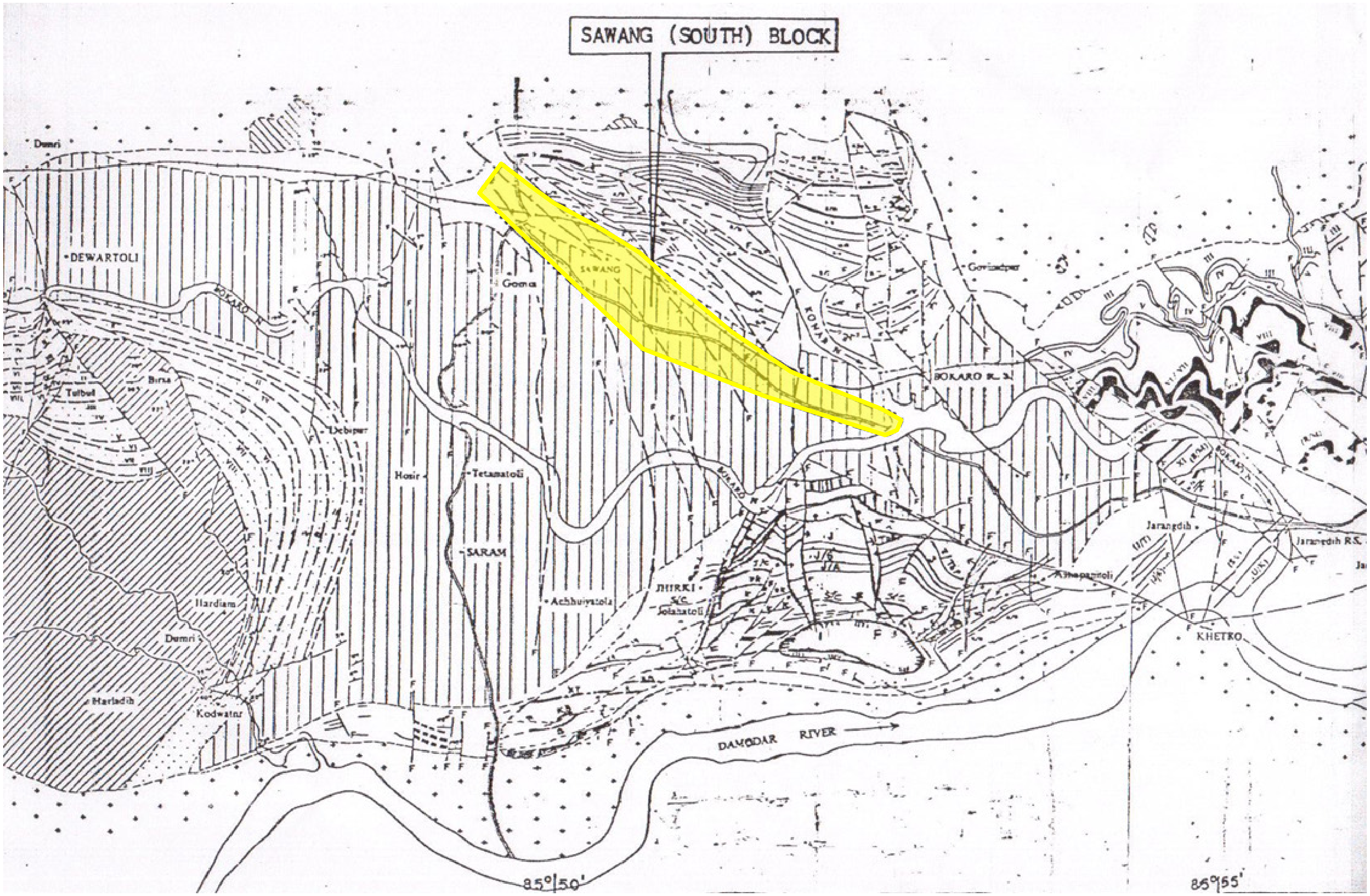
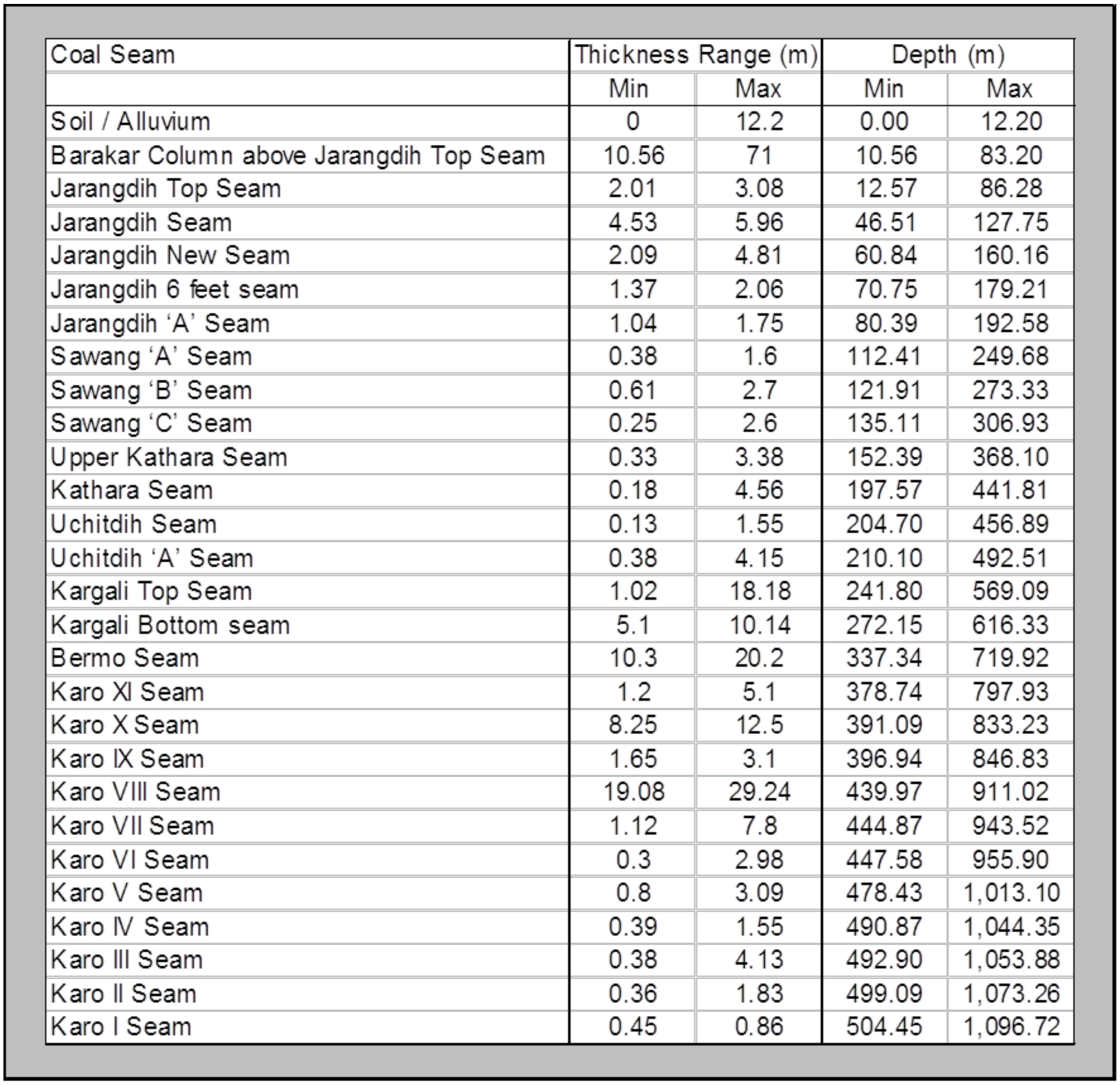


Exhibit 7: Structure Map of the East Bokaro Coal Field with the Sawang South Block Denoted in Yellow

3.1.2 Thickness and Depth

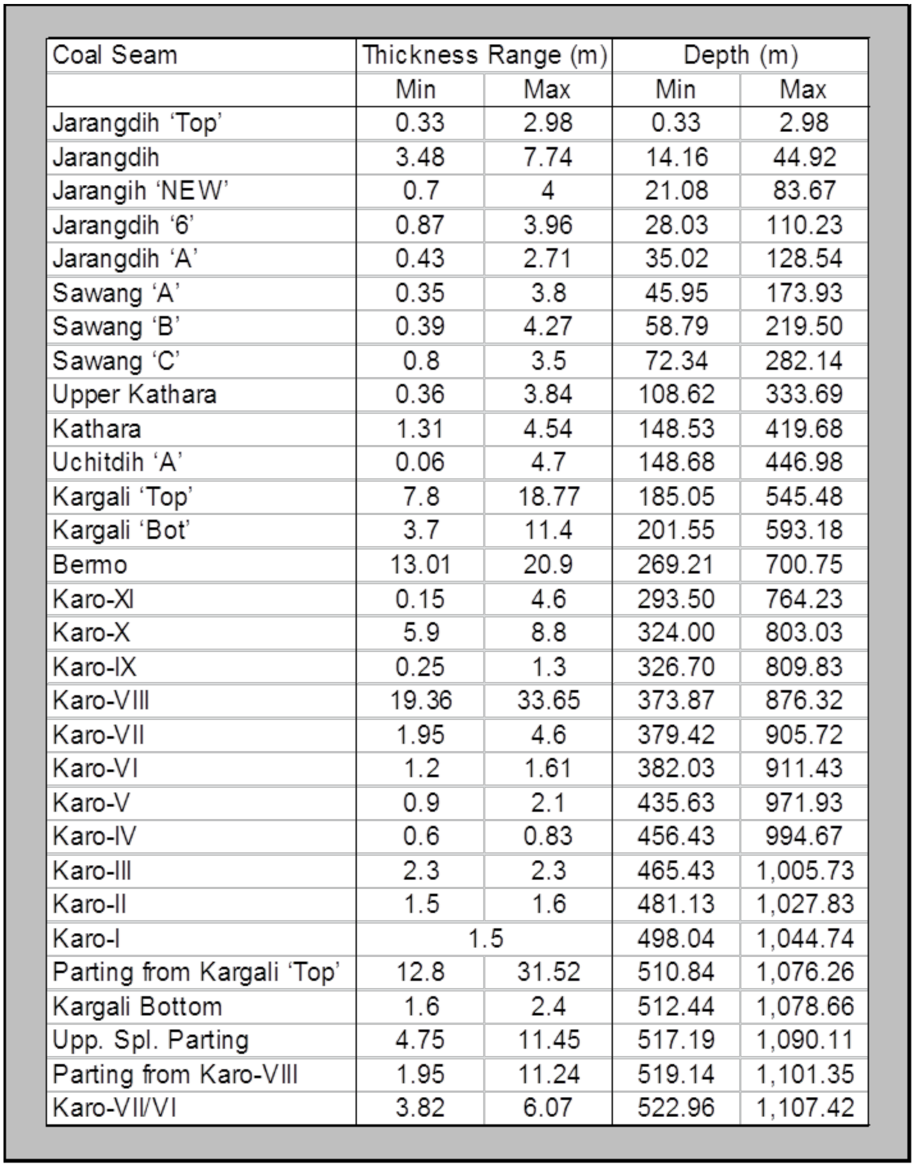
Stratigraphically, the mine area hosts 26 coal bearing seams that are found at a depth of 10 m to over 1,000 m. The seams that are actively mined occur at depths from 12 m to 180 m. Previously mined seams occur from 200 m to 1,000 m in depth. The coal thickness and depth ranges are provided in Exhibit 8 below.



Coal Seam	Thickness Range (m)		Depth (m)	
	Min	Max	Min	Max
Soil / Alluvium	0	12.2	0.00	12.20
Barakar Column above Jarangdih Top Seam	10.56	71	10.56	83.20
Jarangdih Top Seam	2.01	3.08	12.57	86.28
Jarangdih Seam	4.53	5.96	46.51	127.75
Jarangdih New Seam	2.09	4.81	60.84	160.16
Jarangdih 6 feet seam	1.37	2.06	70.75	179.21
Jarangdih 'A' Seam	1.04	1.75	80.39	192.58
Sawang 'A' Seam	0.38	1.6	112.41	249.68
Sawang 'B' Seam	0.61	2.7	121.91	273.33
Sawang 'C' Seam	0.25	2.6	135.11	306.93
Upper Kathara Seam	0.33	3.38	152.39	368.10
Kathara Seam	0.18	4.56	197.57	441.81
Uchitdih Seam	0.13	1.55	204.70	456.89
Uchitdih 'A' Seam	0.38	4.15	210.10	492.51
Kargali Top Seam	1.02	18.18	241.80	569.09
Kargali Bottom seam	5.1	10.14	272.15	616.33
Bermo Seam	10.3	20.2	337.34	719.92
Karo XI Seam	1.2	5.1	378.74	797.93
Karo X Seam	8.25	12.5	391.09	833.23
Karo IX Seam	1.65	3.1	396.94	846.83
Karo VIII Seam	19.08	29.24	439.97	911.02
Karo VII Seam	1.12	7.8	444.87	943.52
Karo VI Seam	0.3	2.98	447.58	955.90
Karo V Seam	0.8	3.09	478.43	1,013.10
Karo IV Seam	0.39	1.55	490.87	1,044.35
Karo III Seam	0.38	4.13	492.90	1,053.88
Karo II Seam	0.36	1.83	499.09	1,073.26
Karo I Seam	0.45	0.86	504.45	1,096.72

Exhibit 8: Sawang Block Coal Thickness and Depth Ranges

The south extension block near the south of the Sawang Colliery has similar depth and thickness ranges, which are provided in Exhibit 9 below.



Coal Seam	Thickness Range (m)		Depth (m)	
	Min	Max	Min	Max
Jarangdih 'Top'	0.33	2.98	0.33	2.98
Jarangdih	3.48	7.74	14.16	44.92
Jarangih 'NEW'	0.7	4	21.08	83.67
Jarangdih '6'	0.87	3.96	28.03	110.23
Jarangdih 'A'	0.43	2.71	35.02	128.54
Sawang 'A'	0.35	3.8	45.95	173.93
Sawang 'B'	0.39	4.27	58.79	219.50
Sawang 'C'	0.8	3.5	72.34	282.14
Upper Kathara	0.36	3.84	108.62	333.69
Kathara	1.31	4.54	148.53	419.68
Uchitdih 'A'	0.06	4.7	148.68	446.98
Kargali 'Top'	7.8	18.77	185.05	545.48
Kargali 'Bot'	3.7	11.4	201.55	593.18
Bermo	13.01	20.9	269.21	700.75
Karo-XI	0.15	4.6	293.50	764.23
Karo-X	5.9	8.8	324.00	803.03
Karo-IX	0.25	1.3	326.70	809.83
Karo-VIII	19.36	33.65	373.87	876.32
Karo-VII	1.95	4.6	379.42	905.72
Karo-VI	1.2	1.61	382.03	911.43
Karo-V	0.9	2.1	435.63	971.93
Karo-IV	0.6	0.83	456.43	994.67
Karo-III	2.3	2.3	465.43	1,005.73
Karo-II	1.5	1.6	481.13	1,027.83
Karo-I	1.5		498.04	1,044.74
Parting from Kargali 'Top'	12.8	31.52	510.84	1,076.26
Kargali Bottom	1.6	2.4	512.44	1,078.66
Upp. Spl. Parting	4.75	11.45	517.19	1,090.11
Parting from Karo-VIII	1.95	11.24	519.14	1,101.35
Karo-VII/VI	3.82	6.07	522.96	1,107.42

Exhibit 9: South Extension Block Thickness and Depth Ranges

Regional studies of the area adjacent to the Sawang mine and Sawang south extension block show a thinning towards the northwest.

3.1.3 Ultimate and Proximate Analysis

Comparing the proximate and ultimate results shown in Exhibit 10 through Exhibit 12, the heat value and volatile matter of the Sawang mine coals align with a medium volatile bituminous. The Sawang south extension block shows a 0.9 to 1.17 percent vitrinite reflectance for the Bermo and seams shallower, which indicates a rank of high volatile sub-bituminous A to medium volatile bituminous.

Various maceral composition studies conducted in the East Bokaro coalfield show a 0.90 to 1.20 percent vitrinite reflectance in the seams above the Bermo. Whereas, the rank transitions to medium volatile bituminous at the Bermo seam and matures to a low volatile bituminous. This maturity is expressed in a vitrinite reflectance increase below the Bermo from 1.4 to 1.51 percent.

Coal Seam	Type of Analysis	PROXIMATE ANALYSIS (AS ANALYSED BASIS)				
		M%	ASH%	VM%	UVM%	Btu/lb
Jarangdih Top	Ex Band	1.5-2.3	25.7-28.8	25.1-27.3	32.3-35.4	10159
	BCS	2.0-2.3	25.9-30.0	26.1-27.3		
	In Band	2.0-2.2	28.1-32.2	24.4-27.3		
Jarangdih	Ex Band	1.8-2.3	17.6-24.4	26.4-28.9	34.0-35.3	10505
	BCS	2.1	26.1-40.7	25.4		
	In Band	1.6-2.0	32.1-40.7	22.7-26.5		
Jarangdih New	Ex BAnd	1.8-2.3	17.6-23.7	25.8-28.5	32.1-34.7	10905
	BCS	2.2	22.3-27.1	24.7		
	In Band	1.8-2.0	24.3-28.5	24.2-27.2		
Jarangdih 6Feet	Ex Band	1.6-2.4	12.4-20.2	24.2-28.8	29.3-33.6	7092
Jarangdih ‘A’	Ex Band	1.7-2.2	13.9-18.0	24.8-28.0	29.1-32.3	12025
	In Band		20.9			
Sawang ‘A’	Ex Band	1.3-2.4	20.8-26.8	25.6-27.8	32.7-33.9	11422
	In Band		31.5			
Sawang ‘B’	Ex Band	1.2-1.9	21.4-25.9	24.6-29.0	31.2-35.7	10766
	BCS	1.5-1.8	22.9-29.7			
	In Band	1.5-1.6	24.9-29.7	25.3-26.8		
Sawang ‘C’	Ex Band	1.1-1.9	18.2-38.7	22.0-28.8	29.6-36.2	11440
	BCS	1.4	24.0-38.7	24.6		
	In Band		21.8-46.3			
Upper Kathara	Ex Band	1.1-2.5	17.6-26.6	23.4-28.9	29.4-33.7	11031
	BCS		25.0-27.2			
	In Band	1.2	27.7-36.7			
Kathara	Ex Band	1.0-2.1	17.7-26.3	24.4-29.9	30.3-36.0	11233
	BCS	1.1-2.4	20.1-24.4	25.2-26.7		
	In Band	1.1-2.4	19.2-35.0	25.2-26.7		
Uchitdih	Ex Band	0.9-1.8	14.2-27.6	22.7-28.2	31.6-35.0	
	BCS		26.0-38.4			
	In Band	0.9-1.7	27.0-45.3	20.6-22.4		
Uchitdih ‘A’	Ex Band	0.9-2.7	15.1-28.5	23.0-29.4	28.5-34.6	11724
	BCS	2	21.8-29.9	26.3		
	In Band	1.2-2.4	19.0-30.2	22.0-27.0		
Kargali Top	Ex Band	0.6-2.0	16.8-23.2	24.2-30.4	29.7-36.9	11670
	BCS	1.8	18.0-21.5	28.5		
	In Band	1.0-1.6	18.1-23.5	26.1-28.0		
Kargali Bottom	Ex Band	0.4-1.8	18.0-27.9	23.0-27.6	26.7-34.3	10824
	BCS		19.2-28.0			
	In Band	0.8-1.6	19.2-31.1	23.4-27.0		
Bermo	Ex Band	0.4-1.0	24.1-26.2	20.2-24.2	23.2-29.8	11207
	In Band		26.6-27.1			
Karo XI	Ex Band	0.4-1.4	25.0-33.7	18.0-23.5	20.8-30.1	10001
	BCS		26.7-35.1			
	In Band	0.9-1.5	28.6-44.5	20.5-22.5		
Karo X	Ex Band	0.5-1.4	26.2-30.4	19.8-23.8	24.8-31.5	9543
	BCS	0.9-1.4	28.1-34.2	19.3-22.3		
	In Band	1.0-1.4	31.1-37.1	19.1-22.1		
Karo IX	Ex Band	0.4-1.6	23.8-37.3	19.6-24.9	25.3-31.9	9561
	BCS	0.9-1.2	28.9-44.3	20.1-22.1		
	In Band	0.9-1.5	30.3-44.3	18.1-20.2		
Karo VIII	Ex Band	0.2-1.5	22.1-28.8	19.0-23.7	23.0-29.9	9214
	BCS	1.3-1.4	27.5-35.0	19.8-20.4		
	In Band	0.9-1.5	32.5-56.9	17.2-19.0		
Karo VII	Ex Band	0.3-1.3	24.7-33.6	38.7-23.2	24.2-29.9	8891
	BCS	1.0-1.2	28.7-39.2	18.1-20.6		
	In Band	0.8-1.2	33.1-51.5	16.1-19.4		
Karo VI	Ex Band	0.4-1.2	22.7-34.2	17.1-21.8	21.7-26.8	9142
	BCS	0.8-2.2	34.7-45.3	15.8-18.6		
	In Band	0.8-2.2	38.5-49.0	15.5-18.6		
Karo V	Ex Band	0.4-8.2	21.7-43.9	16.8-22.2	21.3-29.9	7519
	BCS	1	31.7-39.9	20		
	In Band	0.6-1.1	32.0-43.8	16.2-20.1		
Karo IV	Ex Band	0.2-3.4	14.4-31.5	14.4-24.2	21.4-28.0	11845
	BCS	2.8	26.9-32.0			
	In Band	2.8	19.5-42.6			
Karo III	Ex Band	0.4-1.3	14.3-32.0	16.3	20.4-27.9	12155
	BCS		17.7-21.0			
	In Band	0.8-1.2	20.9-35.4	20.0-23.1		
Karo II	Ex Band	0.4-2.9	13.0-32.1	18.7-25.0	22.4-27.4	11404
	BCS		24.4-41.4			
	In Band	0.8-0.9	24.4-41.4	16.4-22.8		
Karo I	Ex Band	1	10.2			
	BCS		35.7			
	In Band		35.7			

Exhibit 10: Proximate Analysis of Coal Seams at the Sawang Mine

Coal Seam	Ultimate Analysis					CO2% as Carbonate	Phosphorus %
	C%	H%	N%	S%	O%		
					By Diff		
Jarangdih Top					5.60-6.10	0.71-1.69	0.019-0.034
	85.70-86.0	5.20-5.40	2.4	0.6			
Jarangdih					6.8	0.26-0.64	0.02
	84.8	5.3	2.4	0.7			
Jarangdih New					6.50-7.30	0.34-1.26	0201-0.310
	84.80-85.20	8.10-5.30	2.30-2.50	0.5			
Jarangdih 6					6.90-7.10	0.39-0.86	0.324-0.380
	84.90-85.10	5	2.5	0.3			
Jarangdih A					5.90-6.40	0.04-1.03	0.065-0.273
	85.40-86.20	5.00-5.20	2.40-2.50	0.5			
Sawang A							
						0.59	
Sawang B					5.40-5.60	0.24-0.76	0.406
	85.90-86.20	5.3	2.50-2.60	0.6			
Sawang C				0.6	5	0.27-0.51	0.561
	86.8	5.3	2.3				
Upper Kathara	88			0.6	3.8	0.10-1.11	0.444
		5.3	2.3				
Kathara	63.81-66.72	3.85-3.98	1.48-2.40	0.50-0.76	5.7	0.13-1.76	0.239
	86.10-87.19	5.07-5.30					
Uchitdih							
Uchitdih A	64.85-68.87	3.80-4.06	1.41-1.54	0.62-0.69		0.29-1.58	
	87.35-89.92	5.15-5.20					
Kargali Top	68.66-71.20	4.13-4.24	1.30-1.47	0.75-0.92		0.27-0.83	
	86.91-87.90	5.24-5.28					
Kargali Bottom	65.10-68.32	3.84-3.98	1.28-1.40	0.59-0.83		0.54-1.54	
	87.36-88.32	5.14-5.15					
Bermo	68.7	3.94	1.51	0.48		0.36-2.06	
	88.46	5.07					
Karo XI	61.01-62.11	3.44-3.53	1.00-1.33	0.34-0.84		0.13-1.67	
	88.12-89.16	4.97-5.10					
Karo X	68.06-61.85	3.20-3.54	1.14-1.32	0.30-0.47		0.44-0.65	
	88.29-88.97	4.91-5.12					
Karo IX	58.72-63.97	3.35-3.77	1.05-1.34	0.39-0.62		0.45-0.66	
	87.87-88.85	4.99-5.26					
Karo VIII	62.40-64.64	3.47-3.63	1.11-1.26	0.32-0.46		0.44-1.44	
	88.74-89.14	4.92-4.99					
Karo VII	56.83-63.05	3.11-3.50	0.86-1.06	0.33-0.47		0.37-2.02	
	88.21-89.41	4.87-5.16					
Karo VI	57.01-58.28	3.10-3.28	0.84-1.01	0.47-0.49		0.44-0.68	
	88.57-89.70	4.88-4.98					
Karo V	56.57-60.06	3.16-3.28	0.94-0.97	0.41-0.48		0.44-0.58	
	88.68-89.73	4.90-5.05					
Karo IV	67.48-70.73	3.86-3.88	1.04-1.12	0.40-0.42		0.15-0.55	
	88.52-89.27	4.50-5.06					
Karo III	71.14-73.58	3.93-4.00	1.19-1.22	0.42-0.47		0.11-0.61	
	89.65-89.83	4.87-4.96					
Karo II	62.23		0.9	0.43		0.07-0.56	
	89.55	4.943.43					
Karo I							

Exhibit 11: Ultimate Analysis of Coal Seams at the Sawang Mine

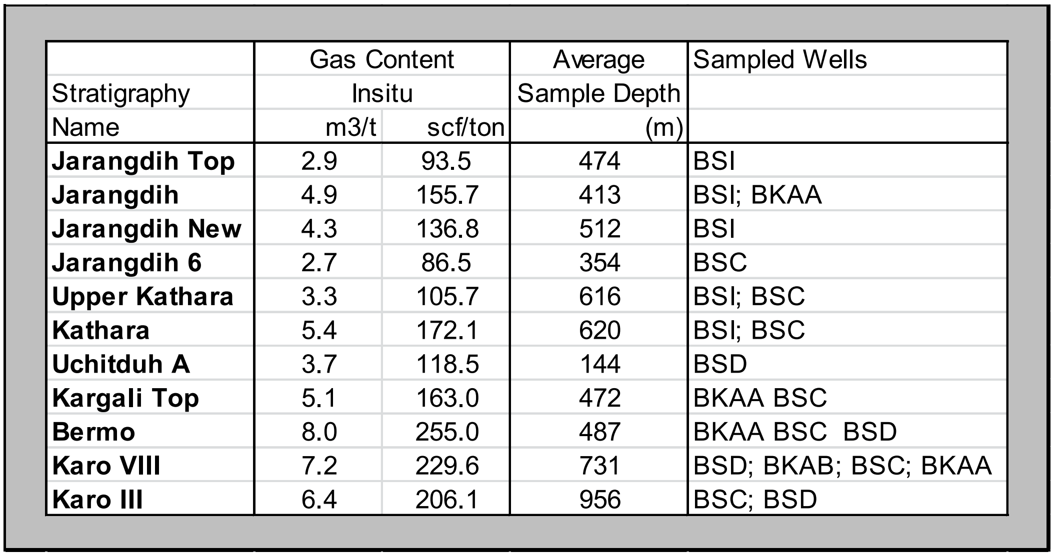
Seam	Ultimate analysis(dmf)		Carbon Dioxide	Phosphorous	Maceral Composition (%)				Vitrinite Reflectance (%)	Btu/lb
	Carbon	Hydrogen			(on mineral matter free basis)					
	(%)	(%)	(%)	(%)	Vitrinite	Exinite	Inertnite	Mineral Matter		
Jarangdih ‘Top’	87.6-88.1	5.0-5.1	0.29-1.12	0.409-0.434	48.7-67.5	3.8-8.9	23.6-29.8	17.7-18.5	0.90-0.97	15,065
Jarangdih	87.1-88.0	4.9-5.7	0.64-1.17	0.271-0.374	45.3-80.0	3.8-5.4	15.0-3.33	13.5-17.5	0.90-0.99	15,249
Jarangdih ‘New’	87.6-88.8	5.0-5.5	0.83-1.67	0.099-0.512	54.1	5.9	30.1	9.9	1.12	15,371
Jarangdih ’6’	87.1-88.0	4.8-5.4	0.18-0.83	0.030-0.228	56.3-77.8	3.1-6.0	19.1-27.8	9.9-10.8	1.12	15,249
Jarangdih ‘A’	87.3-89.3	4.7-5.3	0.49-0.74	0.080-0.297	51.9-58.7	3.2-3.6	33.4-37.7	11.5	1.13	15,249
Sawang ‘A’			0.3	0.215	-	-	-	-	-	15,263
Sawang ‘B’	86.6-87.6	4.8-5.2	0.79-1.74	0.331	74.8	3.4	21.8	10.6	0.93	15,258
Sawang ‘C’	87.1-87.8	4.8-5.0	0.30-0.34	0.341-0.558	63	8.9	28.1	15	0.95	15,186
Upper Kathara	87.5-88.1	4.9-5.1	0.62-0.93	0.465-0.588	69.7	5.9	24.4	13.2	0.96	15,330
Kathara	86.4-88.6	4.7-5.4	0.13-1.07	0.016-0.368	71.6-75.5	1.0-5.4	23.0-23.5	11.6-13.6	1	15,312
Uchitdih ‘A’	87.7-90.3	4.8-4.9	0.86-1.58	0.086-0.167	-	-	-	-	-	15,483
Kargali ‘Top’	88.4-90.5	4.7-5.1	0.76-2.78	0.104-0.134	46.0-78.2	1.4-7.4	20.4-34.2	10.7-12.4	1.03-1.05	15,645
Kargali ‘Bot’ Super Split	88.6-90.0	5.1-5.2	0.89-1.63	0.016-0.033					-	15,519
Kargali ‘Bot’	89.7-92.3	4.6-5.0	1.13-2.50	0.262-0.411	35.2-77.6	2.1-10.4	20.3-39.0	15.4	1.07-1.13	15,645
Bermo	89.6	92.7	0.69-1.69	0.096-0.297	56.3-72.0	0.5-7.3	24.2-27.4	12.2-15.8	1.16-1.17	15,654

Exhibit 12: Sawang South Extension Block Ultimate Analysis Results of Coal Seams

3.2 Gas Content and Gas Resources

The Sawang Colliery is considered a Degree III gassy mine. Measurements of methane emission rates per tonne of mined coal produced in the Jarangdih 6’ seam indicate a gas content of 17.12 cubic meters per tonne (m^3/t) (548.5 standard cubic feet per ton, scf/ton).

ONGC’s development program in the East Bokaro coalfield included several gas adsorption and desorption studies from multiple core holes. The results from the gas desorption program are shown in Exhibit 13 below. The results are from 5 core holes that were chosen to due to their proximity to the Sawang Colliery area (Exhibit 14).



Stratigraphy Name	Gas Content Insitu m3/t	Gas Content Insitu scf/ton	Average Sample Depth (m)	Sampled Wells
Jarangdih Top	2.9	93.5	474	BSI
Jarangdih	4.9	155.7	413	BSI; BKAA
Jarangdih New	4.3	136.8	512	BSI
Jarangdih 6	2.7	86.5	354	BSC
Upper Kathara	3.3	105.7	616	BSI; BSC
Kathara	5.4	172.1	620	BSI; BSC
Uchitduh A	3.7	118.5	144	BSD
Kargali Top	5.1	163.0	472	BKAA BSC
Bermo	8.0	255.0	487	BKAA BSC BSD
Karo VIII	7.2	229.6	731	BSD; BKAB; BSC; BKAA
Karo III	6.4	206.1	956	BSC; BSD

Exhibit 13: In-Situ Gas Desorption Results (ONGC)

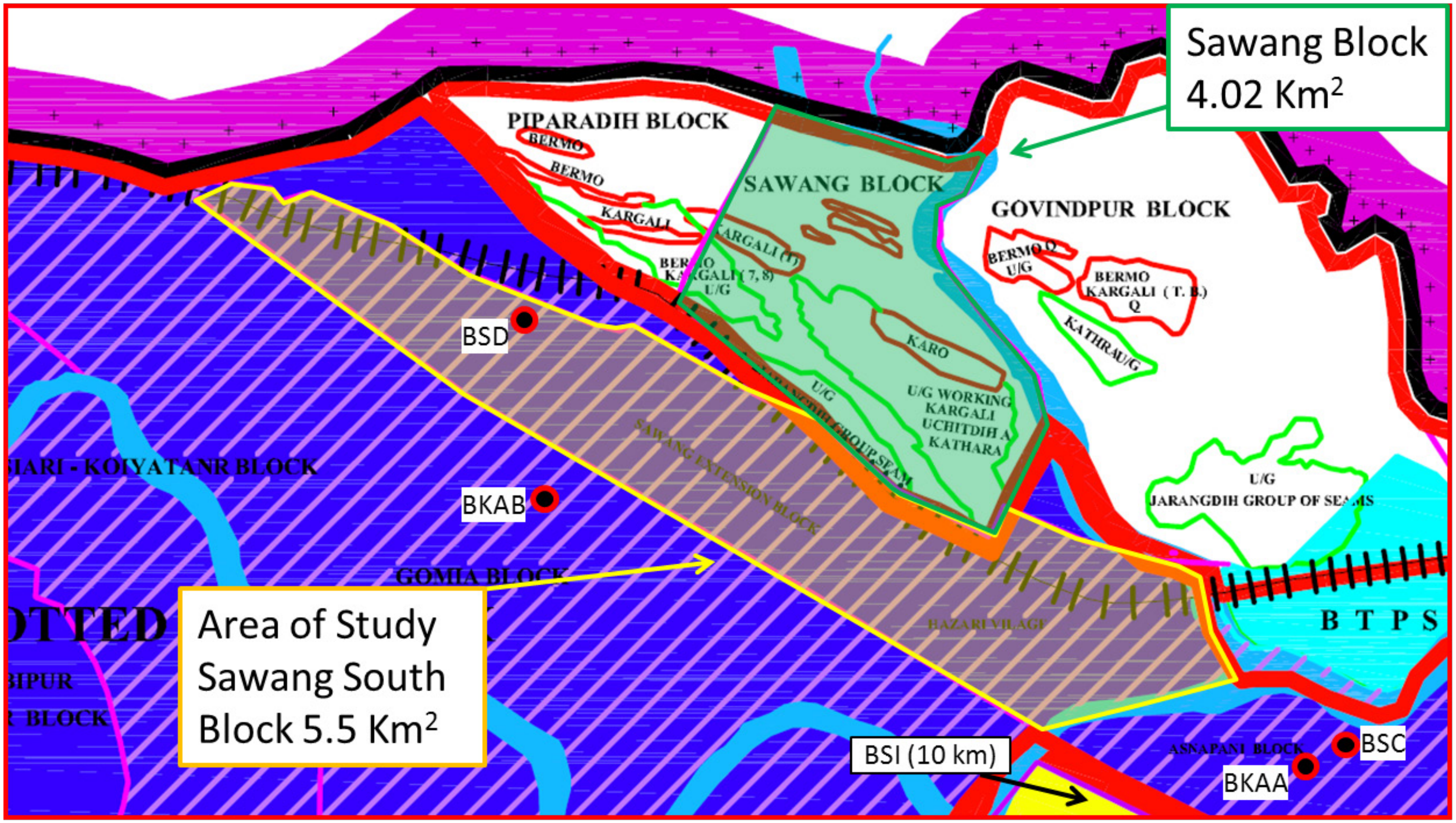


Exhibit 14: Location Map with ONGC Wells

Desorption data were used to compare the measured gas content to the maximum storage capacity, as determined by the isotherm analysis. The comparison gives insight into the degree of saturation within the seams. Core hole BSC's results show that *in-situ* gas generally increases with respect to depth. The shallower seams indicate under-saturation by approximately 40 to 60 percent, while deeper seams are closer to full saturation (Exhibit 15).

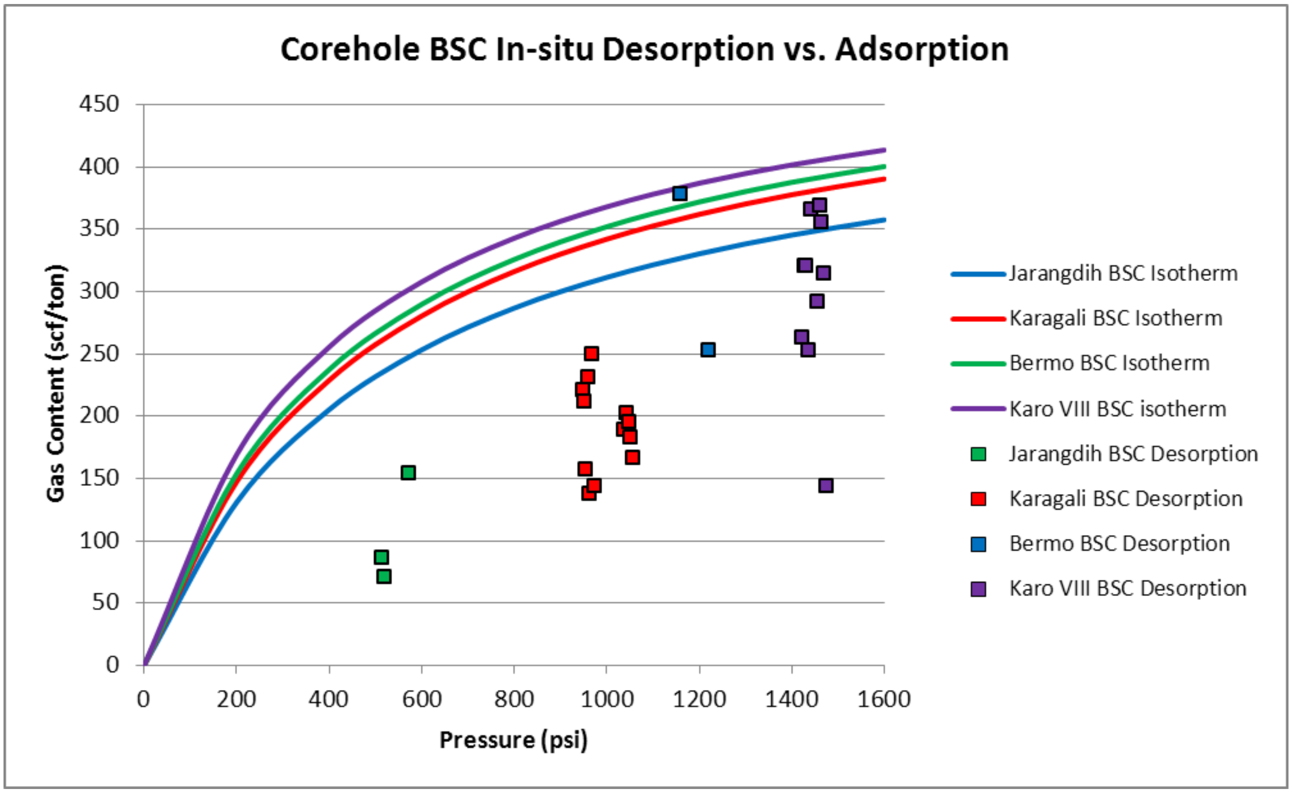


Exhibit 15: Gas Desorption Versus Adsorption for Core Hole BSC (ONGC)

The saturation of the coal seams, however, becomes more complex with additional core hole data. In Exhibit 16 below, the *in-situ* gas desorption and adsorption isotherms from core hole BSD are plotted against core hole BSC. Core hole BSD is located about 5.5 km northeast of core hole BSC. The two core holes are situated on either end of the Sawang south extension block. Core hole BSD, in contrast to core hole BSC, indicates the coal seams are fully saturated with respect to gas. This comparison implies that the degree of saturation increases from the southeast to the northwest. This lateral transition may be related to the structural complexity of the region.

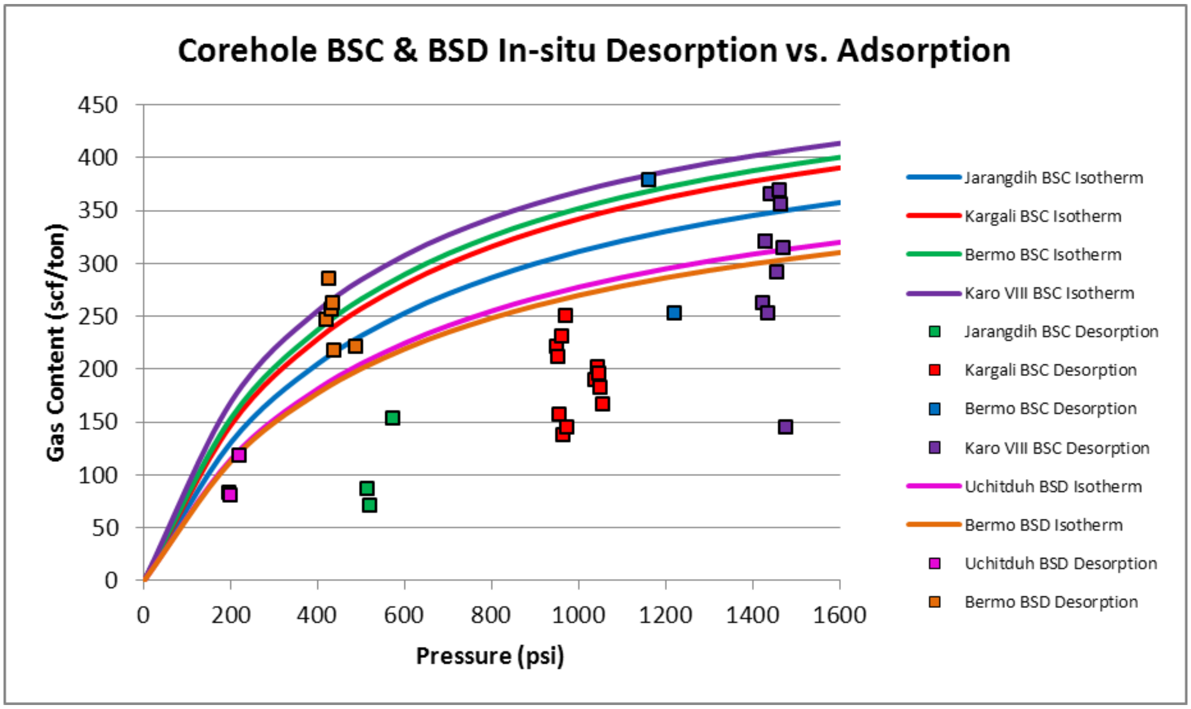


Exhibit 16: Gas Desorption and Adsorption Isotherms of Core Holes BSC and BSD

3.3 Assessment of Available Gas Resources

The resource estimate shown in Exhibit 17 was calculated using thickness and depth data from the 5.5 km^2 (1,359 acres, ac) south extension block and the gas content and density from proximal core holes. The results indicate a potential resource of 145.74 billion cubic feet (Bcf) (4.12 billion cubic meters, Bcm).

Estimated Gas Resource	
Seam	Bcf
Jarangdih 'Top'	1.30
Jarangdih	7.34
Jarangdih '6'	1.76
Upper Kathara	1.87
Kathara	4.23
Uchitdih 'A'	2.37
Kargali 'Top'	18.21
Kargali 'Bot'	10.85
Bermo	37.43
Karo-VIII	56.00
Karo-III	4.36
Total	145.74

Exhibit 17: Gas Resource Estimate of the Sawang South Extension Block

Comparatively, the seamwise gas resource in the Sawang Colliery (Exhibit 18 shows a resource of 31.8 Bcf (0.90 Bcm) based on the indicated and proved coal reserves.

Seam	Total Reserves Proved and Indicated ('000 tons)	Estimated Gas Resource (MMcf)
Jarangdih Top	1,295	121
Jarangdih	3,616	563
Jarangdih 6	1,229	106
Upper Kathara	1,986	210
Kathara	1,055	182
Uchitdih A	1,113	132
Kargali Top	7,925	1,292
Bermo	25,979	6,625
Karo VIII	93,200	21,394
Karo III	6,061	1,249
Total	137,319	31,874

Exhibit 18: Potential Gas Resource of Seams Actively or Historically Mined at the Sawang Colliery

4.0 Market Information

The proposed CMM project at Sawang Colliery is located in the Bokaro district of Jharkhand state, about 125 km from Ranchi. Jharkhand is the 15th largest state in India and it is located in the most industrialized region in the east. Besides Bokaro, some of the main industrial centers are Ranchi, Jamshedpur, and Dhanbad. A number of industries such as power, iron and steel, aluminum, fertilizer, and cement are concentrated in this region due to its proximity to large deposits of coal, iron, copper, bauxite, uranium, and other minerals. This region is also one of the most densely populated areas of the state.

Over the past six years, Jharkhand's industrial output has grown by an average rate of 8 percent. The industrial sector is responsible for 50 percent of Jharkhand's economic output with the service and agricultural sectors contributing 25 percent each. The state's favorable industrial policies, rich mineral resources, and abundance of cheap land and labor make Jharkhand an ideal destination for heavy industries, and suggest that this region will continue to attract investment in the future.

According to the Central Institute of Mining and Fuel Research (CIMFR), Jharkhand's economy is expected to grow at an average rate of more than 10 percent through 2030. As Jharkhand's economy expands, the high concentration of energy intensive industries is expected to drive energy demand growth. Coal is the predominant source of energy in Jharkhand, but demand for natural gas has steadily increased over recent years. As a cleaner and more efficient fuel than coal, natural gas is finding opportunities as a source of fuel for electricity generation and also as a feedstock for many industrial processes.

To better understand the supply and demand dynamics of the natural gas market in Jharkhand, a market study was performed with the objective of identifying potential markets for gas from the Sawang CMM project. The results of this market study are presented below.

4.1 Natural Gas Supply

4.1.1 Conventional and LNG

India’s primary natural gas supply sources are conventional domestic production and liquefied natural gas (LNG) imports. According to the Oil & Gas Journal, India had 43.8 trillion cubic feet (Tcf) of proved natural gas reserves at the end of 2012. About 30 percent of these are onshore reserves, while 70 percent are offshore reserves. However, due to inadequate natural gas infrastructure the country increasingly relies on LNG imports. According to the Energy Information Administration (EIA), India produced 1,426 billion cubic feet (Bcf) of natural gas in 2011, but imported 579 Bcf over the same period. India was the sixth largest LNG importer in 2011 with over five percent of the global market (PFC Energy).

4.1.2 Coalbed Methane

India began awarding CBM blocks for exploration in 2001, and after more than a decade production is beginning to come online. According to the Directorate General of Hydrocarbons (DGH), approximately 92 trillion cubic feet (Tcf) of CBM resources have been identified both onshore and offshore in India. A total of 26 CBM blocks with an expected resource potential of 49 Tcf have been awarded so far in three rounds. The anticipated production potential from these blocks is around 1,342 million standard cubic feet per day (MMscfd). As shown in Exhibit 19, Jharkhand has significant potential for CBM production with 28 percent of all CBM resources located within the state. CBM production began commercially in 2007 in small quantity of about 222 thousand standard cubic feet per day (Mscfd) and is currently being produced at the rate of 2,543 Mscfd in Jharkhand.

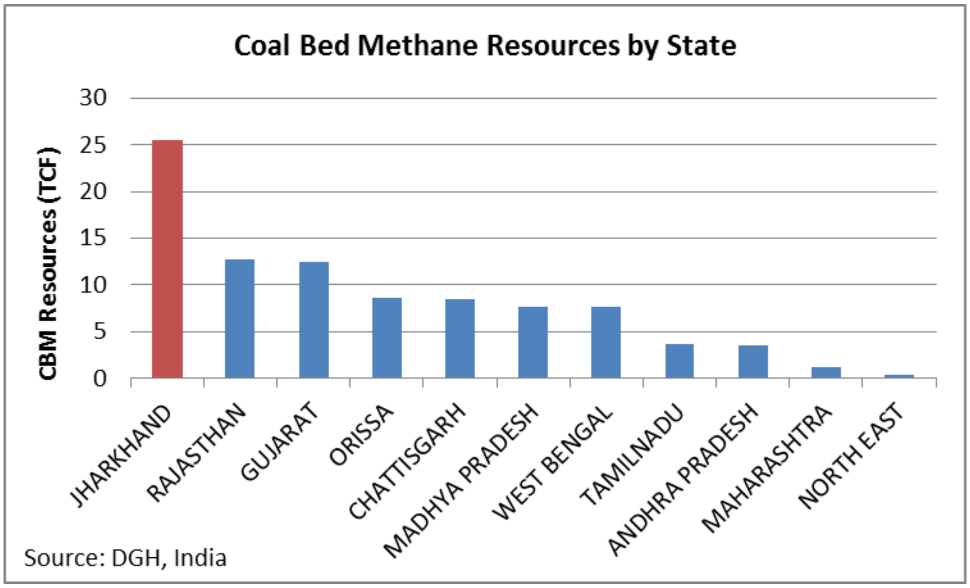


Exhibit 19: Coalbed Methane Resources by State

4.1.3 Coal Mine Methane

Presently there are no commercial-scale CMM projects in India, but the development of CMM is high on the agenda of the Indian coal mining industry. In order to support the growing energy requirements of the country, the coal mining industry in India is shifting from opencast to underground mining techniques. However, due to safety concerns related to methane, increased production from underground mines cannot be realized without the application of proper methane drainage and handling. If captured and utilized properly, methane recovered from existing coal mines will help to satisfy the demand for energy in the region while improving the local environment through the reduction of greenhouse gas (GHG) emissions.

4.2 Natural Gas Demand

On the national level, coal is the dominate source of energy in India providing 41 percent of total energy consumed in 2011, according to the Energy Information Administration (EIA). India consumed 2,076 Bcf of natural gas in 2011 (EIA), representing just 8 percent of India’s energy consumption. However, CIMFR estimates demand for natural gas in India has been increasing by 6.8 percent per year over the last decade. As a cleaner and more efficient fuel than coal, natural gas is finding application in the power, transport, fertilizer, chemicals, and petrochemical industries.

On the local level, current demand for natural gas in Jharkhand is dominated by the iron & steel and aluminum sectors, which represent 67 percent of all state-wide natural gas demand (Exhibit 20). Annual natural gas demand in Jharkhand averaged approximately 3.0 million standard cubic meters per day (MMscmd) (106 MMscfd) in 2010, and according to CIMFR, is expected to more than triple to 9.1 MMscmd (321 MMscfd) by 2025 (Exhibit 21).

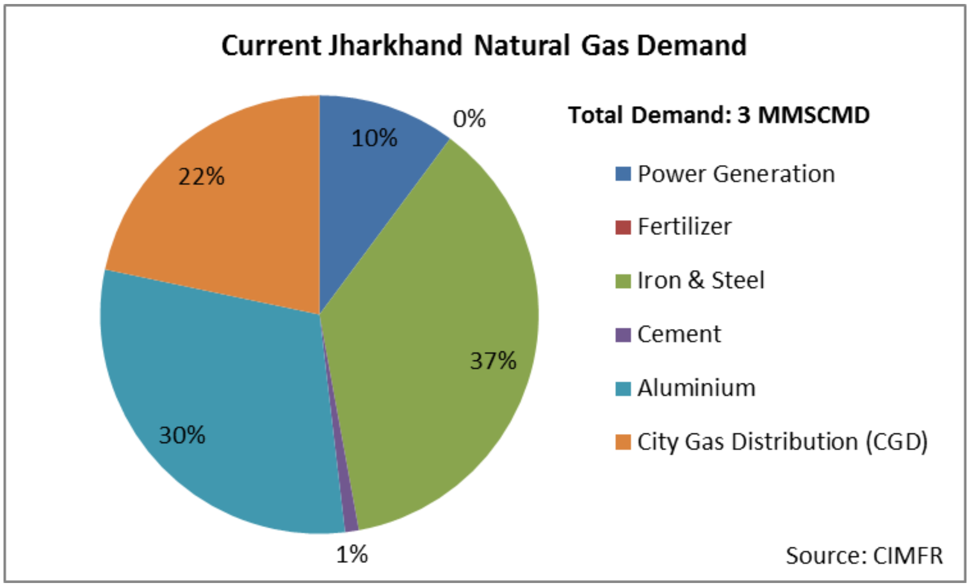


Exhibit 20: Current Jharkhand Natural Gas Demand

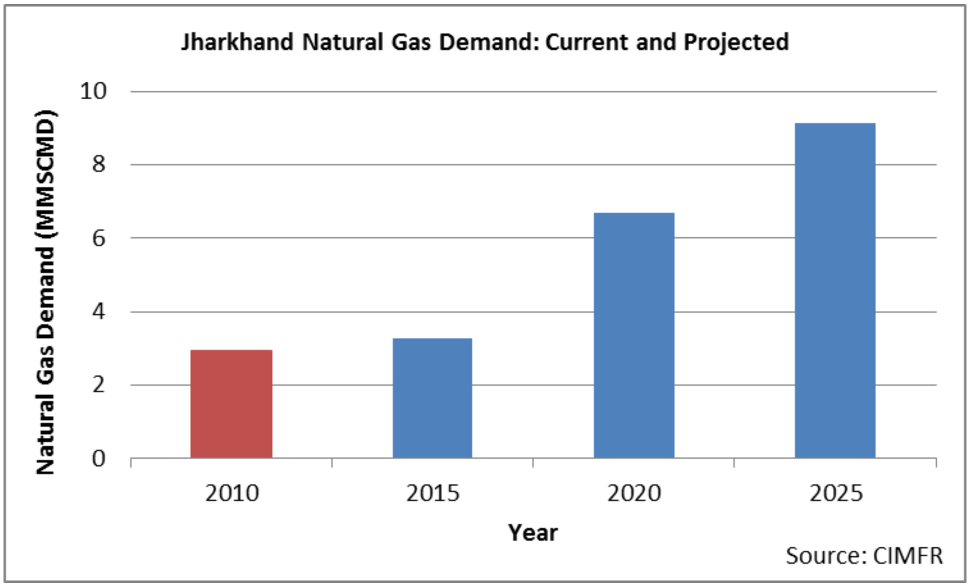


Exhibit 21: Jharkhand Natural Gas Demand: Current and Projected

Based on economic trends and changing market dynamics, CIMFR identified the following industries in Jharkhand as the most-likely to become potential consumers of natural gas in the future:

- Power generation
- Fertilizer production
- Iron and Steel
- City Gas distribution

The following sections discuss each of these potential markets for natural gas in more detail. Demand projections based on the results of a CIMFR study are also presented. CIMFR's state-specific estimates of potential gas consumption were based on several factors such as the locations of industries that will use gas, the economic growth expected for the state, and the locations of cities for potential city gas distribution (CGD) development.

4.2.1 Power Sector

Jharkhand has a total generation capacity of 3,516 MW, of which nearly 40 percent is state owned, while 42 percent is owned by Damodar Valley Corporation (DVC). Independent Power Producers (IPPs) account for approximately 10 percent of the capacity, while the balance is made up by central generating station (CGS) allocations. For the last 5 years, the share of state owned capacity has declined slightly while the share of privately owned capacity has increased. Exhibit 22 shows the capacity mix in Jharkhand by ownership and fuel type. Coal provides 92 percent of the state's electricity generation capacity, while the rest is provided mostly by hydro plants (5 percent) with a small amount of diesel (less than 3 percent) and renewable (less than 1 percent) capacity installed.

Ownership	Thermal				Nuclear	Hydro	Renewable	Grand Total
	Coal	Gas	Diesel	Total				
State	1,260	-	-	**1,260**	-	130	4	**1,394**
DVC	1,380	-	90	**1,470**	-	-	-	**1,470**
Private	360	-	-	**360**	-	-	-	**360**
Central	249	-	-	**249**	-	43	-	**292**
Total	**3,249**	-	**90**	**3,339**	-	**173**	**4**	**3,516**

Source: CEA

Exhibit 22: Jharkhand Installed Electricity Generation Capacity (in MW) by Fuel

The number of power plants located within Jharkhand is likely to increase in the future due to the presence of bountiful steam coal reserves, rich water resources, and abundant labor located in the state. Additionally, the State Government has pledged assistance with procurement of land for plant construction.

Currently, in the eastern region of Jharkhand there is no gas based power capacity, as the state's power capacity mix is dominated by cheaper coal. Furthermore, based on the results of the CIMFR analysis, the availability of cheaper coal would make it difficult for the development of gas-based power in the region. Base load demand is likely to be satisfied by the construction of additional coal plants. However, there may be some gas-based power capacity needed to serve as peaking units.

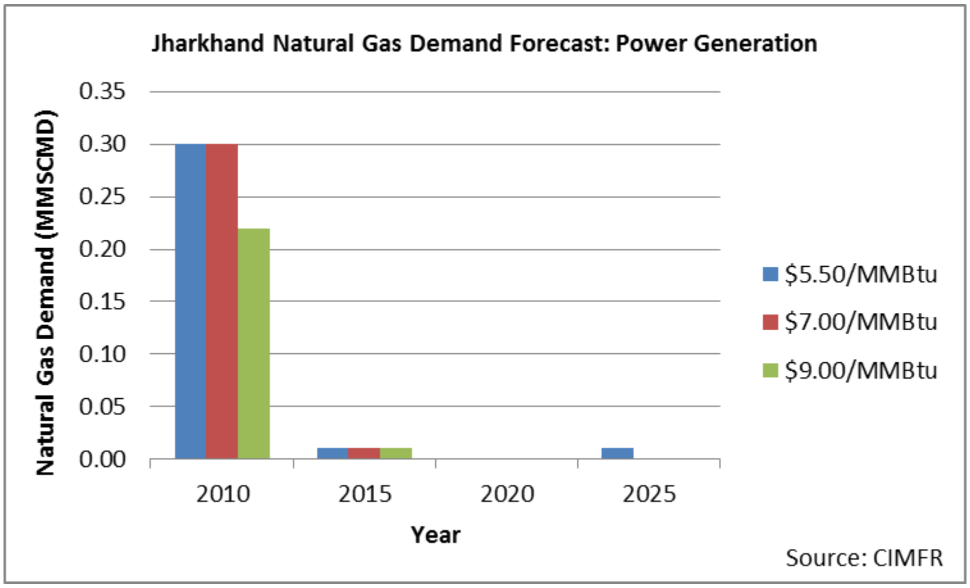


Exhibit 23: Jharkhand Natural Gas Demand Forecast: Power Generation

4.2.2 Fertilizer Sector

Natural gas is the most cost effective feedstock for fertilizer production, and the demand for gas by the fertilizer sector is expected to increase. Additional gas supplies are required not only to meet current shortages faced by existing gas-based units, but also to meet future demand from the conversion of Naphtha- and fuel oil-based units to natural gas. The Ministry of Fertilizer has directed all non-gas based urea units to convert to use gas as a feedstock.

While most of the fertilizer plants in India are located in Uttar Pradesh and Gujarat, Jharkhand has an existing fertilizer plant located in Sindri, but the asset is effectively stranded due to the lack of gas supply and insufficient infrastructure. Under the current development plans it is highly unlikely that production at this plant will be back online in the near term. However, the plant could be restarted once the gas transportation infrastructure is improved and the supply of competitively priced gas becomes available. On these lines, the Steel Authority of India Limited (SAIL) has announced plans to set up a urea-based fertilizer plant near Sindri, which is likely to spur infrastructure investment and increase demand of natural gas in the longer term.

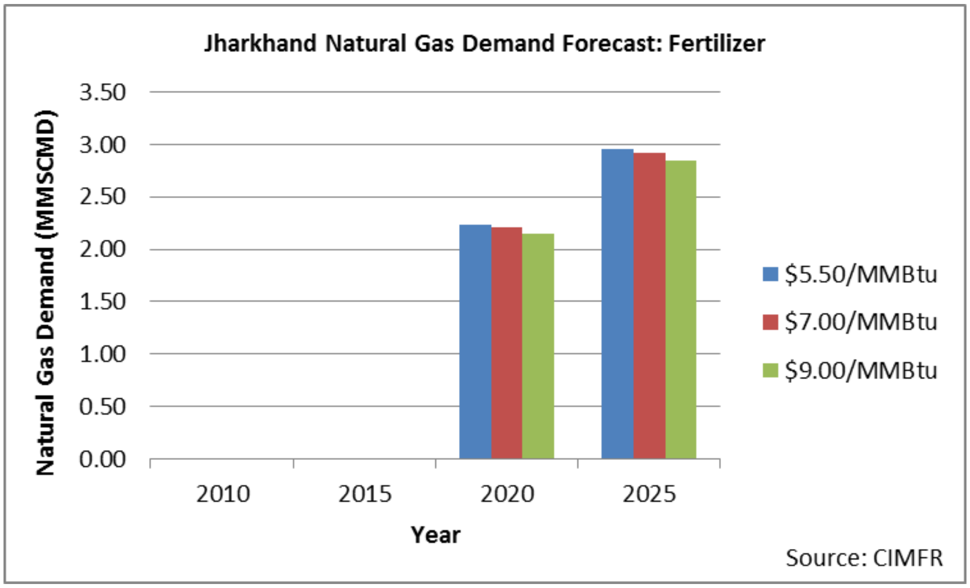


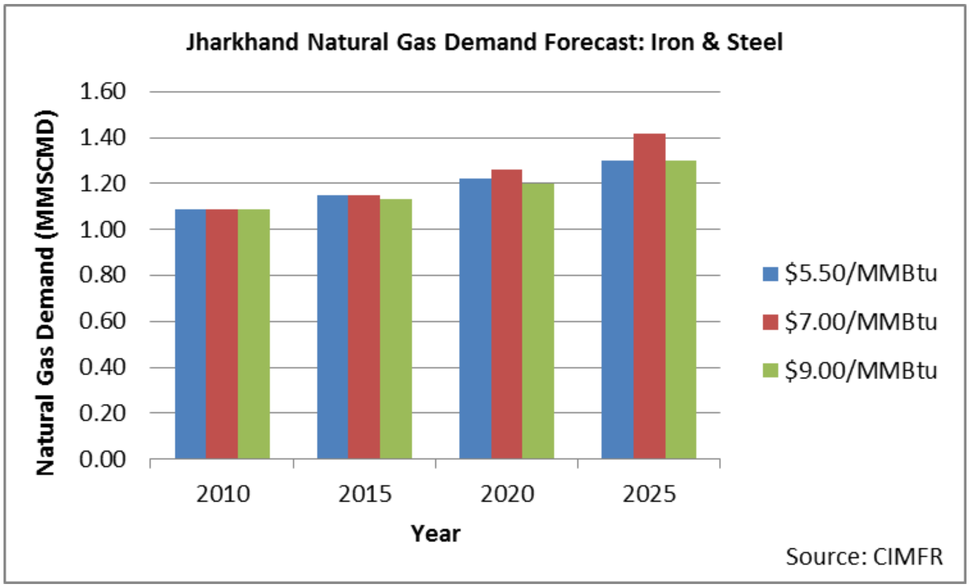
Exhibit 24: Jharkhand Natural Gas Demand Forecast: Fertilizer

4.2.3 Iron and Steel, Aluminum, and Cement Sectors

National steel production grew at an annual average rate of 9.5 percent from 2001 to 2008. The rapid production growth was driven by expansion in capacity and improved capacity utilization. The iron and steel sector is considered vital for economic growth, and a linear relationship has been proven to exist between steel production and national gross domestic product (GDP).

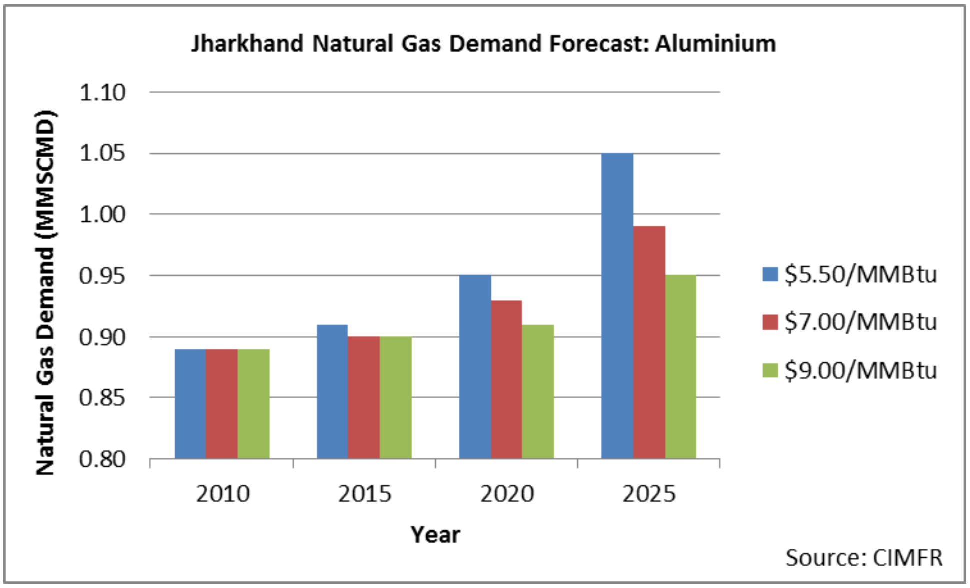
Most of the iron and steel plants in India are located in the states of West Bengal, Jharkhand, and Orissa due to the availability of iron ore, limestone, and coal – the main raw materials needed for iron and steel production. There are two integrated steel plants at Bokaro and Jamshedpur, and many other medium and small sponge iron plants throughout the state. Numerous steel plants by private sector players such as Tata, Jindal, Essar, ArcelorMittal, and state owned firm SAIL, are also under various stages of planning or construction in the state.

In comparison to international standards, India's steel plants are very energy intensive, requiring around 29 gigajoule of energy per tonne of steel produced (GJ/tonne). With steel production in India slated to grow at an annual average rate of 8.2 percent through 2025, the energy demand from steel plants is therefore expected to increase stepwise.



Source: CIMFR

Exhibit 25: Jharkhand Natural Gas Demand Forecast: Iron & Steel



Source: CIMFR

Exhibit 26: Jharkhand Natural Gas Demand Forecast: Aluminum

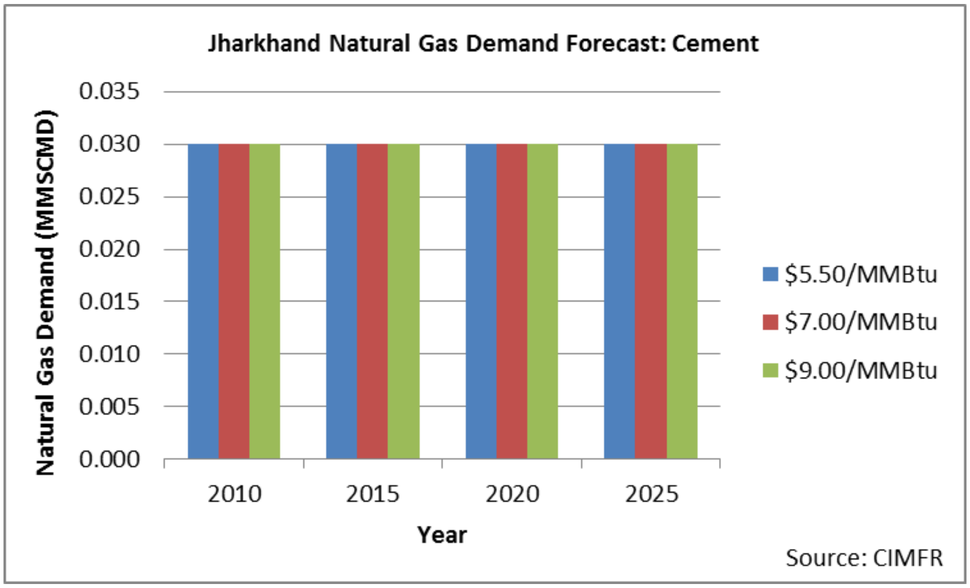
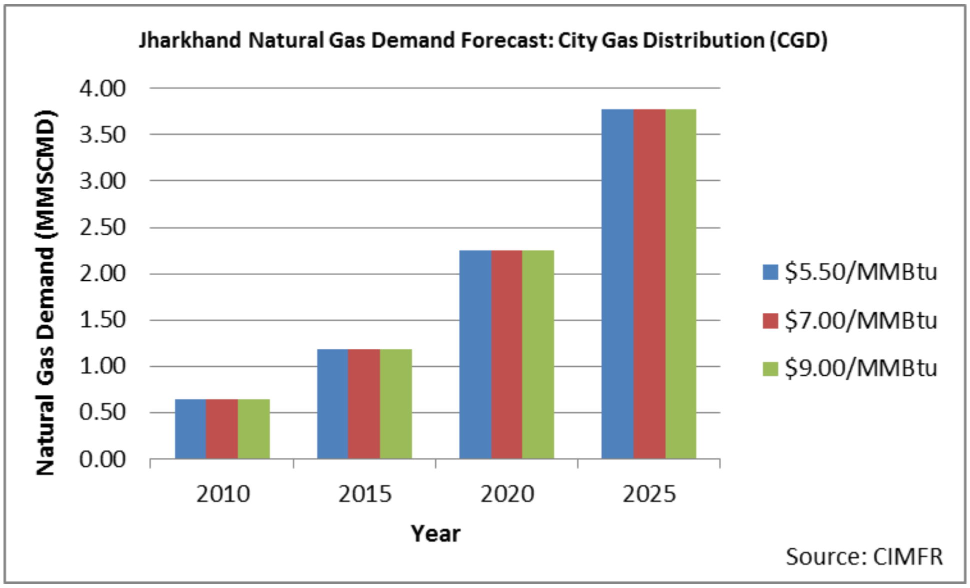


Exhibit 27: Jharkhand Natural Gas Demand Forecast: Cement

4.2.4 City Gas Distribution

The sixteen cities in India that are connected to a CGD network together consume about 4 MMscmd of gas. However, due to gas supply constraints the pace of growth in CGD systems has been hampered. According to the regulatory authority responsible for promoting CGD business in India, the Petroleum & Natural Gas Regulatory Board (PNGRB), significant growth in the CGD network is foreseen in the future, with 200 cities planned to have access to a CGD system over the coming two decades, including cities like Ranchi, Bokaro, Dhanbad, and Jamshedpur in Jharkhand. According to CIMFR, the demand for city gas in Jharkhand is expected to increase to 3.75 MMscmd by 2025 from 0.65 MMscmd in 2010 (Exhibit 28).



Source: CIMFR

Exhibit 28: Jharkhand Natural Gas Demand Forecast: City Gas Distribution (CGD)

4.3 Identification of a Market for Sawang Colliery CMM

The results of the market study highlight the growing energy needs of India. In Jharkhand, energy consumption is constrained by inadequate supplies, and markets for locally produced energy are plentiful. The primary markets available for a CMM utilization project at the Sawang Colliery are power generation using internal combustion engines, and pipeline sales for city gas distribution or use in the fertilizer or industrial (e.g., iron and steel, aluminum, and cement) sectors.

Given the relatively small CMM production volume, as well as the requirement for gas upgrading, constructing a pipeline to transport the gas to demand centers would be impractical. Additionally, discussions with CMPDI indicate power generation for local consumption is the preferred end-use option for the drained gas. Generating electricity on site is attractive because the input CMM gas stream can be utilized as-is, with minimal processing and transportation. Additional generating sets can be installed relatively cheaply and infrastructure for the power plant and distribution system is already planned. Based on gas supply forecasts, the mine could be capable of operating as much as 4.4 MW of electricity capacity.

4.4 Environmental Markets

Markets for environmental attributes include carbon markets such as the European Union Emissions Trading Scheme and the project mechanisms and emissions trading under the Kyoto Protocol, renewable energy markets, green energy markets, and feed-in-tariffs and other subsidies.

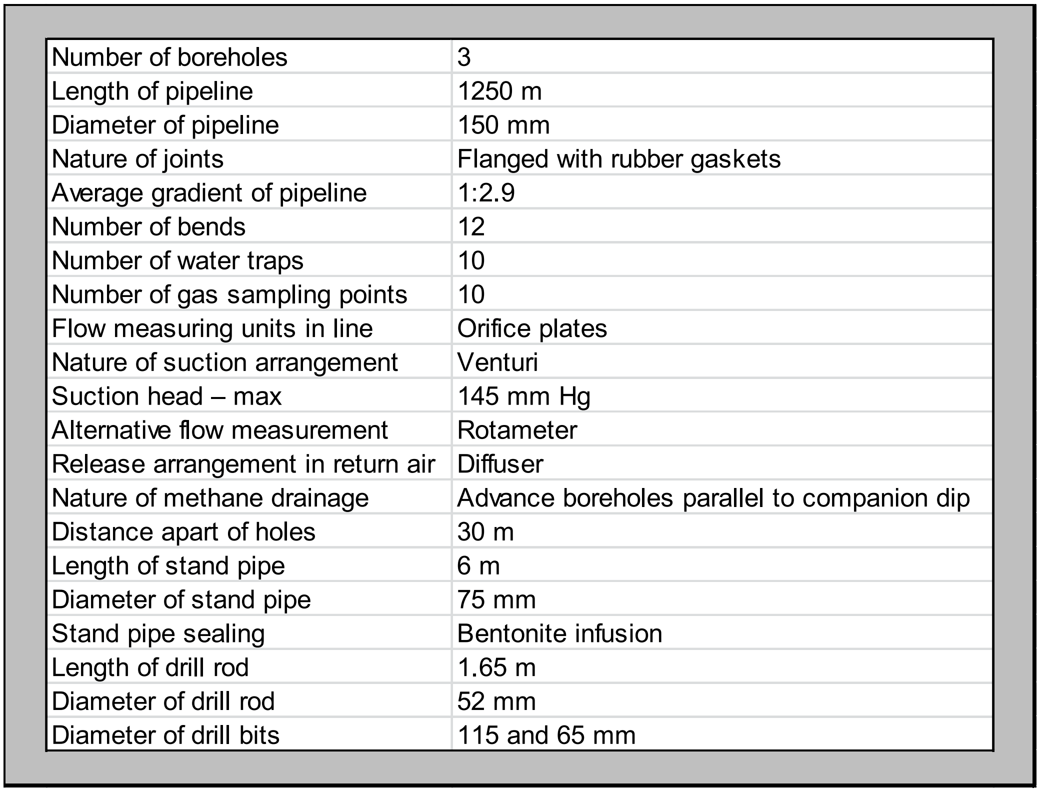
Carbon markets today are generally not viable. Although India has numerous CMM projects registered as Clean Development Mechanism projects, the Kyoto markets have effectively crashed with offsets selling for under US$1 per tonne, well below transaction and other administrative costs. At this time, there is no indication that prices in the Kyoto markets will shift significantly; therefore, a value for the carbon will not drive project development.

5.0 Technical Assessment

As discussed in Section 3, Mine Characteristics, the Sawang mine is considered to be a Degree III gassy mine, the highest category for methane emissions in the Indian system. The mine has been exploiting progressively deeper coal reserves as the mine moves down dip. They are at a point where methane emissions from the unmined south block extension are projected to be very high, which will affect a host of issues including safety, productivity, and ventilation. To help mitigate the projected high methane emission levels, CMPDI and CCL have expressed an interest in pursuing long, in-seam directional drilling to drain methane in advance of mining. Therefore, this technical assessment examined the feasibility of using long (4,000 ft length) in-mine horizontal wells drilled from the existing galleries down-dip into the virgin seams of the southern block extension area.

5.1 Pre-Mine Drainage Pilot Project Results

Methane drainage is not new to the Sawang Colliery. A trial project was conducted in the 1980's which implemented an in-seam degasification system in the Kargali Top seam. A summary of the methane drainage system components is provided in Exhibit 29 below.



Number of boreholes	3
Length of pipeline	1250 m
Diameter of pipeline	150 mm
Nature of joints	Flanged with rubber gaskets
Average gradient of pipeline	1:2.9
Number of bends	12
Number of water traps	10
Number of gas sampling points	10
Flow measuring units in line	Orifice plates
Nature of suction arrangement	Venturi
Suction head – max	145 mm Hg
Alternative flow measurement	Rotameter
Release arrangement in return air	Diffuser
Nature of methane drainage	Advance boreholes parallel to companion dip
Distance apart of holes	30 m
Length of stand pipe	6 m
Diameter of stand pipe	75 mm
Stand pipe sealing	Bentonite infusion
Length of drill rod	1.65 m
Diameter of drill rod	52 mm
Diameter of drill bits	115 and 65 mm

Exhibit 29: Methane Drainage System in the Kargali Top Seam of Sawang Colliery

The first borehole, drilled in August 1981, recorded a methane flow rate of 295 liters/minute (CMRS Project Report, 1986). The second and third boreholes were drilled down dip and are shown in Exhibit 30. The direction of drilling was maintained at 11.11 gon (gon = 1/400 of a turn), 12.22 gon and 10.00 gon inclination to the roadway for borehole 1, 2, and 3, respectively, at an angle of 5.56 gon to the horizontal. The angle and inclination employed were considered to be optimal to cover a maximum length in coal and allow free passage of percolated water from the boreholes.

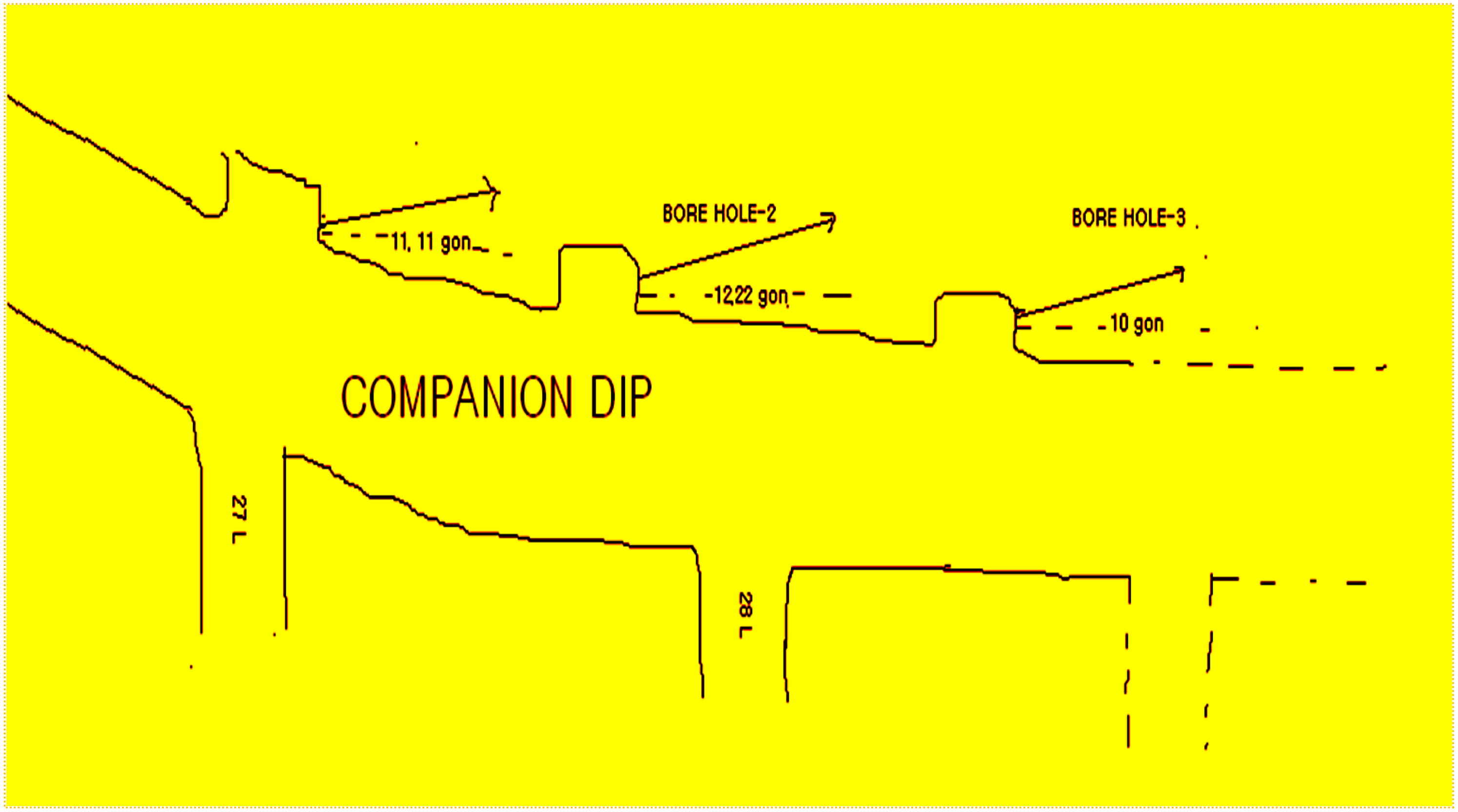


Exhibit 30: Borehole Location in Kargali Top Seam, Sawang Colliery

(Source: CMRS Project Report, 1986)

The 65 millimeter (mm) diameter drainage holes were constructed through the stand pipe. Once the entire length was drilled, each borehole was connected to the gas main. Water traps and an orifice meter connected to each branch were used, respectively, to separate and measure water and gas. Samples of the gas for compositional analysis were taken periodically and evaluated in the laboratory. The composition of gas from different sampling points in the entire range was found to vary little, which indicated negligible leakage. Average compositional results of gas samples from the Sawang Colliery are presented in Exhibit 31.

Gas	Concentration (%)
Methane	91.20
Carbon dioxide	6.05
Carbon monoxide	0.00
Hydrogen	0.00
Oxygen	0.40
Nitrogen	2.35

Exhibit 31: Composition of Recovered Gas at Sawang Colliery (CMRS Project Report, 1986)

To maintain quality concentrations of methane within the stand pipe a Bentonite suspension was applied under pressure. The seal maintained a methane concentration above 91 percent. Methane was recovered from the boreholes at a rate of 0.10 liter/second/meter.

Methane was produced from the three boreholes for a period of three years. However, gas production was discontinued by the colliery mainly due to the vast improvement of gas problems in the seam workings. The producing period and gas yield of the boreholes are shown in Exhibit 32.

Borehole No.	Life of borehole		Production Pure methane basis (m^3)
	From	To	
1.	August 1981	September 1984	221,000
2.	September 1982	January 1985	188,000
3.	March 1984	March 1985	71,000
TOTAL SPECIFIC PRODUCTION			480,000

Exhibit 32: Life and Gas Yield of Boreholes at Sawang Colliery (CMRS Project Report, 1986)

In addition to the actively mined seams the lower seams are virgin and indicate qualities that would make a good repository of gas. Pre-mine degasification of virgin seams by in-mine directional boreholes is viable based on the success of the Kargali Top seam drainage system.

5.2 Reservoir Simulation

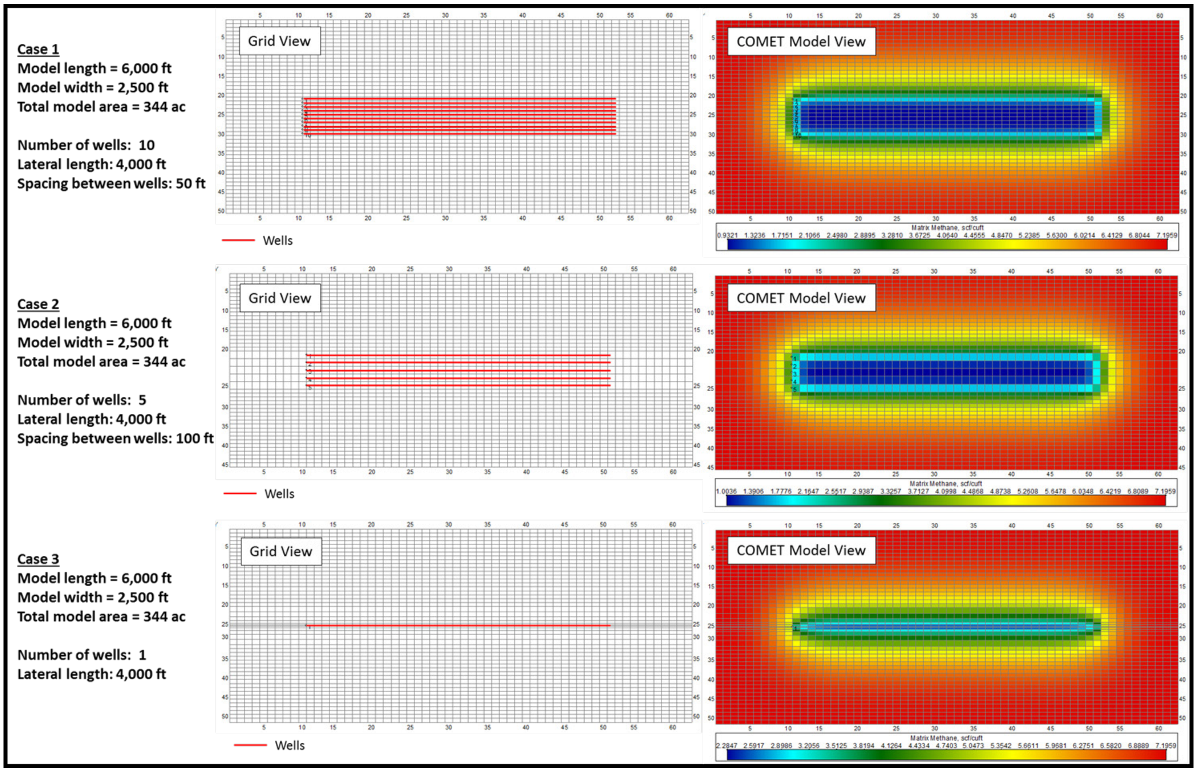
Methane drainage engineers use reservoir simulations to optimize current drainage systems and assess the relative benefits of degasification alternatives. Simulations of a system of long in-seam boreholes can derive, with relative confidence, the necessary borehole spacing and borehole configurations based on time available for methane drainage and/or residual gas content targets. As modern longwall mining operations implement “just in time” management practices to balance costs incurred in gateroad development with income earned from longwall shearer passes, reservoir simulation has become an important tool to aid in the optimization of methane drainage. For this study, reservoir simulations of long in-seam methane drainage boreholes were performed utilizing three borehole spacing cases.

5.2.1 Reservoir Simulator

A reservoir model designed to simulate methane drainage using long in-seam boreholes at the Sawang Colliery was constructed using ARI’s proprietary CBM reservoir simulator, COMET3. For this project, COMET3 was run in dual porosity, single permeability, two phase, two component (methane and carbon dioxide) mode. This was done in order to correctly account for the known carbon dioxide content of desorbed gas.

5.2.2 Long In-Seam Borehole Drainage Model

A total of three single-layer models were constructed in order to simulate gas production from a single longwall panel measuring 4,000 ft by 500 ft and targeting the Kargali Top seam. The models were designed to simulate production from long horizontal drainage wells drilled from existing mine workings according to three separate well spacing cases. As illustrated in Exhibit 33, Case 1 utilizes 10 wells spaced 50 ft apart, Case 2 utilizes 5 wells spaced 100 ft apart, and Case 3 utilizes only one well. All wells are drilled into the Kargali Top seam, which dips at an angle of 15 degrees, and are assumed to be 4,000 ft in lateral length. The models were each run for five years in order to simulate gas production rates and cumulative production volume from the study area. Exhibit 34 is a 3D representation of the model area as shown in the COMET3 reservoir simulator.



Case 1
Model length = 6,000 ft
Model width = 2,500 ft
Total model area = 344 ac

Number of wells: 10
Lateral length: 4,000 ft
Spacing between wells: 50 ft

Case 2
Model length = 6,000 ft
Model width = 2,500 ft
Total model area = 344 ac

Number of wells: 5
Lateral length: 4,000 ft
Spacing between wells: 100 ft

Case 3
Model length = 6,000 ft
Model width = 2,500 ft
Total model area = 344 ac

Number of wells: 1
Lateral length: 4,000 ft

Exhibit 33: Model Layout for Three Well Spacing Cases

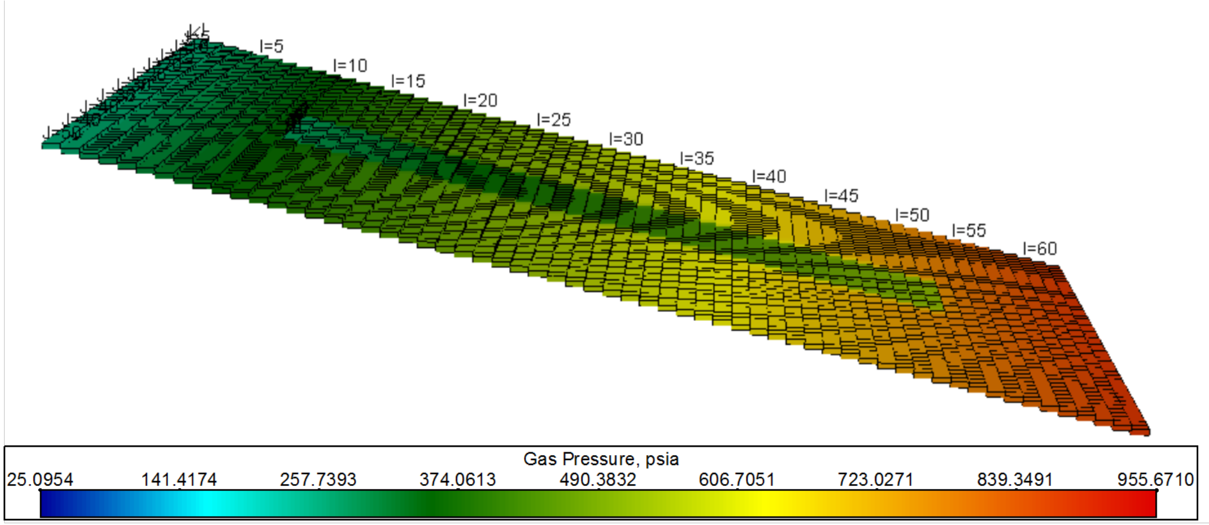
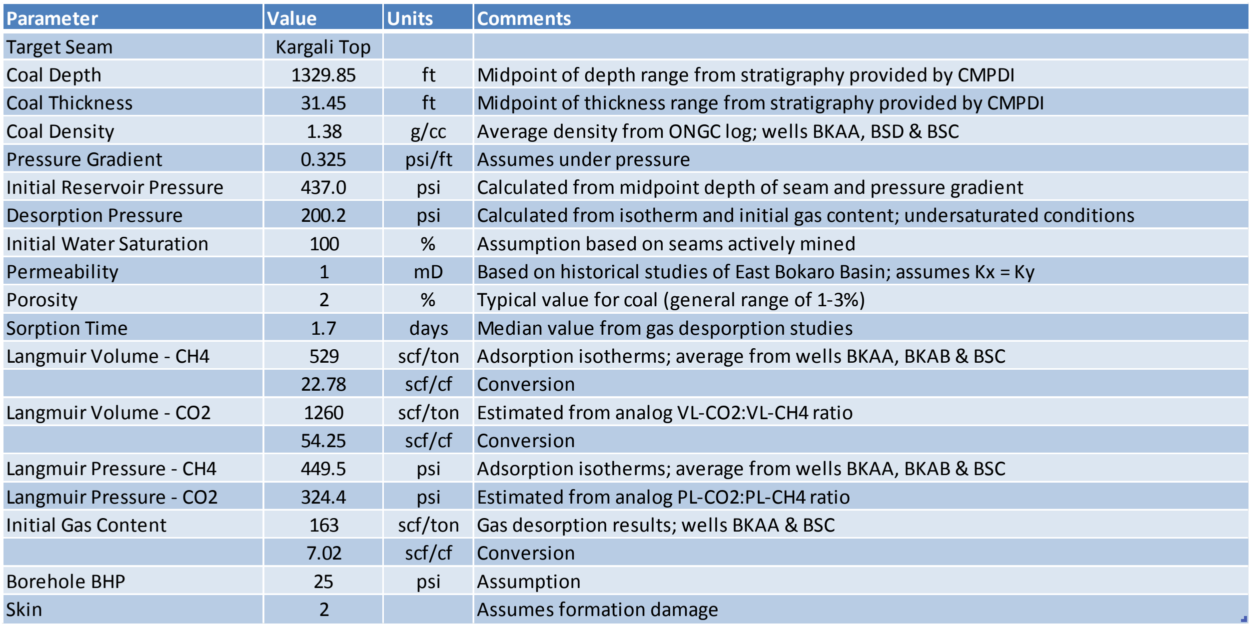


Exhibit 34: Example 3D Representation of Model Area as Shown in COMET3

5.2.3 Discussion of Input Parameters

The input data are derived directly from the geologic analysis conducted as part of this pre-feasibility study. Any unknown reservoir parameters were obtained from analogs. The input parameters used in the COMET3 reservoir simulation study are presented in Exhibit 35, and a brief discussion of each parameter is provided below.



Parameter	Value	Units	Comments
Target Seam	Kargali Top		
Coal Depth	1329.85	ft	Midpoint of depth range from stratigraphy provided by CMPDI
Coal Thickness	31.45	ft	Midpoint of thickness range from stratigraphy provided by CMPDI
Coal Density	1.38	g/cc	Average density from ONGC log; wells BKAA, BSD & BSC
Pressure Gradient	0.325	psi/ft	Assumes under pressure
Initial Reservoir Pressure	437.0	psi	Calculated from midpoint depth of seam and pressure gradient
Desorption Pressure	200.2	psi	Calculated from isotherm and initial gas content; undersaturated conditions
Initial Water Saturation	100	%	Assumption based on seams actively mined
Permeability	1	mD	Based on historical studies of East Bokaro Basin; assumes Kx = Ky
Porosity	2	%	Typical value for coal (general range of 1-3%)
Sorption Time	1.7	days	Median value from gas desporption studies
Langmuir Volume - CH4	529	scf/ton	Adsorption isotherms; average from wells BKAA, BKAB & BSC
	22.78	scf/cf	Conversion
Langmuir Volume - CO2	1260	scf/ton	Estimated from analog VL-CO2:VL-CH4 ratio
	54.25	scf/cf	Conversion
Langmuir Pressure - CH4	449.5	psi	Adsorption isotherms; average from wells BKAA, BKAB & BSC
Langmuir Pressure - CO2	324.4	psi	Estimated from analog PL-CO2:PL-CH4 ratio
Initial Gas Content	163	scf/ton	Gas desorption results; wells BKAA & BSC
	7.02	scf/cf	Conversion
Borehole BHP	25	psi	Assumption
Skin	2		Assumes formation damage

Exhibit 35: Reservoir Parameters for Kargali Top Seam at Sawang Colliery

5.2.3.1 Permeability

Coalbed permeability, as it applies to production of methane from coal seams, is a result of the natural cleat (fracture) system of the coal and consists of face cleats and butt cleats. This natural cleat system is sometimes enhanced by natural fracturing caused by tectonic forces in the basin. The permeability resulting from the fracture systems in the coal is called “absolute permeability” and it is a critical input parameter for reservoir simulation studies. Absolute permeability data for the coal seams in the study area were not provided, but based on historical studies of the East Bokaro Basin a permeability of 1 millidarcy (mD) was assumed for the reservoir simulations of the Kargali Top Seam.

5.2.3.2 Methane Isotherm

The methane (CH_4) isotherm used in this simulation study was based on the average adsorption isotherm from samples taken from wells BKAA, BKAB, and BSC. Exhibit 36 is a graphical representation of the isotherm used in the reservoir simulations showing a Langmuir volume (V_L) of 529 scf/ton and a corresponding Langmuir pressures (P_L) of 449.5 pounds per square inch absolute (psia), respectively.

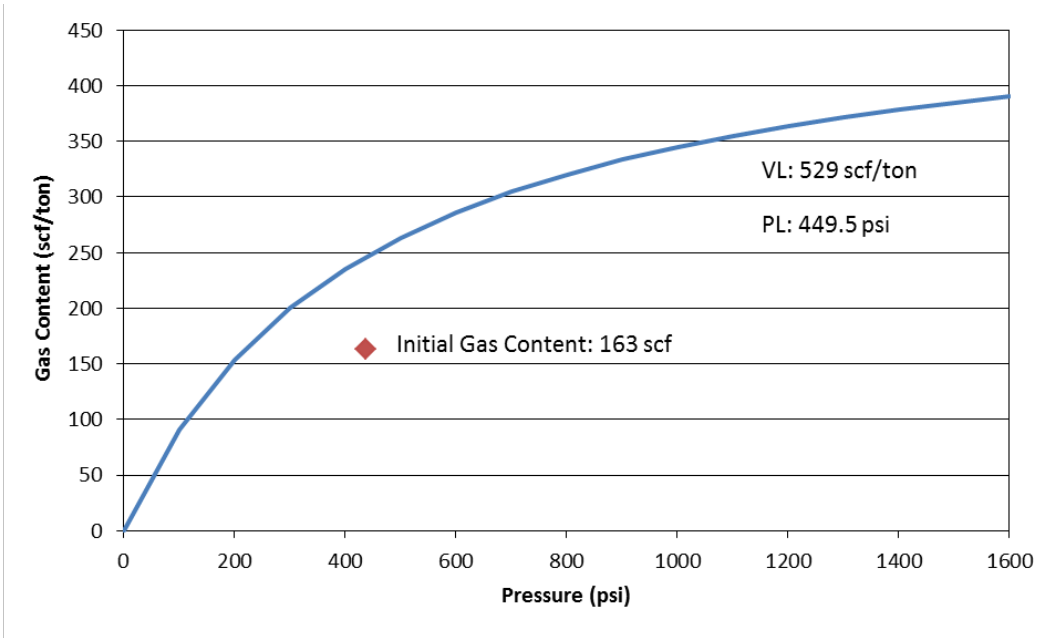


Exhibit 36: Methane Isotherm and In-Situ Gas Content

An average coal density of 1.38 grams per cubic centimeter (gm/cc) was used to convert Langmuir volume expressed as unit volume per mass to units of standard volume to reservoir volume for use in the COMET3 reservoir simulator. The average density was derived from ONGC logs for wells BKAA, BSD, and BSC.

5.2.3.3 Carbon Dioxide Isotherm

Compositional analysis of the desorbed gas indicates the presence of carbon dioxide (CO_2). As a result, it is necessary to account for the presence of CO_2 in the model simulations; however, no directly measured CO_2 isotherms are available. ARI has utilized its data base of laboratory derived isotherms to derive the ratio of V_LCO_2 to V_LCH_4 and of P_LCO_2 to P_LCH_4. Applying these ratios to the methane isotherm discussed above, values of V_LCO_2 and P_LCO_2 were determined to be 1260 scf/ton and 324 psia, respectively.

5.2.3.4 Gas Content

Initial gas content is assumed to be 163 standard cubic feet (scf) (see Exhibit 36), which corresponds to the average gas content from desorption studies performed on multiple core holes (wells BKAA and BSC) as part of ONGC's development program in the East Bokaro coalfield.

5.2.3.5 Coal Seam Depth and Thickness

The thickness and midpoint depth of the Kargali Top coal seam is taken to be 31.45 ft and 1329.85 ft, respectively. The coal block dips at an angle of 15 degrees. These values are derived from average thickness and depth from stratigraphic data provided by CMPDI for the Sawang Colliery.

5.2.3.6 Porosity

Porosity is a measure of the void spaces in a material. In this case, the material is coal, and the void space is the cleat fracture system. Since porosity values for the coal seams in the study area were not available, a value of 2 percent was used in the simulations. Typical porosity values for coal range between 1 percent and 3 percent.

5.2.3.7 Initial Water Saturation

The cleat and natural fracture system in the reservoir was assumed to be 100 percent water saturated.

5.2.3.8 Reservoir and Desorption Pressure

The initial reservoir pressure is assumed to be 437 psia, which at a midpoint depth of 1,346 ft represents a pressure gradient of 0.325 psia/ft. Based on an initial in-situ gas content of 163 scf, desorption pressure is 200 psia as calculated using the Langmuir equation.

5.2.3.9 Sorption Time

Sorption time is defined as the length of time required for 63 percent of the gas in a sample to be desorbed. In this study we use a sorption time of 1.7 days. This value was determined by using the median value measured during gas desorption studies of coal from core holes. Production rates and cumulative production forecasts are typically relatively insensitive to sorption time.

5.2.3.10 Relative Permeability

Relative permeability is a reservoir parameter that describes the degree of effective permeability of one fluid phase in the presence of another fluid phase. Relative permeability is a dimensionless number that is multiplied by the absolute permeability (described above) in order to obtain the value of effective permeability that will be used. Relative permeability is a function of saturation, and is usually plotted against the liquid (water) phase.

Relative permeability data for the coal of the study area were not available. Therefore, a relative permeability data set was used, which was derived from numerous reservoir simulation history-matching studies conducted in India for coals of similar age and rank. The relative permeability curve used in the simulation study is shown in Exhibit 37.

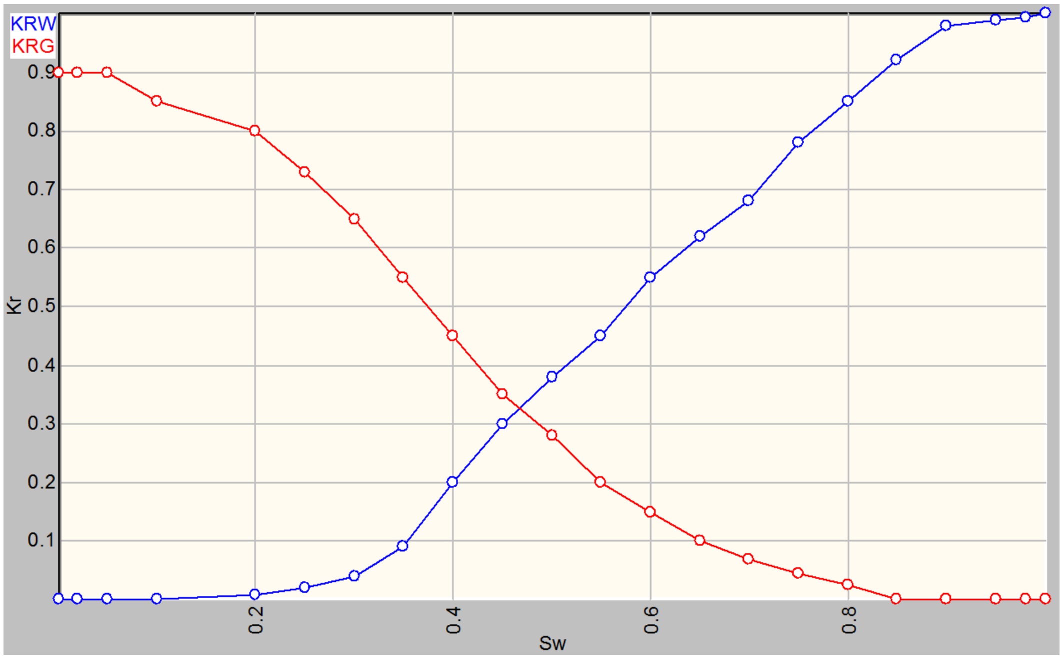


Exhibit 37: Relative Permeability

5.2.3.11 Completion

Long in-seam boreholes with lateral lengths of 4,000 ft are proposed to be drilled and completed in the Kargali Top seam. For modeling purposes, a skin value of 2 is assumed (formation damage).

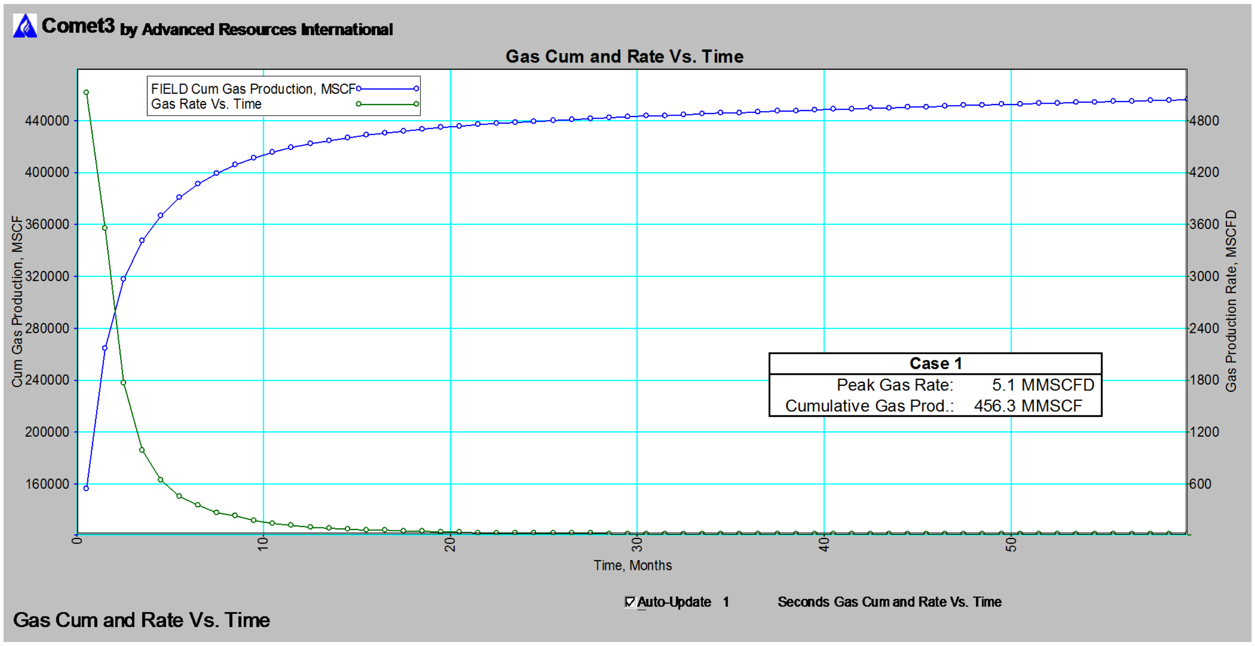
5.2.3.12 Pressure Control

For the current study, an in-mine pipeline with a surface vacuum station providing vacuum pressure of 25 psi was assumed. In coal mine methane operations, low well pressure is required to achieve maximum gas content reduction. The wells were allowed to produce for a total of five years.

5.2.4 In-Seam Gas Drainage Borehole Model Results

As noted previously, three reservoir models were created to simulate gas production for a representative longwall panel located at the Sawang Colliery. Each of the models was run for a period of five years and the resulting gas production profiles, as well as the methane content of the coal seam, are highlighted below. Simulated gas production rate and cumulative gas production for Case 1, Case 2, and Case 3 are shown in Exhibit 38, Exhibit 40, and Exhibit 42, respectively. All simulated gas production represents total production for the entire model area.

One of the benefits of pre-drainage is the reduction of methane content in the coal seam prior to mining. Exhibit 39, Exhibit 41, and Exhibit 43 illustrate the reduction in *in-situ* gas content in the coal seam over time. All gas contents represent averages from within the longwall panel area only.



Case 1

Peak Gas Rate: 5.1 MMSCFD

Cumulative Gas Prod.: 456.3 MMSCF

Exhibit 38: Gas Rate and Cumulative Production: Case 1

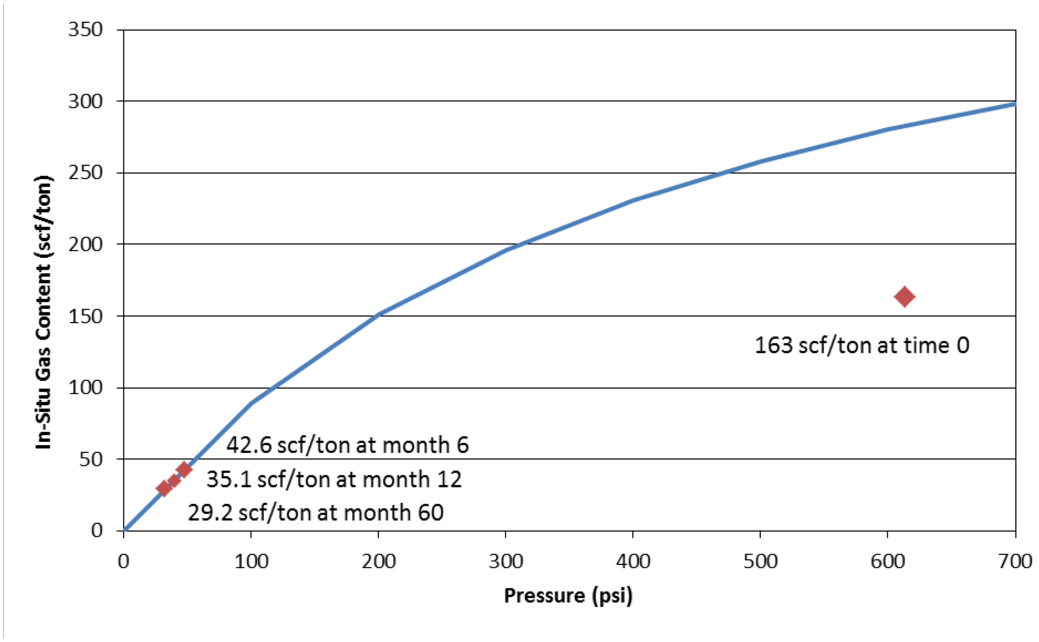


Exhibit 39: Reduction in In-Situ Gas Content Over Time: Case 1

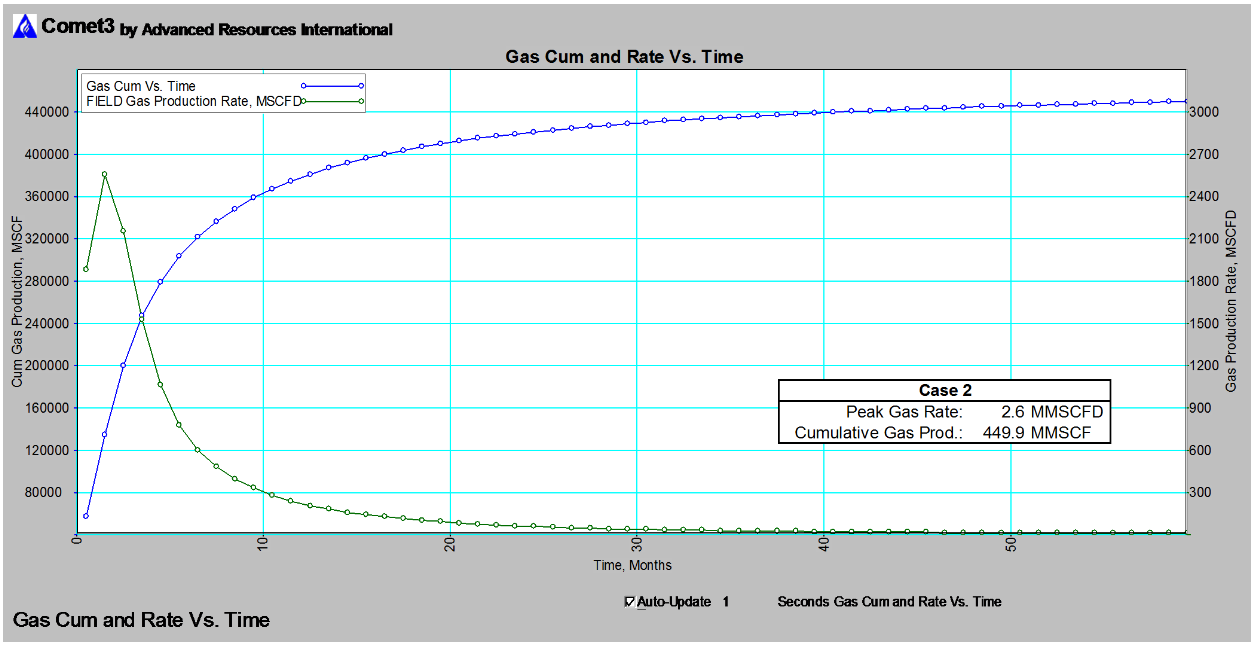


Exhibit 40: Gas Rate and Cumulative Production: Case 2

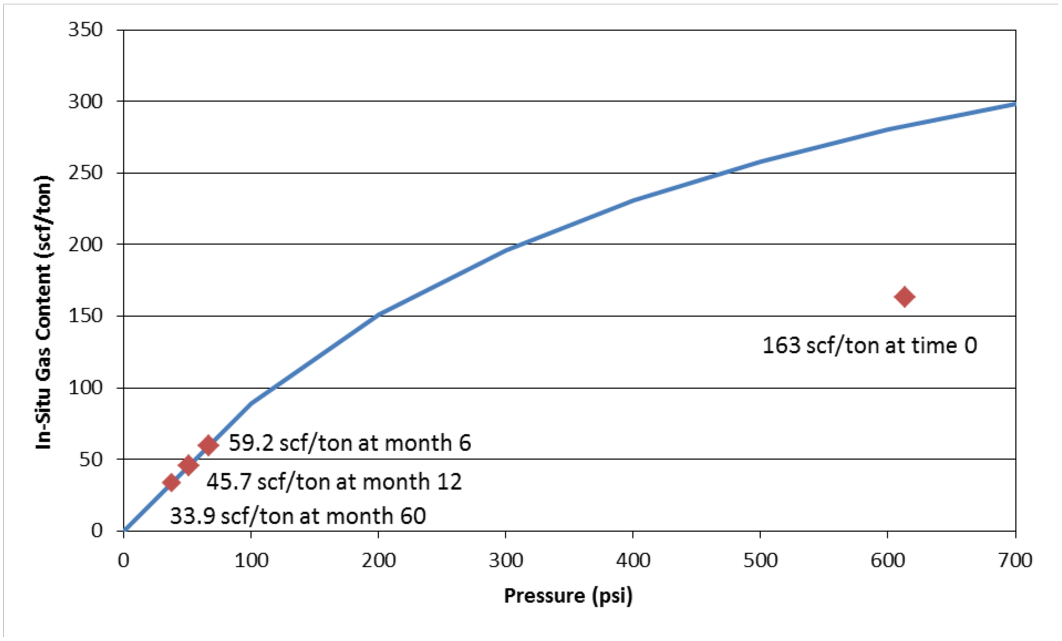
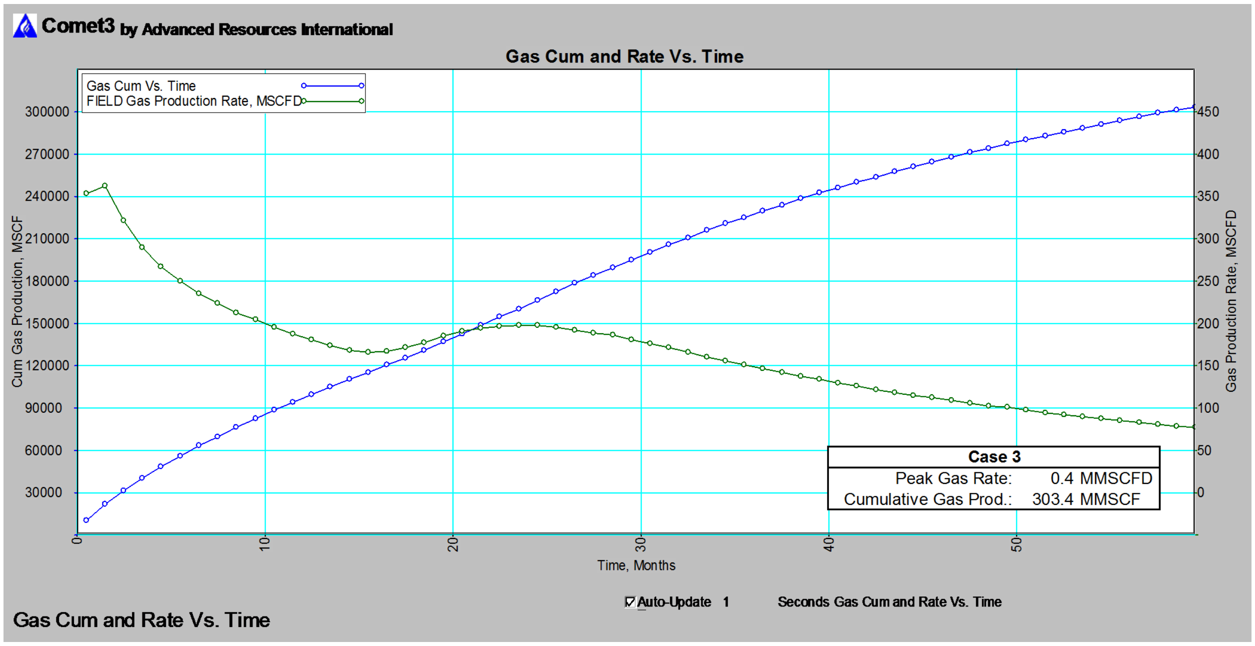


Exhibit 41: Reduction in In-Situ Gas Content Over Time: Case 2



Case 3
Peak Gas Rate: 0.4 MMSCFD
Cumulative Gas Prod.: 303.4 MMSCF

Exhibit 42: Gas Rate and Cumulative Production: Case 3

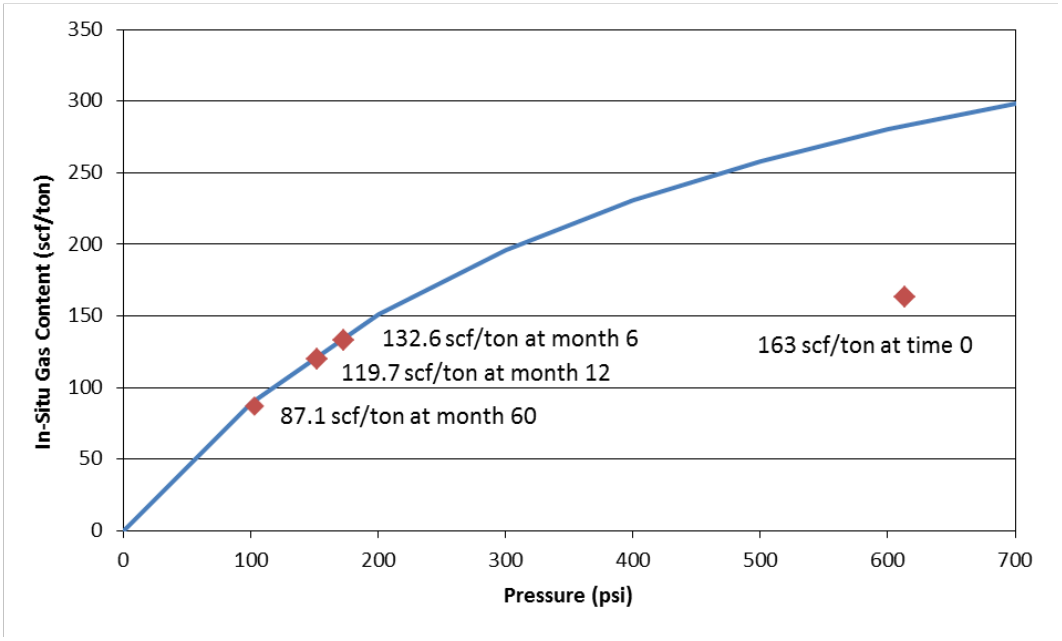


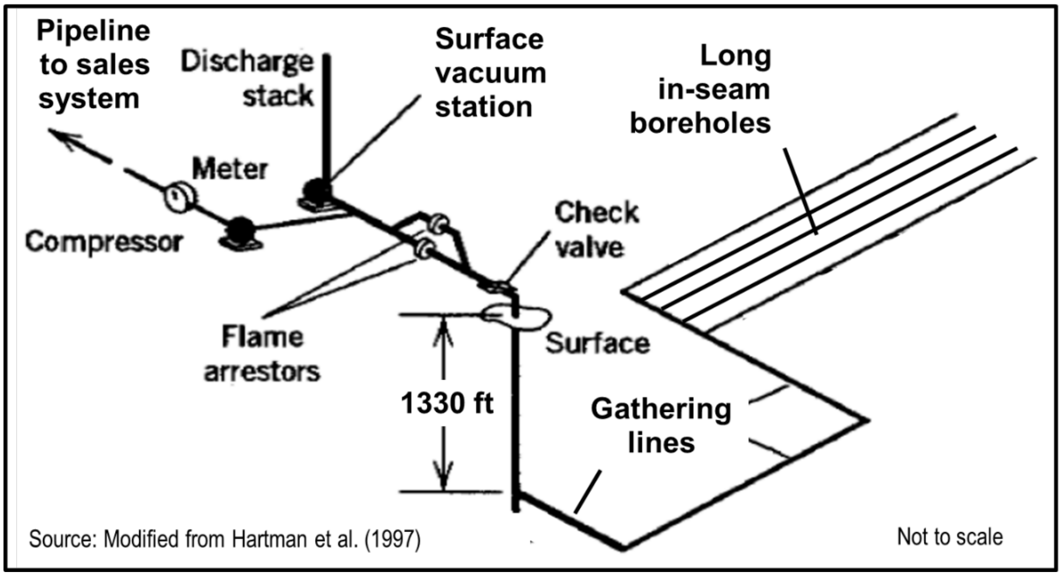
Exhibit 43: Reduction in In-Situ Gas Content Over Time: Case 3

6.0 Economic Assessment

6.1 Well Spacing Optimization

The initial objective of the economic assessment is to determine the optimum well spacing for the development of the proposed CMM project at the Sawang Colliery. Based on the reservoir simulation results for each of the three well spacing cases, project costs were estimated and a series of cash flows were generated to determine the most economically viable well spacing case. The optimized well spacing pattern will be used to forecast gas production for the project, which will then be input into the economic model to determine if the proposed project is economically feasible.

To aid in the cost estimation process, a proposed project development scenario was created, as summarized in Exhibit 44. As shown in the schematic diagram, the major cost components for the CMM project at Sawang Colliery include the in-seam boreholes, gathering system, surface vacuum station, compressor, and pipeline to the sales system.

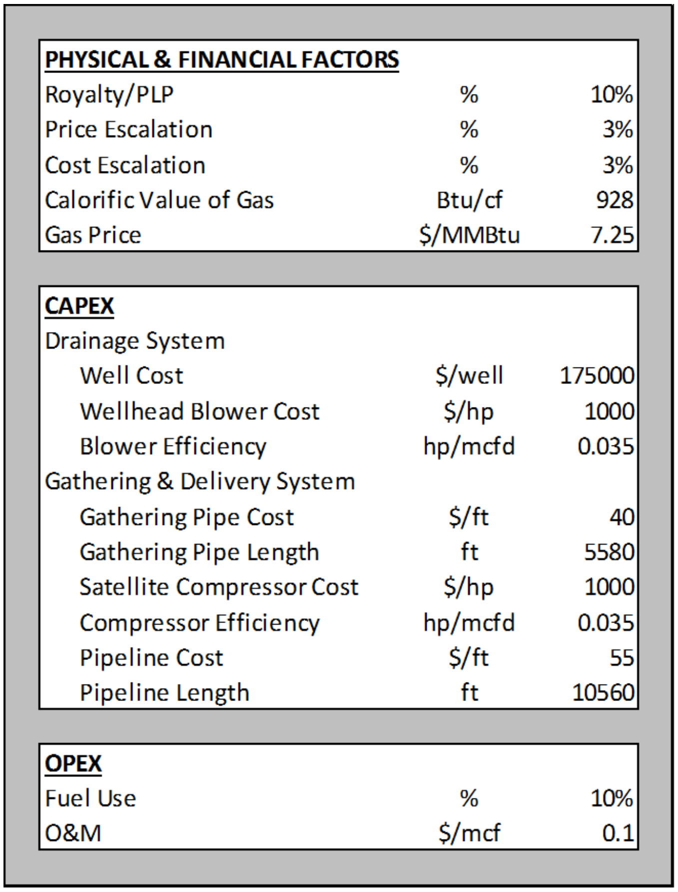


Source: Modified from Hartman et al. (1997)

Exhibit 44: Schematic Diagram of CMM Project at Sawang Colliery

6.1.1 Overview of Economic Assumptions

Cost estimates were developed for the goods and services required for the development of the CMM project at the Sawang Colliery. These cost estimates were based on a combination of known average development costs of analogous projects in India and the U.S., and other publically available sources.[1] The input parameters and assumptions used in the economic analysis are summarized in Exhibit 45. A more detailed discussion of each input parameter is provided below.



PHYSICAL & FINANCIAL FACTORS		
Royalty/PLP	%	10%
Price Escalation	%	3%
Cost Escalation	%	3%
Calorific Value of Gas	Btu/cf	928
Gas Price	$/MMBtu	7.25
CAPEX		
Drainage System		
Well Cost	$/well	175000
Wellhead Blower Cost	$/hp	1000
Blower Efficiency	hp/mcfd	0.035
Gathering & Delivery System		
Gathering Pipe Cost	$/ft	40
Gathering Pipe Length	ft	5580
Satellite Compressor Cost	$/hp	1000
Compressor Efficiency	hp/mcfd	0.035
Pipeline Cost	$/ft	55
Pipeline Length	ft	10560
OPEX		
Fuel Use	%	10%
O&M	$/mcf	0.1

Exhibit 45: Summary of Economic Input Parameters

6.1.2 Physical and Financial Factors

6.1.2.1 Taxes

The income tax rate for domestic companies is set at 30 percent. However, a seven-year tax holiday currently exists for companies engaged in commercial production of

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[1] User's Manual for the Coal Mine Methane Project Cash Flow Model (Version 2). USEPA Coalbed Methane Outreach Program, January 2011; U.S. Environmental Protection Agency (USEPA). Coal Mine Methane Recovery: A Primer. EPA-430-R-09-013 prepared under Task Orders No. 13 and 18 of USEPA Contract EP-W-05-067 by Advanced Resources, Arlington, USA, September 2009

natural gas. Since the current project lifetime is only five years, all project economics are calculated on a pre-tax basis.

6.1.2.2 Royalty

Under the New Exploration Licensing Policy, royalties for natural gas production are set at 10 percent. An additional production-linked payment (PLP) payable to the central government is also generally included. This payment, calculated on a sliding scale based on the production level, is a biddable item which varies on a project-specific basis. Due to the preliminary status and small scale of the proposed project, a PLP is currently not accounted for in the project economics.

6.1.2.3 Price and Cost Escalation

All prices and costs are assumed to increase by 3 percent per annum.

6.1.2.4 Calorific Value of Gas

The reservoir simulation results indicate the methane concentration of produced CMM gas to be 91 percent. The gas is assumed to have a calorific value of 928 Btu/scf. This is based on a calorific value of 1020 Btu/scf for pure methane adjusted to account for lower methane concentration of the CMM gas as produced at Sawang Colliery.

6.1.2.5 Gas Price

The gas price utilized in the economic evaluation is $7.25/MMBtu, which represents the current gas price as set by the government of India.

6.1.3 Capital Expenditures

The drainage system includes the in-seam drainage wells and vacuum pumps used to bring the drainage gas to the surface. The major input parameters and assumptions associated with the drainage system are as follows:

6.1.3.1 Well Cost

An in-mine borehole with a lateral length of 4000 ft is assumed to cost $175,000 per well. The cost of $43.75 per foot is representative of costs observed for analogous projects.

6.1.3.2 Surface Vacuum Station

Vacuum pumps draw gas from the wells into the gathering system. Vacuum pump costs are a function of the gas flow rate and efficiency of the pump. To estimate the capital costs for the vacuum station, a pump cost of $1000 per horsepower (hp) and a pump efficiency of 0.035 hp/Mscfd are assumed. The maximum gas flow rate used in the calculation of pump cost, as based on the simulation results, is shown in Exhibit 46. Total capital cost for the surface vacuum station is estimated as the product of pump cost, pump efficiency, and peak gas flow (i.e., $/hp x hp/Mscfd x Mscfd).

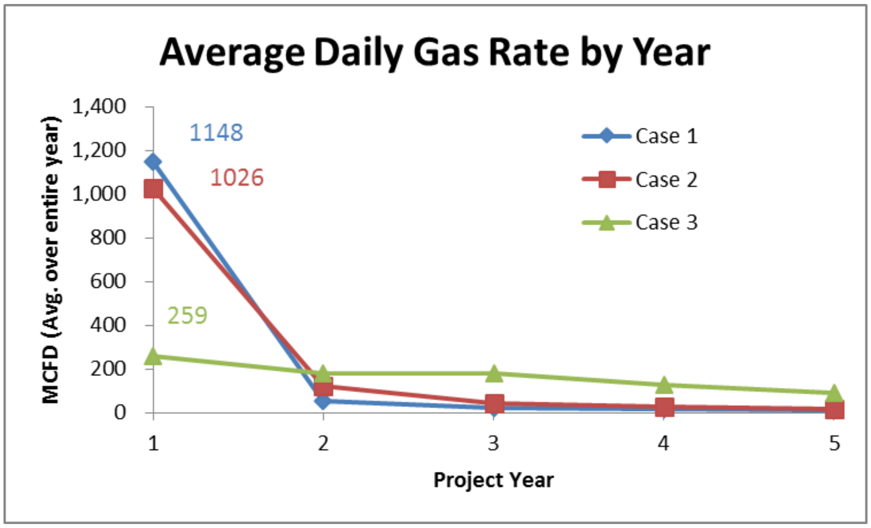


Exhibit 46: Average Daily Gas Rate by Year

The gathering system consists of the piping and associated valves and meters necessary to get the gas from within the mine to the satellite compressor station located on the surface. The major input parameters and assumptions associated with the gathering system are as follows:

6.1.3.3 Gathering System Cost

The gathering system cost is a function of the piping length and cost per foot. For the proposed project, we assume a piping cost of $40/ft and 5580 ft of gathering lines (Note: as Case 3 is a single well case, it assumes less gathering lines are required, 5080 ft).

The delivery system consists of the satellite compressor and the pipeline that connects the compressor to the sales system leading to the utilization project. The major input parameters and assumptions associated with the delivery system are as follows:

6.1.3.4 Satellite Compressor Cost

Satellite compressors are used to move gas through the pipeline connected to the end-use project. Similar to vacuum pump costs, compression costs are a function of the gas flow rate and efficiency of the compressor. To estimate the capital costs for the compressor, we assume a compressor cost of $1000/hp and an efficiency of 0.035 hp/Mscfd. As with the vacuum pump costs, the maximum gas flow rate used in the calculation of compression cost is shown in Exhibit 46. Total capital cost for the compressor is estimated as the product of compressor cost, compressor efficiency, and peak gas flow (i.e., $/hp x hp/Mscfd x Mscfd).

6.1.3.5 Pipeline Cost

The cost of the pipeline to the sales system is a function of the pipeline length and cost per foot. For the proposed project, we assume a pipeline cost of $55/ft and length of 10,560 ft.

6.1.4 Operating Expenses

6.1.4.1 Fuel Use

For the proposed project, it is assumed that CMM is used to power the vacuum pumps and compressors in the gathering and delivery systems. Total fuel use is assumed to be 10 percent, which is deducted from the gas delivered to the end use.

6.1.4.2 Normal Operating and Maintenance Costs

The normal operating and maintenance cost associated with the vacuum pumps and compressors is assumed to be $0.10/Mscf.

6.1.5 Well Spacing Optimization Results

Utilizing the gas production profiles generated in the reservoir simulation portion of this study, discounted cash flow analyses were performed on each of the three well spacing cases. Exhibit 47, Exhibit 48, and Exhibit 49 present the detailed cash flow results for cases 1, 2, and 3, respectively. The cash flow results were used to calculate various metrics – such as the simple payback period, net present value (NPV), and internal rate of return (IRR) – which provided the basis for the selection of the optimal development scenario for the proposed CMM project.

Payback period represents the number of years it takes to recover the initial cost of the project. Exhibit 50 shows the cumulative cash flow (undiscounted) for each drilling case. The year where the cumulative cash flow profile crosses into positive territory represents the simple payback period. Case 2 has the shortest payback period and is, therefore, the preferred case.

NPV is the sum of the present values of all future cash flows from the project, and represents the present value of the expected cash inflows minus the initial cost of the project. The discount rate used to calculate the NPV should be based on the cost of capital adjusted for any project-specific risks. Since the cost of capital for the proposed project is not known, NPV profiles were generated for each of the three drilling cases over a wide range of discount rates. From the NPV profiles presented in Exhibit 51, the NPVs for Case 2 and Case 3 are very similar, with Case 2 having a higher NPV at the corresponding benchmark discount rate of 10 percent.

IRR is the discount rate that makes the NPV equal to zero (i.e., where the present value of future cash inflows equals the initial cost of the project). In Exhibit 51, the IRRs are represented where the NPV profiles cross over the axis at zero NPV. Again, Case 2 has the greatest IRR and is, therefore, the preferred case.

Exhibit 52 presents a tabular summary of the results of the economic assessment. Based on the economic metrics calculated, five wells per panel (Case 2) is the optimal well spacing pattern for the CMM project at Sawang Colliery.

Simple Economics (Before-Tax)	
Case 1	1
Sawang Colliery, India	
5 Year Project Life	

Input Parameters		
Royalty	10.0%	
Price Escalation	3%	per year
Cost Escalation	3%	per year
Calorific Value of Gas	928	Btu/cf
Gas Price	7.25	$/MMBtu
	6.73	$/Mcf
Well Cost	175	,000
Wellhead Blower Cost	1000	$/hp
Blower Efficiency	0.035	hp/mcfd
Gathering Pipe Cost	40	$/ft
Gathering Pipe Length	5580	ft
Satellite Compressor Cost	1000	$/hp
Compressor Efficiency	0.035	hp/mcfd
Pipeline Cost	55	$/ft
Pipeline Length	10560	ft
Fuel Use	10.0%	
O&M	0.1	$/mcf

Project Cashflow

Project Year	Gross Prod. mmcf	Net Prod. mmcf	Gas Price $/mcf	Net Revenue $,000	Operating Cost $,000	Operating Income $,000	Capital Cost $,000	Cashflow $,000	Cum. Cashflow $,000	Wells Drilled
0	-	-	-	-	-	-	2,626.4	(2,626.4)	(2,626.4)	10
1	419.20	339.55	6.73	2,285.0	34.0	2,251.0	-	2,251.0	(375.3)	0
2	19.68	15.94	6.93	110.5	1.6	108.9	-	108.9	(266.5)	0
3	7.63	6.18	7.14	44.1	0.6	43.5	-	43.5	(223.0)	0
4	5.29	4.28	7.35	31.5	0.4	31.1	-	31.1	(191.9)	0
5	4.48	3.63	7.57	27.5	0.4	27.1	-	27.1	(164.8)	0
Total	456.28	369.59		2,498.6	37.0	2,461.6	2,626.4	(164.8)		10

Present Value Table

Discount Rate		Net Present Value
10%	-	(419.3)
15%	-	(526.8)
20%	-	(623.8)
25%	-	(712.0)
30%	-	(792.4)

Economic Parameters

NPV-10 ($,000)	-419.3
Internal Rate of Return	-5.4%
Payback Period (Years)	-
Profitability Index	0.8

Exhibit 47: Cash Flow and Economic Results for Case 1

Simple Economics (Before-Tax)

Case 2	2
Sawang Colliery, India	
5 Year Project Life	

Input Parameters		
Royalty	10.0%	
Price Escalation	3%	per year
Cost Escalation	3%	per year
Calorific Value of Gas	928	Btu/cf
Gas Price	7.25	$/MMBtu
	6.73	$/Mcf
Well Cost	175	,000
Wellhead Blower Cost	1000	$/hp
Blower Efficiency	0.035	hp/mcfd
Gathering Pipe Cost	40	$/ft
Gathering Pipe Length	5580	ft
Satellite Compressor Cost	1000	$/hp
Compressor Efficiency	0.035	hp/mcfd
Pipeline Cost	55	$/ft
Pipeline Length	10560	ft
Fuel Use	10.0%	
O&M	0.1	$/mcf

Project Cashflow

Project Year	Gross Prod. mmcf	Net Prod. mmcf	Gas Price $/mcf	Net Revenue $,000	Operating Cost $,000	Operating Income $,000	Capital Cost $,000	Cashflow $,000	Cum. Cashflow $,000	Wells Drilled
0	-	-	-	-	-	-	1,743.7	(1,743.7)	(1,743.7)	5
1	374.62	303.44	6.73	2,042.0	30.3	2,011.7	-	2,011.7	268.0	0
2	44.42	35.98	6.93	249.4	3.7	245.7	-	245.7	513.7	0
3	16.20	13.12	7.14	93.7	1.4	92.3	-	92.3	606.0	0
4	8.83	7.15	7.35	52.6	0.7	51.9	-	51.9	657.9	0
5	5.87	4.76	7.57	36.0	0.5	35.5	-	35.5	693.4	0
Total	449.94	364.45		2,473.7	36.6	2,437.1	1,743.7	693.4		5

Present Value Table

Discount Rate		Net Present Value
10%	-	415.0
15%	-	299.4
20%	-	196.0
25%	-	103.1
30%	-	18.9

Economic Parameters

NPV-10 ($,000)	415.0
Internal Rate of Return	31.2%
Payback Period (Years)	0.9
Profitability Index	1.2

Exhibit 48: Cash Flow and Economic Results for Case 2

Simple Economics (Before-Tax)

Case 3	3
Sawang Colliery, India	
5 Year Project Life	

Input Parameters		
Royalty	10.0%	
Price Escalation	3%	per year
Cost Escalation	3%	per year
Calorific Value of Gas	928	Btu/cf
Gas Price	7.25	$/MMBtu
	6.73	$/Mcf
Well Cost	175	,000
Wellhead Blower Cost	1000	$/hp
Blower Efficiency	0.035	hp/mcfd
Gathering Pipe Cost	40	$/ft
Gathering Pipe Length	5080	ft
Satellite Compressor Cost	1000	$/hp
Compressor Efficiency	0.035	hp/mcfd
Pipeline Cost	55	$/ft
Pipeline Length	10560	ft
Fuel Use	10.0%	
O&M	0.1	$/mcf

Project Cashflow

Project Year	Gross Prod. mmcf	Net Prod. mmcf	Gas Price $/mcf	Net Revenue $,000	Operating Cost $,000	Operating Income $,000	Capital Cost $,000	Cashflow $,000	Cum. Cashflow $,000	Wells Drilled
0	-	-	-	-	-	-	975.3	(975.3)	(975.3)	1
1	94.45	76.51	6.73	514.8	7.7	507.2	-	507.2	(468.1)	0
2	66.10	53.54	6.93	371.1	5.5	365.6	-	365.6	(102.5)	0
3	64.60	52.32	7.14	373.5	5.4	368.2	-	368.2	265.7	0
4	45.69	37.01	7.35	272.1	3.8	268.3	-	268.3	534.0	0
5	32.59	26.40	7.57	199.9	2.7	197.2	-	197.2	731.2	0
Total	303.42	245.77		1,731.6	25.1	1,706.5	975.3	731.2		1

Present Value Table

Discount Rate		Net Present Value
10%	-	370.3
15%	-	235.7
20%	-	123.0
25%	-	27.5
30%	-	(54.2)

Economic Parameters

NPV-10 ($,000)	370.3
Internal Rate of Return	26.6%
Payback Period (Years)	2.3
Profitability Index	1.4

Exhibit 49: Cash Flow and Economic Results for Case 3

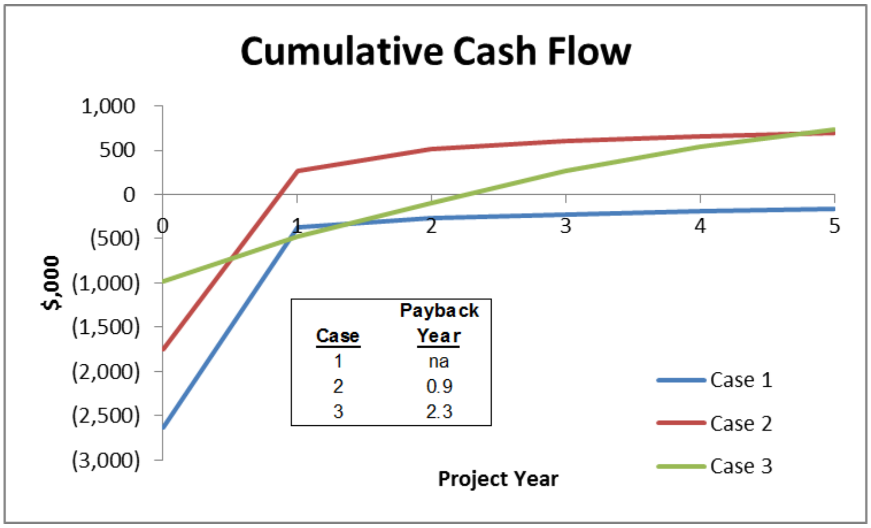


Exhibit 50: Economic Results – Cumulative Cash Flow by Case

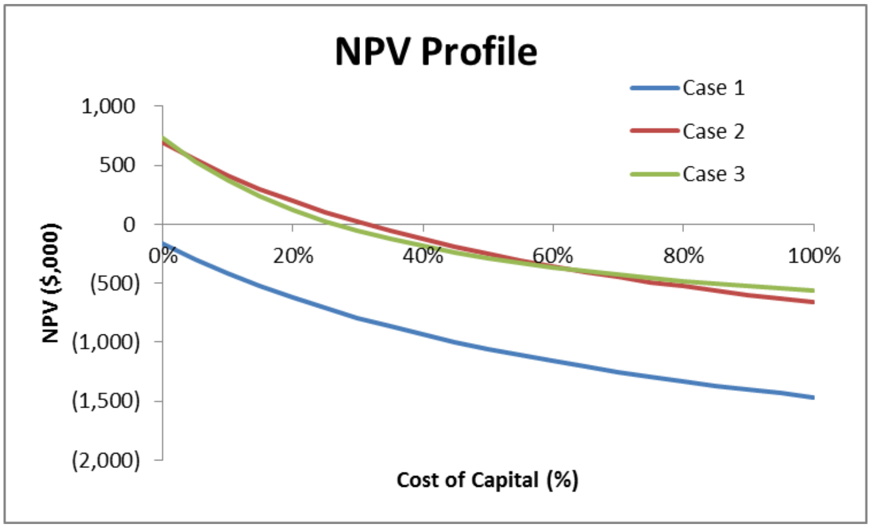


Exhibit 51: Economic Results – NPV Profile by Case

Case	Number of Wells	Capital ($,000)	NPV-10 ($,000)	IRR	Incr. Capital ($,000)	Incr. NPV-10 ($,000)
1	10	2626	(419)	-5%	883	(834)
2	5	1744	415	31%	768	45
3	1	975	370	27%	0	0

Exhibit 52: Summary of Economic Results

6.1.6 Well Spacing Optimization Sensitivity Analysis

Sensitivity analysis was performed to gauge the robustness of the economic results over a range of input parameters. The key input parameters of gas price, operating expense, and capital expenditure were varied by a range of +/- 50 percent of their original values. As illustrated in Exhibit 53, the selection of Case 2 as the optimal well spacing case is supported by the results of the sensitivity analysis. The economic results of Case 2 and Case 3 are very similar; however, when the reduction of the methane content in the coal seam is accounted for, Case 2 is far superior to Case 3 as *in-situ* methane content is reduced by 79 percent after 5 years of pre-mine drainage, whereas Case 3 results in only a 47 percent reduction in *in-situ* methane content over the same period.

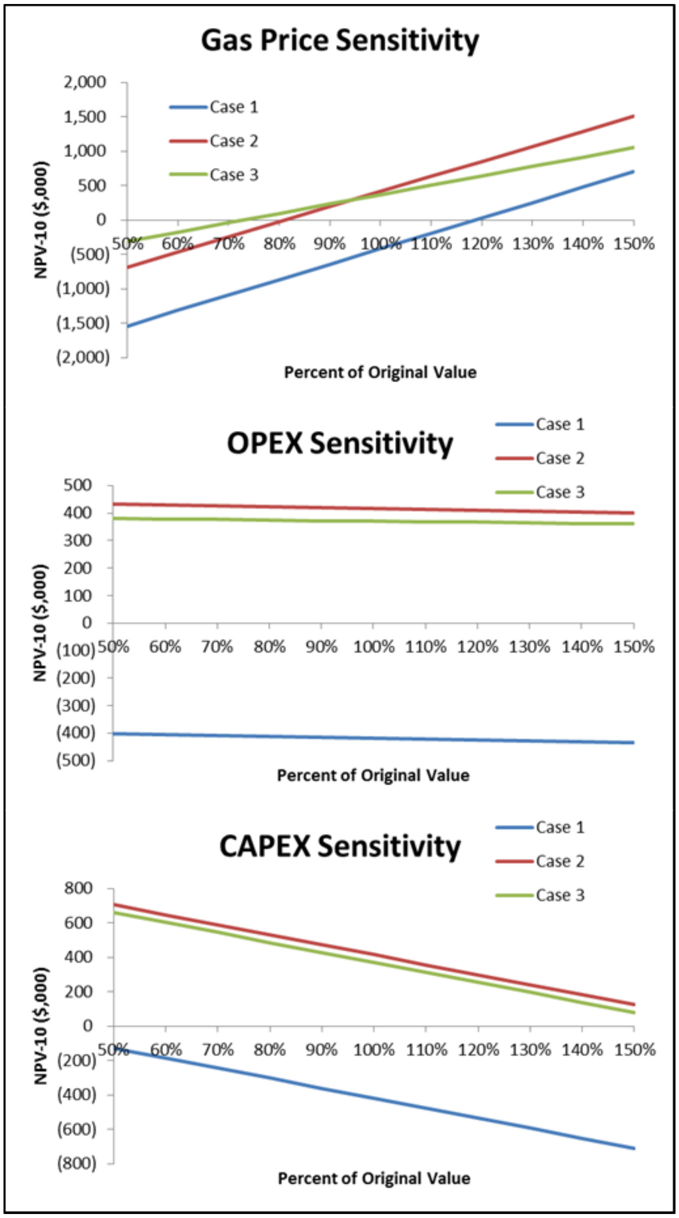


Exhibit 53: Results of Sensitivity Analysis

6.2 Project Economics

Based on the results of the well spacing analysis, the optimal well spacing for the development of the CMM project at the Sawang Colliery is 100 ft per well, or 5 wells per longwall panel (Case 2). Using this development approach, the objective of this section of the study is to determine the economic feasibility at the project level. The optimized well spacing pattern was used to forecast gas production for the project, which was then input into the economic model to assess the economic feasibility of the project.

For the proposed project development scenario, discounted cash flow analysis was performed for the upstream portion (i.e., CMM production) and the downstream portion (i.e., electricity production). A breakeven gas price was calculated in the upstream segment where the present value of cash outflows is equivalent to the present value of cash inflows. The breakeven gas price was then used in the downstream segment to calculate the fuel cost for the power plant. A breakeven electricity prices was calculated for the downstream segment, which can be compared to the current price of electricity observed at the mine in order to determine the economic feasibility of a CMM-fired power project at the mine. The results of the analysis are presented on a pre-tax basis.

6.2.1 Project Development Scenario

The proposed pre-drainage project – which utilizes long, in-seam boreholes to drain gas ahead of mining – focuses on mining of the Kargali Top coal seam located in the south block extension. Based on the mine maps provided by CMPDI, the total project area encompasses 1,359 ac (5.5 km^2). Assuming 25 percent of the mine area is either unmineable or reserved for roadways and supports, a total of 22 individual longwall panels measuring 4,000 ft in length by 500 ft in width (46 ac) can be developed within the project area. At 5 wells per panel, a total of 110 boreholes will be required by the project. Boreholes are drilled and begin producing five years prior to the initiation of mining activities at each panel. Assuming a longwall face advance rate of 11 ft per day, each longwall panel will take approximately one year to mine. With 5 years of pre-drainage at each longwall panel, degasification and mining of the 22 longwall panels will be completed over a 27 year project life.

6.2.2 Gas Production Forecast

Gas production forecasts were developed using the previously discussed simulation results (Exhibit 40) and the proposed development approach. The CMM production forecast for the project is shown in Exhibit 54.

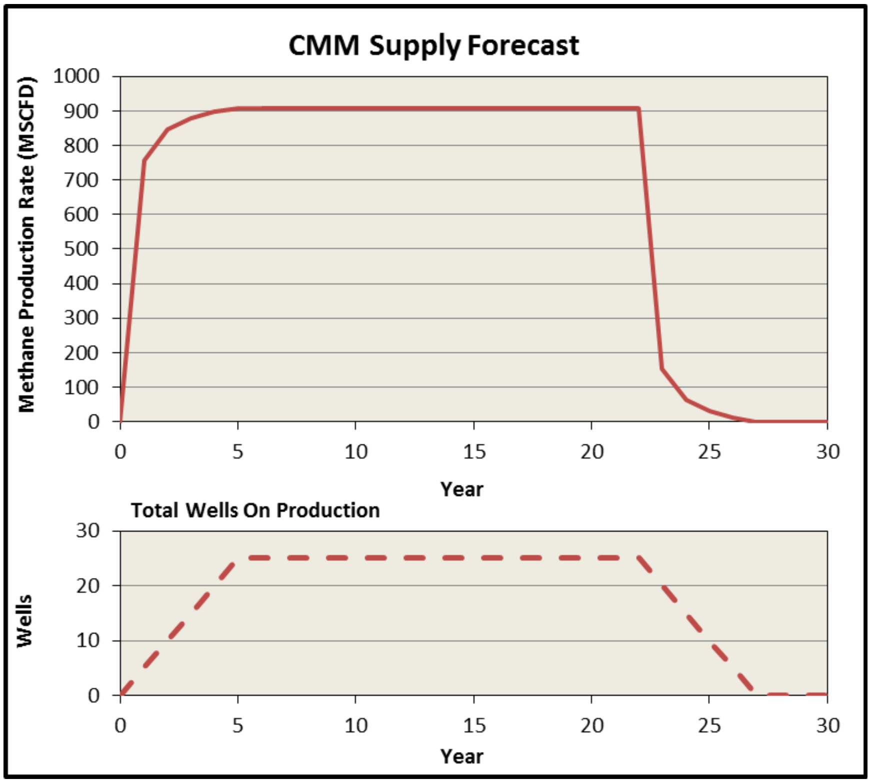


Exhibit 54: CMM Production Forecast for South Block Extension

6.2.3 Upstream (CMM Project) Economic Assumptions and Results

The assumptions used to calculate project economics for the upstream portion of the project are the same as those described earlier in Section 6.1. The pro-forma cash flow for the CMM project is shown in Exhibit 55. Based on the forecasted gas production, the breakeven cost of producing gas through in-seam drainage boreholes is estimated to be $3.00/MMBtu.

Simple Economics (CMM)	
Case 2	2
Sawang CMM Pre-Feasibility Study	
5 wells per panel; 5 years pre-drainage	

Input Parameters		
Royalty	10.0%	
Price Escalation	3.0%	per year
Cost Escalation	3.0%	per year
Gas Price	3.00	$/MMBtu
	2.78	$/Mcf
Well Cost	175.0	$,000/well
Surface Vacuum Station	1000	$/hp
Vacuum Pump Efficiency	0.035	hp/mcfd
Gathering Pipe Cost	40	$/ft
Gathering Pipe Length	135	ft/well
Satellite Compressor Cost	1000	$/hp
Compressor Efficiency	0.035	hp/mcfd
Pipeline Cost	55	$/ft
Pipeline Length	10560	ft
Field Fuel Use (gas)	10.0%	%
O&M	0.1	$/mcf

Project Cashflow

Project Year	Gross Gas Prod. mmcf	Net Gas Prod. mmcf	Gas Price $/mcf	Net Revenue $,000	Operating Cost $,000	Operating Income $,000	Capital Cost $,000	Cashflow $,000	Cum. Cashflow $,000	Wells Drilled	Net CH4 Prod mmcf
0	-	-	-	-	-	-	645.5	(645.5)	(645.5)	-	-
1	374.6	303.4	2.86	869.3	31.3	838.0	936.9	(98.9)	(744.3)	5	276.1
2	419.0	339.4	2.95	1,001.5	36.0	965.5	959.8	5.7	(738.6)	5	308.9
3	435.2	352.5	3.04	1,071.4	38.5	1,032.9	987.2	45.7	(693.0)	5	320.8
4	444.1	359.7	3.13	1,125.9	40.5	1,085.5	1,016.2	69.2	(623.7)	5	327.3
5	449.9	364.5	3.22	1,175.1	42.2	1,132.8	1,045.6	87.3	(536.5)	5	331.7
6	449.9	364.5	3.32	1,210.3	43.5	1,166.8	1,076.9	89.9	(446.6)	5	331.7
7	449.9	364.5	3.42	1,246.6	44.8	1,201.8	1,109.2	92.6	(354.1)	5	331.7
8	449.9	364.5	3.52	1,284.0	46.2	1,237.8	1,142.5	95.3	(258.7)	5	331.7
9	449.9	364.5	3.63	1,322.5	47.6	1,275.0	1,176.8	98.2	(160.5)	5	331.7
10	449.9	364.5	3.74	1,362.2	49.0	1,313.2	1,212.1	101.1	(59.4)	5	331.7
11-30	5,526.1	4,476.1		20,486.8	736.6	19,750.2	17,718.0	2,032.2		60	4,073.3
Total	9,898.7	8,017.9	4.01	32,155.6	1,156.2	30,999.4	29,026.6	1,972.8		110	7,296.3
											91%

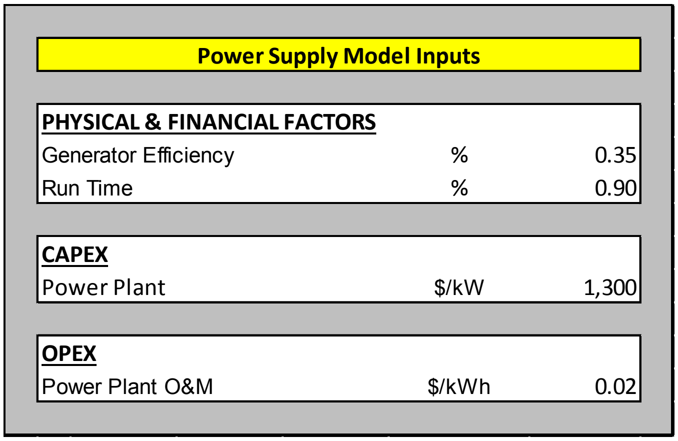
Present Value Table		
Discount Rate		Net Present Value
10%	-	-
15%	-	(278.5)
20%	-	(424.9)
25%	-	(508.8)
30%	-	(560.5)

Economic Parameters	
Internal Rate of Return	10.0%
Payback Year	10.6
Net Income / Net Capital	1.1

Exhibit 55: CMM Project Cash Flow

6.2.4 Downstream (Power Project) Economic Assumptions and Results

The drained methane can be used to fire internal combustion engines that drive generators to make electricity for use at the mine or for sale to the local power grid. The major cost components for the power project are the cost of the engine and generator, as well as costs for gas processing to remove solids and water, and the cost of equipment for connecting to the power grid. The assumptions used to assess the economic viability of the power project are presented in Exhibit 56. A more detailed discussion of each input parameter is provided below.



Power Supply Model Inputs		
PHYSICAL & FINANCIAL FACTORS		
Generator Efficiency	%	0.35
Run Time	%	0.90
CAPEX		
Power Plant	$/kW	1,300
OPEX		
Power Plant O&M	$/kWh	0.02

Exhibit 56: Summary of Input Parameters for the Evaluation of Downstream Economics (Power Project)

6.2.4.1 Physical and Financial Factors

Generator Efficiency and Run Time: Typical electrical power efficiency is between 30 percent and 44 percent and run time generally ranges between 7,500 to 8,300 hours annually. For the proposed power project an electrical efficiency of 35 percent and an annual run time of 90 percent, or 7,884 hours, were assumed.

6.2.4.2 Capital Expenditures

Power Plant Cost Factor: The power plant cost factor, which includes capital costs for gas pretreatment, power generation, and electrical interconnection equipment, is assumed to be $1,300 per kilowatt (kW).

6.2.4.3 Operating Expenses

Power Plant Operating and Maintenance Cost: The operating and maintenance costs for the power plant are assumed to be 0.02/kWh.

6.2.4.4 Downstream (Power Project) Economics

The power generation forecast and estimated generating capacity are summarized in Exhibit 57, and the pro-forma cash flow for the power project is shown in Exhibit 58. The breakeven power sales price, inclusive of the cost of methane drainage, is estimated to be $0.064/kWh. A 4.4 MW CMM-to-power utilization project at the mine would be economically feasible if the mine currently pays a higher price for electricity. Although power combined with CMM drainage appears to be economic, removing the cost of mine degasification from downstream economics as a sunk cost would significantly reduce the marginal cost of power.

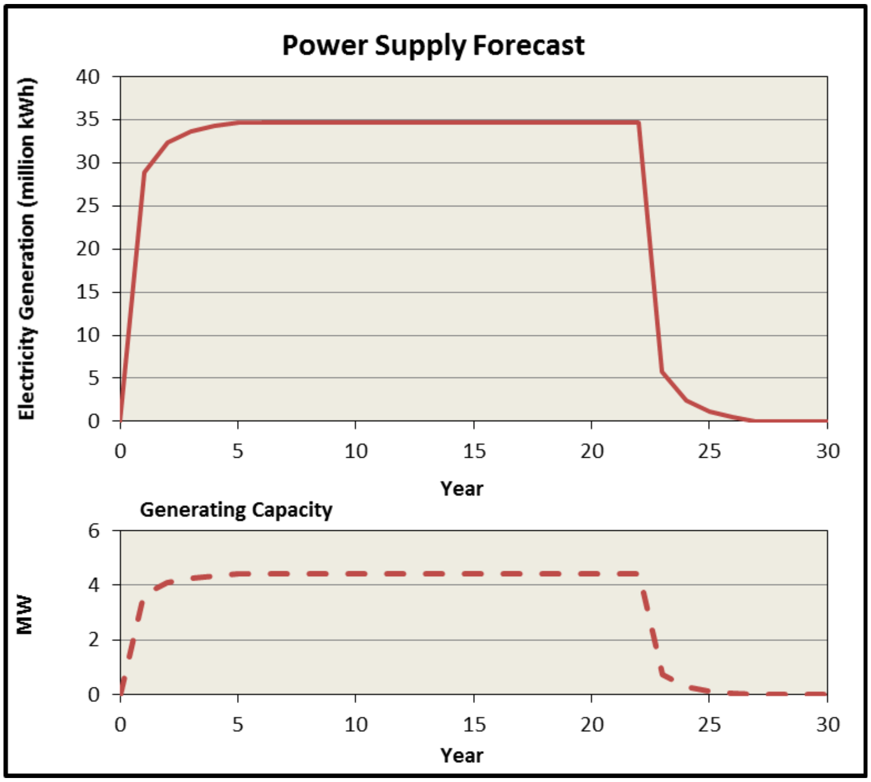


Exhibit 57: Power Supply Forecast

Simple Economics (Power)
Case 2
Sawang CMM Pre-Feasibility Study
5 wells per panel; 5 years pre-drainage

Input Parameters		
Power Sales Price	0.0641	$/kWh
Generator Size	4.4	MW
Power Plant Cost Factor	1300	$/kW
Generator Efficiency	0.35	
Run Time	90%	
Price Escalation	3.0%	
Cost Escalation	3.0%	
Power Plant O&M	0.02	$/kWh
Fuel Cost Switch	1	

Project Cashflow

Project Year	Generator Output MWh	Sales Price $/kWh	Revenue $,000	Fuel Cost $,000	Operating Cost $,000	Operating Income $,000	Capital Cost $,000	Cashflow $,000	Cum. Cashflow $,000	Delivered CH4 mmcf	Generator Sizing MW
0	-	0.0641	-	-	-	-	5,721.9	(5,721.9)	(5,721.9)	-	-
1	28,892	0.0660	1,908.2	869.3	595.2	443.8	-	443.8	(5,278.1)	276.1	3.7
2	32,318	0.0680	2,198.5	1,001.5	685.7	511.3	-	511.3	(4,766.8)	308.9	4.1
3	33,567	0.0701	2,352.0	1,071.4	733.6	547.0	-	547.0	(4,219.7)	320.8	4.3
4	34,248	0.0722	2,471.7	1,125.9	770.9	574.9	-	574.9	(3,644.9)	327.3	4.3
5	34,701	0.0743	2,579.5	1,175.1	804.6	599.9	-	599.9	(3,045.0)	331.7	4.4
6	34,701	0.0766	2,656.9	1,210.3	828.7	617.9	-	617.9	(2,427.0)	331.7	4.4
7	34,701	0.0789	2,736.6	1,246.6	853.6	636.5	-	636.5	(1,790.6)	331.7	4.4
8	34,701	0.0812	2,818.7	1,284.0	879.2	655.6	-	655.6	(1,135.0)	331.7	4.4
9	34,701	0.0837	2,903.3	1,322.5	905.5	675.2	-	675.2	(459.8)	331.7	4.4
10	34,701	0.0862	2,990.4	1,362.2	932.7	695.5	-	695.5	235.7	331.7	4.4
11-30	426,190		44,973.6	20,486.8	14,027.3	10,459.6	-	10,459.6		4,073.3	54.1
Total	763,421	0.0925	70,589.6	32,155.6	22,016.9	16,417.2	5,721.9	10,695.3		7,296.3	4.4

Present Value Table

Discount Rate		Net Present Value
10%	-	0.0
15%	-	(1,784.9)
20%	-	(2,806.1)
25%	-	(3,439.8)
30%	-	(3,860.9)

Economic Parameters

Internal Rate of Return	10.0%
Payback Year	9.7
Net Income / Net Capital	2.9

Exhibit 58: Power Project Cash Flow

7.0 Conclusions, Recommendations and Next Steps

As a pre-feasibility study, this document is intended to provide a high level analysis of the technical feasibility and economics of the CMM project at the Sawang Colliery. The analysis performed reveals that methane drainage using long, in-seam directional drilling in association with the development of the south block extension area is feasible, and could provide the mine with additional benefits beyond the sale of gas or power, such as improved mine safety and enhanced productivity.

Based on the forecasted gas production, the breakeven cost of producing CMM through in-seam drainage boreholes is estimated to be $3.00/MMBtu. The results of the economic assessment indicate the lowest CMM production costs are associated with 5 wells drilled per panel, with 5 years of pre-drainage (Case 2).

In terms of utilization, the power production option appears to be economically feasible. More rigorous engineering design and costing would be needed before making a final determination of the best available utilization option for the drained methane. According to the Central Electricity Authority, as of March 2014 the electricity tariff for large industrial customers in Jharkhand was $0.081/kWh, which does not include transmission and distribution charges and associated losses. When compared to the breakeven power sales price of $0.064/kWh calculated in the economic analysis, utilizing drained methane to produce electricity would generate a profit of at least $17 per MWh of electricity produced, or possibly more if the fully landed cost of electricity is accounted for. Furthermore, on-site power production would provide added energy security and help insulate the mine from the electricity shortages and chronic blackouts experienced throughout the country.

The power production option appears to be economically feasible, and removing the cost of mine degasification from downstream economics, as a sunk cost, would reduce the marginal cost of electricity and improve the economics even further. In addition, net emission reductions associated with the destruction of drained methane are estimated to average just under 95,000 tCO2e per year. Should CCL wish to continue with the proposed drainage plan, a phased project approach is recommended. The first phase would be to demonstrate the benefits of the proposed approach, and would likely include the following steps:

- On-site scoping mission and meetings with mine technical personnel.
- Develop methane drainage approach and scope of work for demonstration project including estimated costs.
- Obtain budget approval for demonstration program.
- Meet to discuss and finalize project approach.

- Evaluate and approve drill room location and configuration and required utilities (water supply/discharge and electricity).
- Evaluate, design and install gas collection and safety system.

Once the first phase is completed and the results are evaluated, a corporate decision should be made on whether or not to proceed with Phase II. The second phase would include equipment purchase and training to implement the proposed modern methane drainage technologies in house.

APPENDIX

A1 Geologic Overview

A1.1 Stratigraphy of Gondwana Sediments

The Gondwana sediments of eastern India, which host the bulk of India’s coal reserves, have been studied in depth and the stratigraphy has been summarized thoroughly (Fox, 1931; GSI, 1971; Mitra, 1979; Laskar, 1979; Mitra *et al.*, 1979) on the basis of lithologic characteristics. These sediments are generally divided into two sections, the Upper and Lower Gondwana. General stratigraphy for a section of Gondwana sediments includes the following, from the top:

1. Yellow, grey, gritty, coarse to medium sandstone associated with conglomerate lenses depicting the Supra Panchet and Panchet formation of the Upper Gondwana.

2. Medium to fine grained white, brown or grey sandstone prominent in Damuda group of rocks of the Lower Gondwana.

The general stratigraphy of the Gondwana sediments in eastern India, by basin, is shown in Exhibit 59.

Geological Time				
Upper Triassic	Supra Panchet Lugu Formation	Mahadeva Formation	Mahadeva Formation	359-500
Upper Permian	Raniganj formation	Kamthi Formation	Kamthi Formation	500-1035
Lower Permian	Barakar Formation	Barakar Formation	Barakar Formation	300-1250
Lower Permian to Upper Carboniferous	Talcher Formation	Talcher Formation	Talcher Formation	Up to 275

Exhibit 59: Classification of Gondwana Super Groups by Basin

Upper Gondwana Formation

The Triassic age Panchet and Supra Panchet/Mahadeva Formation of the Upper Gondwana form hill caps that vary in thickness from 300 to 650m in the Koel, Damodar, and Son Valley areas. The Raniganj coalfield, in the Damodar Valley, has a maximum thickness of 305 m in the Supra Panchet and 610 m in the Panchet series overlying the Raniganj Formation. To the south in the Mahanadi Valley, the Upper Gondwana formations are absent, outcropping just south of the Talcher coalfield. In the eastern part of Godavari Valley, southwest of the Mahanadi Valley, the Upper Gondwana formations are prolific and abut against the basin boundary fault. In this eastern portion of the valley the maximum thickness of the Panchet and Mahadeva formation is 450 m and 400 m, respectively. However, the Mahadeva formation is devoid of coal measures except for a few carbonaceous horizons in the Gujarat and Satpura area to the west.

Lower Gondwana Formation

The Lower Gondwana formation is the main coal-bearing sequence in all the established coalfields of India. The maximum thickness of the lower Gondwana is found in the Son-Mahanadi Valley where it reaches 1,600 m thick and doubles in thickness towards the north in the Koel-Damodar valley where it is 3,400 m thick. The Lower Gondwana reaches a thickness of 3,000 m southwest of the Son-Mahanadi Valley in the Godavari-Pranhita Valley. Basement complexes in these valleys include Archean age deposits that form the base of the Lower Gondwana formation and are beneath the Talcher Glacial beds of the Upper Carboniferous or Lower Permian.

The Damuda Series occurs in a series of stages above the glacial age basal deposits of the Lower Gondwana. The Damuda series has been subdivided into four stages based on lithology and floral assemblage. From top to bottom these stages include the Raniganj, Ironstone shales/Barren Measures, Barakar, and the Karharbari. The Karharbari formation is found throughout the Damodar and Manhanadi Valleys and ranges from 70 m to 305 m in thickness. The bottom most coal seam (Zero Seam) is found in the under-developed Karharbari Series, which overlies the Talchir Formation and is a high quality coking coal (Ghosh and Basu, 1969). The best example of the Damuda series is preserved in the Jharia coalfield, the principal coking coal mine in the country.

The Barakar formation, which is found above the Damuda series, has a uniform thickness of 600 m to 800 m over major portions of the following Gondwana coalfields: Damodar Valley (600-800 m), Mahanadi Valley (600-750 m), eastern Son Valley (600 m), and the Jharia coalfield (1,250 m). In the western Son Valley the Barakar formation decreases to 300 m in thickness around Umaria, Johilla, Jhillimili, Sonhat, and Lakhanpur areas. The Barakar to the southwest in the Wardha Valley, which includes Umrer, Nand Bander, Bokhara, and Makardhokra areas, also has a comparable thickness of approximately 300 m. In parts of Chanda Wardha Valley and Godavari Valley, the Barakar series may reach thicknesses of up to 600 m.

The Barren measures that overlie the Barakar formation are well developed in the Damodar Valley and are thickest in the Jharia coalfield at 630 m (Chandra, 1992). These measures are categorized as the Supra Barakar, an extension of the Barakar formation, in the Mahanadi Valley, Kamthi in Korba, Raigarh, and the Western Son Valley basin. The Wardha Valley, southwest of the Mahanadi valley, is covered by the overlying Kamthi formation in a majority of the area. This formation’s thickness reaches a maximum of 200 m in the Lhoara Block in the western section of the Wardha Valley coalfield. In Godavari Valley, the Kamthi attains a thickness of up to 500 m (Ramamurthy and Rao, 1987).

The coal bearing Raniganj formation is well developed in the Raniganj area and can reach a thickness of up to 1,035 m in the eastern part of Damodar Valley. Towards the western areas and in the Son Valley the formation thins to 430 m and 500 m, respectively. The formation prevails in pockets due to erosion and is found across the Godavari Valley and north to the Singarauli coalfield, where the Jhingurdah seam has escaped erosion. Recent geological exploration subdivides the formation in the Godavari Valley into an upper and lower part at 300 m and 450 m, respectively.

The maximum thickness of the main coal-bearing series within the Gondwana deposits detailed above is estimated range from 1,035 m to 1,250 m, which is considered the standard depth limit for exploring Gondwana coal seams.

A2 Geology of Bokaro Coal Basin

The Bokaro basin is one of the most prominent coal basins in the Damodar Valley (Exhibit 60). It is well known for its multitude of superior quality metallurgical coal bearing seams of substantial thickness. The basin encompasses an area of about 510 km^2 and takes its name from the Bokaro River, which runs through it. Longitudinally, the basin is 64 km long and has a maximum north-south width of 12 km in the western half of the basin (see Exhibit 61).

Structurally, the basin is considered an elongated synclinal graben, with the youngest formation (Mahadeva) in the core and preceding older formations cropping out progressively towards both east and west. A central high land (Lugu hill – 975 m), broadly divides the basin into two major segments referred to as 'East Bokaro' (243 km^2) and the 'West Bokaro' (218 km^2). The western part of the East Bokaro segment, morphotectonically, is an ideal graben; both the northern and southern boundaries are demarcated by boundary faults. The eastern part assumes a half graben configuration, with a prominent boundary fault along the southern margin only.

Recent geophysical studies have shown new characteristics of the basin geometry and revealed the existence of three gravity lows in the basin, two in the East Bokaro segment and one in the West Bokaro segment. The area around Saram, east of the Lugu hill, has been postulated to be the deepest part (around 2 km) of this basin. Lugu Hill, capped by the youngest Gondwana sediments (Late Triassic), exhibits high gravity values and has an interpreted basin depth of 1.3 km.

Contrasting patterns of coal development have been documented in the two segments of the Bokaro basin. In the sub-basinal area, comprised of two gravity lows, east of the north-south geographical line of 85°29' (Gumia-Tenughat divide - marked by a zone of faulting), 1.02 km of deposits and 26 regional coal seams (cumulative thickness -140 m) have been recorded in the Barakar Measures. In the sub-basinal area west of the Gumia-Tenughat divide, the thickness of the Barakar progressively decreases westward along an 8 km strike from about 600 m near Siari (10 to 14 coal seams with a cumulative thickness of 93 m) to around 400 m near the Koiyotanr and Dumri areas (10 coal seams with 28 m to 50 m of total thickness).

A2.1 East Bokaro Coalfield

The East Bokaro coalfield covers approximately a 243 km^2 area east of Lugu Hill, between latitudes 23°44' and 23°49' and longitudes 85°42' and 86°04'30" (Exhibit 61) in the Giridih and Hazaribagh districts of Jharkhand Province, India. The coalfield has a complete sequence of Gondwana sediments from Talchir (Early Permian) to Mahadeva (Late Triassic). This coalfield is a major resource of high rank coals and also a source of medium coking metallurgical coals in India.

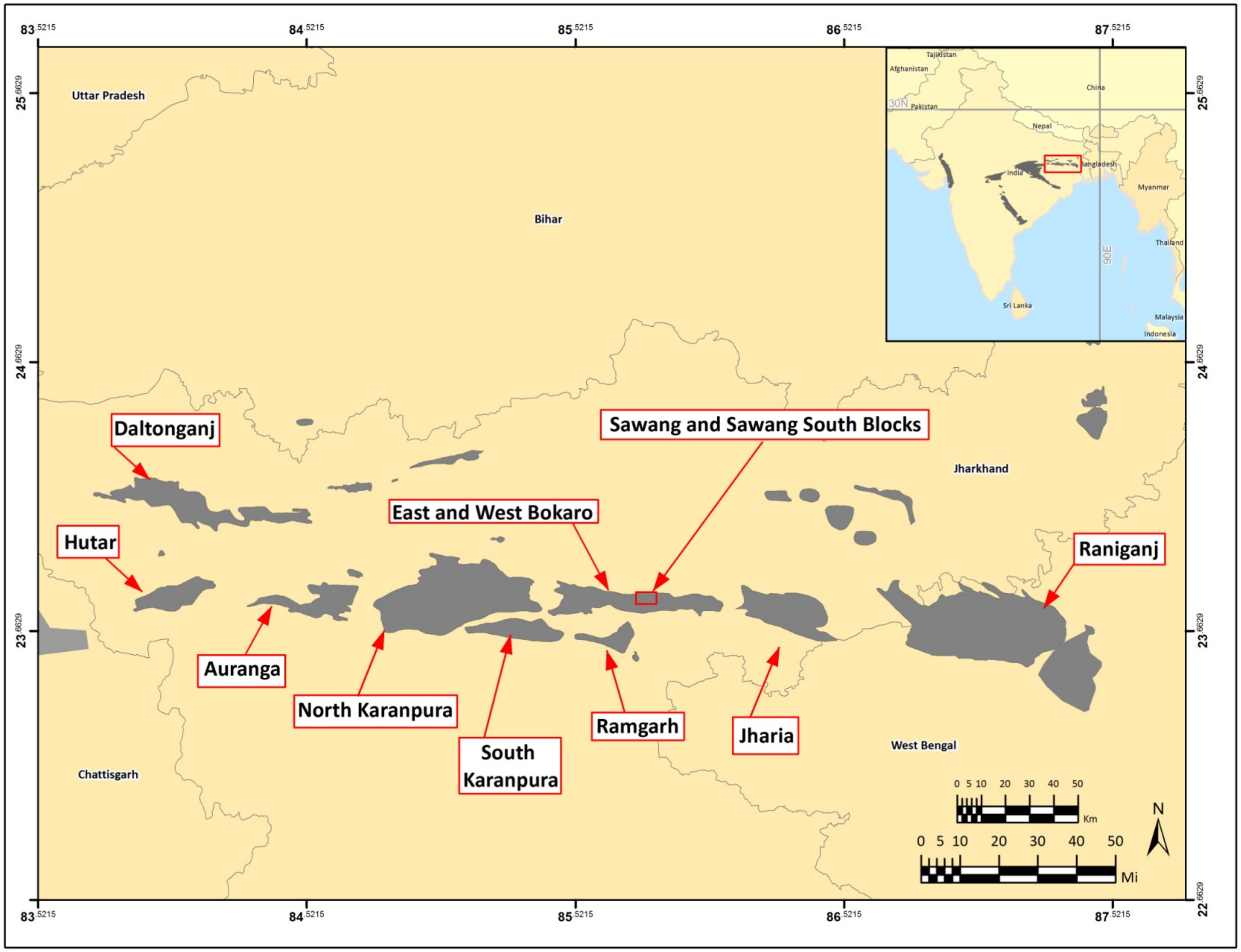


Exhibit 60: Damodar Valley Coalfields and Basins

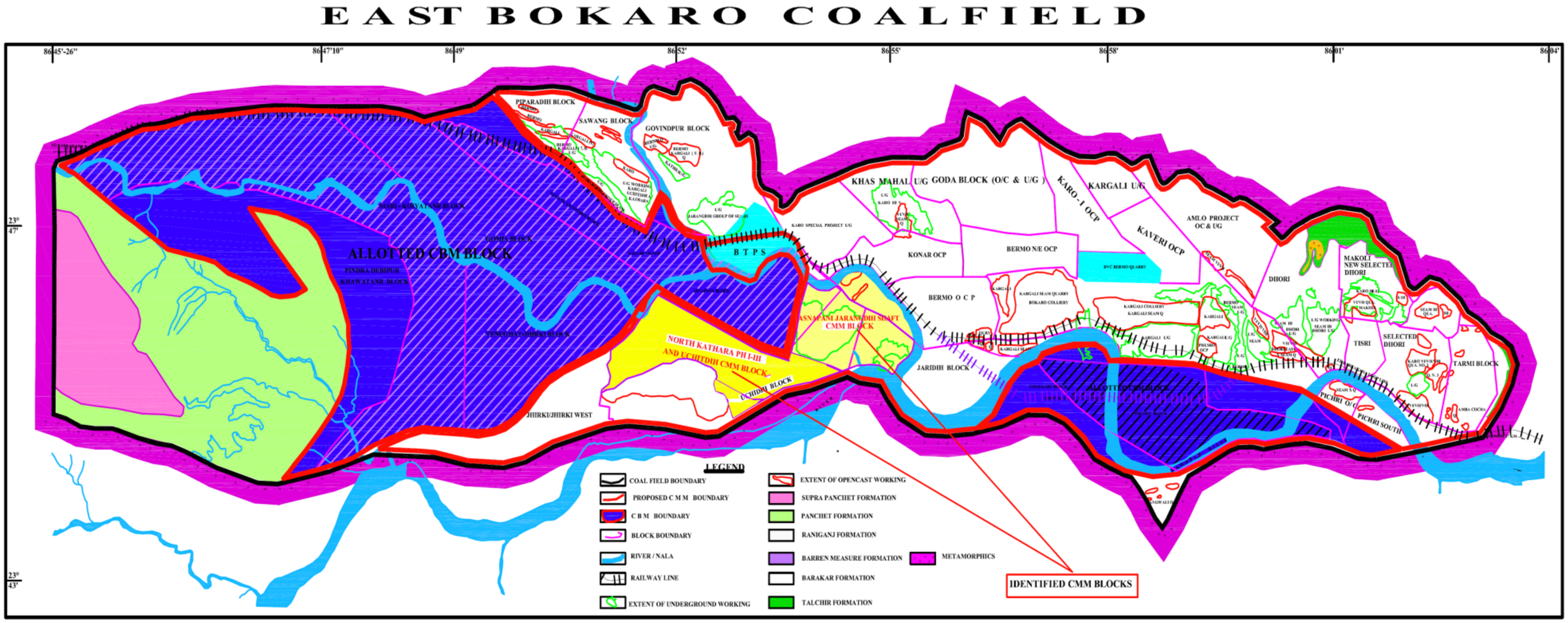


Exhibit 61: Geological Map of East Bokaro Coalfield

A2.2 Stratigraphy of the East Bokaro Coalfield

The stratigraphic sequence of East Bokaro coalfield is shown in Exhibit 62 below:

Age		
Late Cretaceous	Basic and Ultrabasic Intrusive	
----Unconformity----		
Early Triassic	Panchet	500
	Barren Measures	500
---Unconformity-----		
Precambrian	Metamorphics	

Exhibit 62: Stratigraphic Sequence of the East Bokaro Coalfield

Unconformably overlying the basement, the Talchir formation is restricted in the sub-surface and crops out as scattered patches along the northeastern periphery around Chapri and the northern boundary, west of Gumia. The formation is comprised of tillite at the base overlain by ripple laminated fine-grained sandstone, rhythmite, and siltstone.

Outcrops of the overlying Barakar formation cover a major part of East Bokaro coalfield and rest directly on the Precambrian basement along the boundaries in the east and the south. East of the Gumia-Tenughat divide the formation is characterized by predominance in fine clastics. Based on the lithofacies organization and coal development in the sedimentary column, the formation can be subdivided into *basal, lower, middle, and upper members*. The *basal member* (70 m to 90 m) has a conglomerate at the base overlain by an alternating succession of coarse clastics interbanded and thin (less than 1 m to greater than 3 m) dull looking coal seams (Karo I-V). The *lower member* is about 300 m to 350 m thick and contains a number of seams of appreciable thickness (Karo Lower Major, Karo Upper Major, Kargali, etc.) and intermittent partings of coarse-grained sandstone, grey, and carbonaceous shales. *The middle member* is comprised of thinly bedded shale-sandstone and multiple thin coal seams of good quality (Uchitdih Kathara, Sawang, etc.). A thick multilayer sandstone unit (46 m to 76 m) is present at the top part of this member. The *upper member* (125 m to 200 m thick) is dominated by shale and contains a group of six coal seams (Jarangdih Group).

West of the Gomia-Tenughat divide, significant lithological changes in the Barakar formation have been documented. In this area the Barakar formation is thinner and exhibits a preponderance of coarser clastics. In the Koiyotanr-Siari area, ten to fourteen coal seams are present in a 400 m to 600 m thick Barakar section. The thickness of the Barakar increases eastward to 600 m in Siari area where 14 coal seams (I, II, etc.) are present. In the extreme northwestern part, around Dumri, ten regionally persistent coal seams (I to X) have been documented in a 400 m thick Barakar section. The basin margins west of the divide contain more sandstone then the interiors. Within the interior a higher overall sandstone-shale ratio is recorded in Koiyotanr area than in the Siari area.

Above the Barakar formation are the Barren Measures, which are well documented in crescent-shaped outcrops. These outcrops cover a large area in the central and western parts and up to the eastern flank of the Lugu Hill. The formation is also exposed over a small east-west trending fault-bound tract in the southeastern part of the coalfield. In the northwestern flank, the formation is dominated by black shale with ferruginous interbands. Grey shale with ripple laminated ferruginous sandstone form the bulk of the clastic fill in the south.

The successively overlying Raniganj and Panchet formations also follow the same crescent pattern as the Barren Measures in the western part of the coalfield. The Raniganj Formation has a large aerial extent along the base of the Lugu Hill. This formation is also preserved as a narrow strip in the southeastern part of the coalfield due to the intrabasinal Dhori-Pichri fault. The Raniganj formation is composed of grey shale and medium to coarse-grained calcareous sandstone interbedded with 8 to 9 thin coal seams. The sandstone is fine grained and micaceous in the upper part of the sequence.

The Panchet formation covers a large tract in the northern, eastern, and southern flanks of Lugu Hill and has a generally unbroken gradational contact (except minor overlaps) with the underlying Raniganj strata. The formation is comprised of fine-grained, well-sorted, greenish micaceous sandstones that are closely interbanded with splintery green shale. In the upper part of the sequence the presence of coarse grained ferruginous sandstone and chocolate colored shale are well marked. The Panchet formation shows both overlapping and faulting due to the southern basement structure south of Lugu Pahar.

The Supra-Panchet beds (Mahadeva Formation) that occupy the higher elevation in Lugu Pahar at the westernmost part of the Bokaro coalfield exhibit an angular unconformity with the underlying Panchet formation at the southeastern part of the Lugu Pahar.

The Gondwana sediments are intruded by basic (dolerite) and ultrabasic (lamprophyre) intrusives. The dolerites cutting across the Kargali seams have been identified in various quarries in the coalfield. However, evidence shows that mostly lamprophyre sills and dykes affect the coal seams rather than the dolerite intrusives. These lamprophyre intrusions have been recorded in the Govindpur, Sawang, Kargali, and Kathara quarries.

A2.3 Structure of the East Bokaro Coalfield

The East Bokaro coalfield is an east-west aligned synclinal half-basin closing towards the east and is marked by prominent E-W trending border faults, especially towards the west. The strike of the beds is E-W in both the northern and southern limbs and dip angles usually range between 10 degrees and 20 degrees. Steep dips of up to 50 degrees have been recorded from the tilted and fault bounded blocks near the southwestern border and eastern edge.

The coalfield is structurally disturbed by faults of considerable lengths, the most prominent being the Southern Boundary fault, which is represented mostly as a zone of closely spaced sub-parallel faults along the southern border. A major part of the coalfield is traversed by a set of east-west trending intrabasinal faults, which run along the axial region of the basin for a considerable distance and are sensitive to the boundary faults. The fault bound troughs generated by the interplay of intrabasinal and boundary faults has facilitated preservation of younger sediments. The western part of the Gumia-Tenughat divide is also affected by a network of N-S and NW-SE trending intrabasinal faults, which trend along the boundary faults and have disturbed and tilted the strata in varying proportions.

A2.4 Coal Seams of the East Bokaro Coalfield

The East Bokaro coalfield is a major producing coalfield in India and contains very thick seams of metallurgical and thermal coal. Coal seams are present in both the Barakar and Raniganj formations. A large number of coal seams are contained in the Barakar formation, which exhibit a wide range of variation in thickness and quality. The thick Kargali seam of Barakar formation, which crops out all along the northern margin in the eastern part of the coalfield, is particularly significant. Coal seams of the Raniganj formation, in comparison, are mostly thin, irregular, and inferior in quality. Coal development in Barakar formation in the western part of the coalfield, however, is significantly different from coal east of the Gumia-Tenughat divide.

A2.5 Coal Seams of Barakar Formation in the East Bokaro Coalfield

A table summarizing the development pattern of coal seams in the Barakar formation of the East Bokaro coalfield is provided below in Exhibit 63.

<table>
<tr><th colspan="6">Development Pattern</th></tr>
<tr><th colspan="2"></th><th colspan="4">East</th></tr>
<tr><th>Dumri</th><th>Siari-Koiyotanr</th><th colspan="4">Saram-Pipradih-Sawang-Bermo-Kargali-Dhori area</th></tr>
<tr><td rowspan="6">10 regional seams (I-X) represented by 10 individual seams (Cumulative thickness up to 28 m)</td><td rowspan="6">10 regional seams (I-X) represented by 10-14 individual seams (<1-14 m) (Cumulative thickness 50 m to 93 m)</td><td colspan="4">(cumulative coal thickness 100-140 m) from West to East</td></tr>
<tr><td>Member</td><td>No. of seams</td><td>Name</td><td>Thickness (m)</td></tr>
<tr><td>Upper</td><td>6</td><td>Jarangdih</td><td>6 – 22</td></tr>
<tr><td>Middle</td><td>7</td><td>Uchitdih, Kathara, Sawang</td><td>5 – 20</td></tr>
<tr><td>Lower</td><td>8</td><td>Kargali, Bermo, Karo VI –XI</td><td>70-100</td></tr>
<tr><td>Basal</td><td>5</td><td>Karo I - V</td><td>3-17</td></tr>
</table>

Exhibit 63: Development Pattern of Coal Seams in Barakar Formation in East Bokaro Coalfield

A2.6 Barakar Coal Seams in the Eastern Bokaro Basin

Coal characteristics of 26 to 29 regionally correlatable coal seams (individual thickness 0.18 m to 63.90 m) have been obtained and summarized for the Barakar formation from the main sub-basinal area, east of the Gumia-Tenughat divide. The seams are characterized by low moisture (usually less than 2 percent), low to moderate ash (usually 20 to 30 percent), low to medium volatile contents (15 to 25 percent), and have a medium-coking character. The Karo group of seams, particularly the lower ones, are interbedded with dirt bands and contain a higher percentage of ash. Comparatively, the younger seams Kargali, Uchitdih, and Jarangdih have less ash content. The sequence of Barakar coal seams (in seven groups) and the parting sediment classification is presented in Exhibit 64 below (Raja Rao, 1987).

Seams/Partings	**Thickness (m)**
Jarangdih Top	0.4-4.5
Cg sst	*14-40*
Jarangdih	1.8-9.6
Grey Sh. & sst.	*12-32*
Jarangdih New	0.7-7.0
Grey Sh. with sst	*4-26*
Jarangdih '6'	1.1-2.9
Grey Sh. with fg to mg sst	*8-27*
Jarangdih 'A'	0.9-1.8
Fg to mg sst with grey sh .interbands	*21-72*
Sawang 'A'	0.4-1.8
Fg to mg sst with grey sh. interbands	*9-63*
Sawang 'B'	0.3-4.2
Inerbedded sh. and sst.	*1-47*
Sawang 'C'	0.4-2.5
Fg to mg sst with grey sh. interbands	*17-64*
Upper Kathara	0.3-3.1
Fg to mg sst with grey sh. interbands	*46-69*
Kathara	0.7-4.6
Grey Sh. & sst.	*7-47*
Uchitdih	0.3-4.9

Seams/Partings	**Thickness (m)**
Grey Sh. with fg to mg sst	*5-44*
Uchitdih 'A'	0.8-4.0
Grey sh & thick carb. Sh.	*19-58*
Kargali (Full seam)	24.4-36.6
Kargali Top	12.5-18.7
Mg to cg sst	*14-37*
Kargali Bottom	1.6-17.4
Cg to vcg sst	*14-88*
Bermo	13.7-19.7
Cg to vcg sst	*20-90*
Karo-XI	1.8-4.5
Cg to vcg sst	*5-20*
Karo-X	4.0-15.9
Cg to vcg sst	*<1-10*
Karo-IX	0.4-3.7
Mg to cg sst	*3-33*
Karo-VIII	19.5-63.9
Mg to cg sst	*<1-20*
Karo-VII	2.6-7.5
Mg to cg sst	*0-7*
Karo-VI	1.0-10.7
Mg to cg sst	*8-50*
Karo-V	1.0-4.6
CG sst	*10-22*
Karo-IV	0.3-7.1
CG sst	*<1-10*
Karo-III	1.0-3.0
Cg to vcg sst	*9-30*
Karo-II	0.5-1.6
Cg to vcg sst	*10-21*
Seams/Partings	Thickness(m)
Karo-I	0.4 -1.2
CG to vcg sst. and conglomerate	
Talchir Formation/Metamorphics	

Exhibit 64: Sequence of Barakar Coal Seams in East Bokaro Coalfield

The Karo-I to Karo-V seams are included in the basal members of the lower part of the Barakar seam sequence and are part of the fourth member in a fold sub-division of the Barakar strata.

The Karo-I and Karo-II seams are relatively thin and laterally discontinuous and are only recorded from the Chapri area in the east and the Pipradih, Sawang, and Govindpur areas in the west. The Karo-II seam has a low ash content of 13 percent to 19 percent.

The Karo-III seam, also known as ‘Karo special’, is continuous throughout the northern limb between the Pipradih-Sawang areas in the west and Dhori-Pichri in the extreme east. The seam also appears between the south-central and southeastern parts of the coalfield around the Uchitdih, Jarangdih, Bokaro, Kargali, and Chalkari areas. Seam thickness increases towards the north (up to 3 m) and east (up to 7 m). Ash content is low in most of the areas at 15 percent to 18 percent.

The Karo-IV and V seams are also present throughout the northern limb of the basin. The Karo-IV is found in the southeastern part of the coalfield and thickens to 3 m in the northwestern part. The quality of the two seams is generally inferior with ash contents of 22 percent to 29 percent in the Karo-IV and 27 percent to 38 percent in the Karo-V. The Karo-IV seam improves in quality due to a lower ash content of 15 percent to 22 percent in the southeast near the Bokaro and Kargali colliery areas.

The upper six seams of Karo group (Karo-VI to Karo-XI), which overly the Bermo and Kargali seams, are part of the lower member of the Barakar Formation.

The Karo-VI and VII seams range in thickness from 1 m to 4 m and 2.6 m to 4.8 m, respectively. The seams are thinner and have inferior quality in the western area of the coalfield near the Pipradih, Sawang, and Govindpur areas. Towards the east, in the Karo area, seam thickness increases to 8.5 m to 10.7 m for the Karo-VI and 4.7 m to 7.5 m for the Karo-VII. Proximate analysis results of ash content for the Karo-VI and VII range between 25 percent to 30 percent and 24 percent to 35 percent, respectively. The Caking index results provide ranges between 14 to 21 and 13 to20, respectively. The seams morphologically change near the Sawang, Karo, Uchidih, and Govindpur areas.

In these areas they occur as a paired seam and have a combined thickness of between 8 m and 18 m. The proximate analysis shows that when the seams are combined their ash content and caking index only vary slightly at 25 percent to 33 percent and 14 to 18, respectively.

The Karo-VIII Seam, also known as Karo Lower Major, is the thickest seam (up to 64 m) of the coalfield and is continuous throughout. Higher volatile matter (23 percent to 30 percent dmf) and ash content (24 percent to 29 percent dmf) indicate that the seam is generally inferior in quality. The basal section of the seam (3 m to 4 m), however, is better in quality (ash content of 24 percent to 28 percent) throughout the coalfield. The topmost section (3 m to4 m) also exhibits improvement in quality (ash content of 22 percent to 27 percent) in Bokaro, Kargali, and parts of Karo colliery areas. The seam is part of a composite horizon (34 m to 55 m) in the east around Dhori with Karo-VI and Karo-VII seams.

The Karo-IX seam is present through the northern and southeastern parts of the coalfield. The seam composes the upper and sometimes lower part of a composite seam in the Dhori area. The quality of the seam is inferior due to a high ash content (up to 33 percent), but has a high coking propensity. The ash content quality improves near Karo area (ash content of 18 percent to 25 percent).

The Karo-X seam (Karo Upper Major) is present throughout the entire coalfield and is exposed in the northern and northwestern parts of the coalfield. Magmatic lamprophyre intrusives have affected the seam in the west around the Sawang and Govindpur areas. Proximate analysis shows that ash content and volatile matter range between 24 percent and 30 percent and 22 percent and 30 percent, respectively. The seam coalesces with the underlying seams VI, VII, VIII, and IX to form a composite seam in the east.

The Karo-XI seam is heavily interbedded and is of inferior quality particularly in the west. Proximate analysis results show that the ash content varies from 26 percent to 33 percent.

The Bermo is a fairly thick and persistent seam in the East Bokaro coalfield. The seam is extensively mined in the eastern part of the Dhori colliery area. In the western part, the seam is partially burnt by intrusive activity near the Sawang, Govindpur, and Kathara areas. The seam is developed in three sections. The bottom section (4 m to 7 m) is the most continuous one and contains 24 percent to27 percent ash. The middle section (2.5 m to 7 m thick) improves in quality towards the Pipradih and Sawang Colliery areas. The top section (2 m to 6 m) is generally inferior in quality and is burnt in its western part around the Sawang area.

The Kargali seam is the most important seam in the East Bokaro coalfield due to its thickness and high quality. A maximum thickness of approximately 45 m is recorded in the southwest area near Kathara. Around the Kargali and Bokaro colliery areas, in the central part of the coalfield, the seam is affected sporadically by mica-peridotite dikes and sills. The seam has two distinct sections in certain areas. The Kargali Top and Kargali Bottom seams exist around the Govindpur, Kathara, and Jhirki areas in the west, and also in the east in the Dhori colliery area. In the east, the thickness of the top and bottom sections range from 11 m to 15 m and 10 m to 11 m, respectively. The top and bottom sections vary only slightly in the west with thicknesses ranging from 12 m to 17 m and 9 m to 12 m, respectively. The Kargali Top generally has less ash (23 percent to 27 percent) versus the Kargali Bottom (26 percent to 31 percent). Both seams have good coking propensities with caking and swelling indexes between 17 and 23 and between 2 and 3.5, respectively.

The Uchitdih A and Uchitdih, Kathara, Upper Kathara, and Sawang A, B, and C seams comprise the middle member of Barakar Formation. The Uchitdih A and Uchitdih are two thin seams of the lower part of this member and are discontinuous between the Dhori colliery area in the east and Gumia-Saram area in the west. The Uchitdih A seam is relatively clean and of good quality based on an average ash content of 14 percent to 20 percent and volatile matter between 21 percent and 29 percent. However, in the Govindpur area the seam’s quality is partially affected by lamprophyre intrusives. Here the quality deteriorates with a higher ash content (31 percent to 42 percent) and volatile matter (29 percent to 32 percent). The Uchitdih seam is best developed in the south-central part of the coalfield around the Uchitdih, Kathara, and Jhirki areas. Ash content and volatile matter range between 12 percent and 24 percent and 31 percent and 33 percent, respectively.

The Kathara seam is present over a large area and is currently being developed in a number of collieries. The seam's quality is particularly well developed in the south central area near Jarangdih, Uchitdih, Kathara, and Jhirki. In these areas the seam thickness ranges from 3 m to 6.5 m and the ash and volatile matter range from 16 percent to 22 percent and 26 percent to 35 percent, respectively. The Upper Kathara, however, is a relatively thin seam present in areas between Pipradih in the west and the Chalkari colliery area in the east. Proximate analyses yield ash content ranges of between 20 percent and 29 percent.

The Sawang group of seams, from top to bottom: Sawang A, Sawang B, and Sawang C, are continuous in the Sawang and Pipradih colliery areas in the west. The lower two, Sawang B and Sawang C, are comparatively cleaner than the Sawang A seam in these areas. In addition, the Sawang A is partially affected by lamprophyre intrusives. Exband ash content ranges between 23 percent and 27 percent, while volatile matter varies from 24 percent to 29 percent. All of the seams are classed as medium grade coking coals.

Six seams of the Jarangdih group compose the upper member of the Barakar formation. The Jarangdih seam is the most well developed seam in the Jarangdih area. The seam contains 22 percent to 31 percent ash (ex-band). The Jarangdih 6 is a relatively clean coal with an ash content of 16 percent to 19 percent. The seams deteriorate in quality towards the northwest near Govindpur. Further west, near the Sawang Colliery, the seam's coking properties lessen to an index of 14/16 to 15/17.

A2.7 Coal Seams of Raniganj Coal Formation in East Bokaro Coalfield

Coal seams of the Raniganj formation are relatively insignificant and generally uneconomic to mine in the East Bokaro coalfield. Eight coal seams (R-I to R-VIII in ascending order) of 0.45 m to 3.0 m in thickness are present in the Raniganj Formation. Proximate analysis results show ash and volatile matter contents varying between 19 percent and 39 percent and 25 percent and 32 percent, respectively. Seam numbers R-I, R-III, and R-V are generally continuous and correlatable, while the remaining five seams are inconsistent.

A2.8 Rank and Petrological Characters

A summary of the petrological characters and rank development is presented below:

I) Maceral content varies on both sides of Gomia-Tenughat divide;

II) Vitrinite content is between 36 percent and 43 percent in the Kargali Top and Bottom seams in the eastern part of the coalfield;

III) Vitrinite content of the equivalent seam V in the area west of Gomia-Tenughat divide varies from 40 percent to 66 percent;

IV) Lower seams (Karo-III to Karo-VIII) exhibit high rank ($R_{o\,max}$ – 1.20 percent) at depths of 1 km and beyond and decreases upward to 0.85 percent in the Jarangdih seam in the area east of Gomia-Tenughat axis; and

V) Upper seams exhibit an inverse increase of R_O max percentage up to 1.60 in the main sub-basin east of the Gomia-Tenughat axis. In the area west of this divide, near the northern boundary fault, enhancement of rank (R_O max greater than 1.20 percent) and inverse increase of rank (R_O max 1.2 percent to 1.4 percent) have been recorded.

Exhibit 65 below incorporates mean maceral and reflectance values of some important seams in different parts of the East Bokaro coalfield.

Seam	Section of Coalfield	Vitrinite (%)	Exinite (%)	Inertinite (%)	Reflectance (%)
Jarangdih A	Central	47	9	27	0.93
Jarangdih 6	Central	60	4	22	0.94
Kathara	East	38	10	37	0.93
	Southwest	67	1	19	1.05
Uchitdih	East	51	7	31	1.00
	Southwest	65	2	21	1.12
Uchitdih A	East	47	9	36	1.01
	Southwest	64	1	20	1.13
Kargali/ Kargali Top	East	41	10	32	1.02
	Southwest	51	1	36	1.15
Bermo	East	38	3	39	1.08
	Central	45	5	28	0.97
	West	49	7	25	0.87
	Southwest	49	5	35	1.16
Karo X-IX/X -X(T)	East	34	3	48	1.15
	Central	38	7	37	1.05
	Southwest	30		51	1.35
	Northwest	52	5	28	0.98
Karo VIII	Central	29	5	48	1.09
	Southwest	35		50	1.62
	Northwest	50	2	23	1.05
Karo III	East	16		67	1.22
	West	36	2	44	0.96
	Northwest	42		34	1.33

Exhibit 65: Maceral and Reflectance Values of Different Coal Seams

A2.9 Coal Resources of East Bokaro Coalfield

A total geological resource of approximately 8.14 billion tonnes of coal is estimated to a depth of 1,200 m (CIMFR). Of this resource, 98 percent (7.97 billion tonnes) is classified as 'Medium coking' type (Exhibit 66).

Depth Range	Medium Coking	Non-coking					Grand Total
		Superior	Intermediate	Inferior	Ungraded	Total	
0-300	3895.85	18.79	33.43	99.76	-	151.98	4047.83
300-600	1646.26	1.10	3.16	10.33	-	14.59	1660.85
600-1200	2436.08	-	-	-	-	-	2436.08
0-1200	7978.19	19.89	36.59	110.09	-	166.57	8144.76

Exhibit 66: Non-Coking and Coking Coal Resources of East Bokaro Coalfield

About 51 percent (around 4,080 million tonnes) of the total resource of medium coking coal exists below 300 m. The Siari, Hosir, Pindra, and Koiyotanr areas in the western part of the coalfield have approximately 1,750 million tonnes (about 22 percent of the total resource). This coal is predominantly medium coking and 92 percent exists below 300 m. Nearly 70 percent of this resource (about 1,230 million tonnes) is classified as Washery Grade III and IV. East of the Gomia-Tenughat divide the Karo-VIII, Karo-X, Kargali, and Bermo seams constitute a majority (70 percent to 80 percent) of the coking coal resource. About 84 percent of this resource is coking coal deeper than 300 m. It is contained in the Kargali, North Kathara, Asnapani, Phusro-Angwal, and North Govindpur areas and is classified as Washery Grade II, III, and IV.

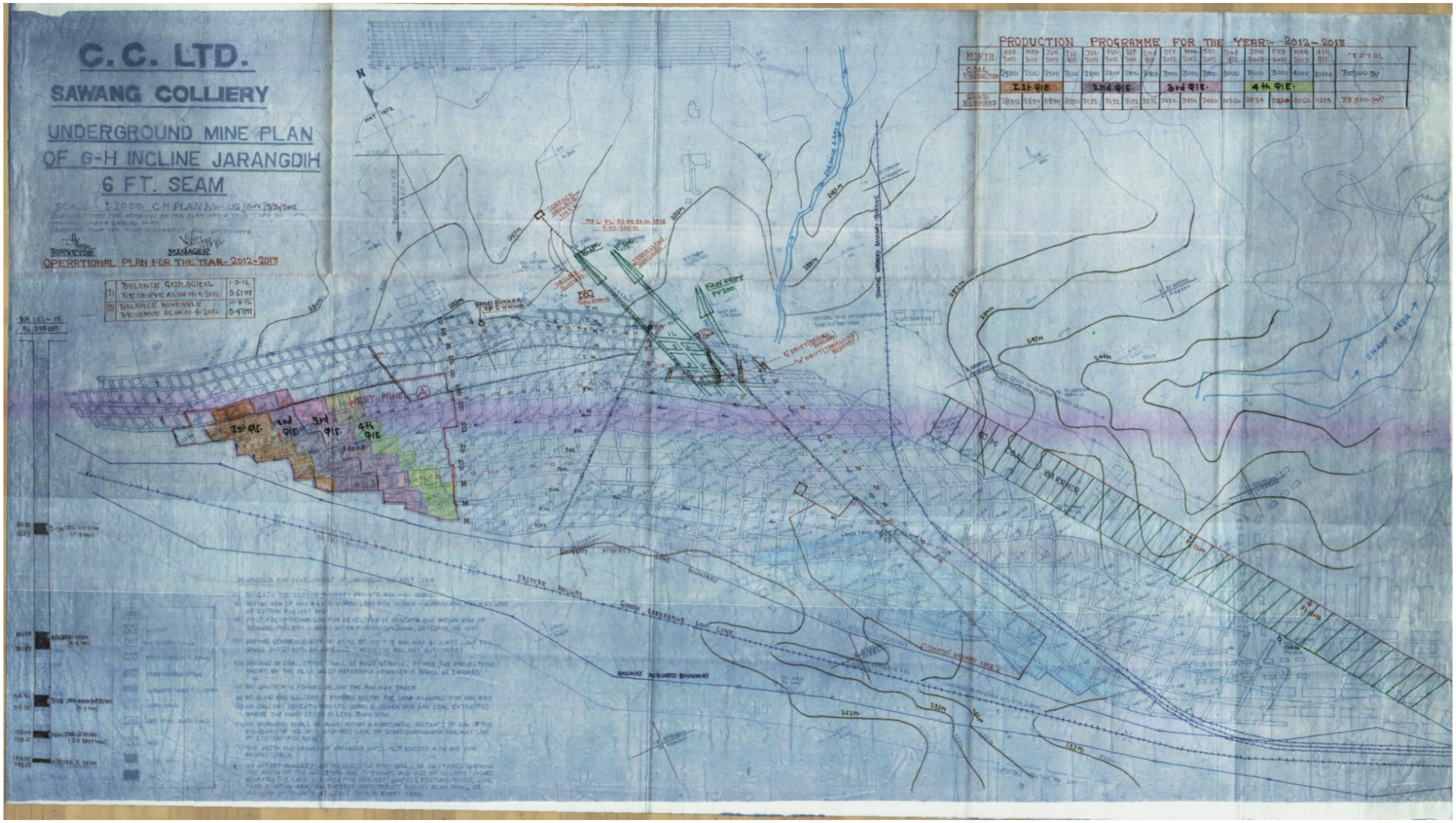
A3 Mining Activity and Mining Characteristics at the Sawang Mine

Exhibit 67 and Exhibit 68 show the working seam maps of the Jarangdih 6’, Jarangdih AB, and Jarangdih Top seam C & D incline. These upper seams have been developed through a pair of inclines. All seams have been exploited by the board and pillar method, except for the Kargali Top where longwall panels have been used. All depillaring activities are immediately followed by stowing.

The development of the Jarangdih 6’ seam (Exhibit 67) in the west section is complete and currently undergoing depillaring and stowing at a rate of 120 tons per day. The geological reserve for the Jarangdih 6’ seam was estimated to be 0.61 MT as of April 1, 2012. The mineable reserve is approximately 22 percent less than the geological reserve at 0.47 MT. The production program for April 2012 through April 2013 estimated a total of 35,000 tonnes of coal to be mined, which would require 39,900 m^3 of sand for stowing. Ongoing activity for the Jarangdih 6’ is currently in the northwestern portion of the Sawang mine.

The underground mine plan for the Jarangdih seam A&B incline is shown in Exhibit 68. The geological reserve, as of April 1, 2012 was 1.44 MT, and the mineable portion is approximately a quarter less at 1.08 MT. The mining program from April 2012 through April 2013 was slated to take place southeast of the central part of the mine. An estimated 55,000 tonnes of coal was projected for mining, a volume which would require 60,500 m^3 of sand for stowing.

The Jarangdih Top C&D incline shown in Exhibit 69 has a geological reserve of 0.34 MT and mineable reserve of 0.21 MT. The production program for the period from April 2012 to April 2013 includes only sand stowing for a total of 20,400 m^3.



(1)	BALANCE GEOLOGICAL RESERVE AS ON 01-4-2012	1-3-12 0.61MT
(2)	BALANCE MINEABLE RESERVE AS ON 01-4-2012	11-3-12 0.47MT

PRODUCTION PROGRAMME FOR THE YEAR:- 2012-2013

MONTH	APR 2012	MAY 2012	JUN 2012	1st QIE	JUL 2012	AUG 2012	SEP 2012	2nd QIE	OCT 2012	NOV 2012	DEC 2012	3rd QIE	JAN 2013	FEB 2013	MAR 2013	4th QIE	TOTAL
COAL PRODUCTION	2500	2500	2500	7500	2800	2800	2800	8400	3000	3000	3000	9000	3100	3000	4000	10100	35000 (Te)
	1st QIE				2nd QIE				3rd QIE				4th QIE				
SAND REQUIRED	2850	2850	2850	8550	3192	3192	3192	9576	3420	3420	3420	10260	3534	3420	4560	11514	39900 (m³)

Exhibit 67: Jarangdih 6’ Seam of the G-H Incline

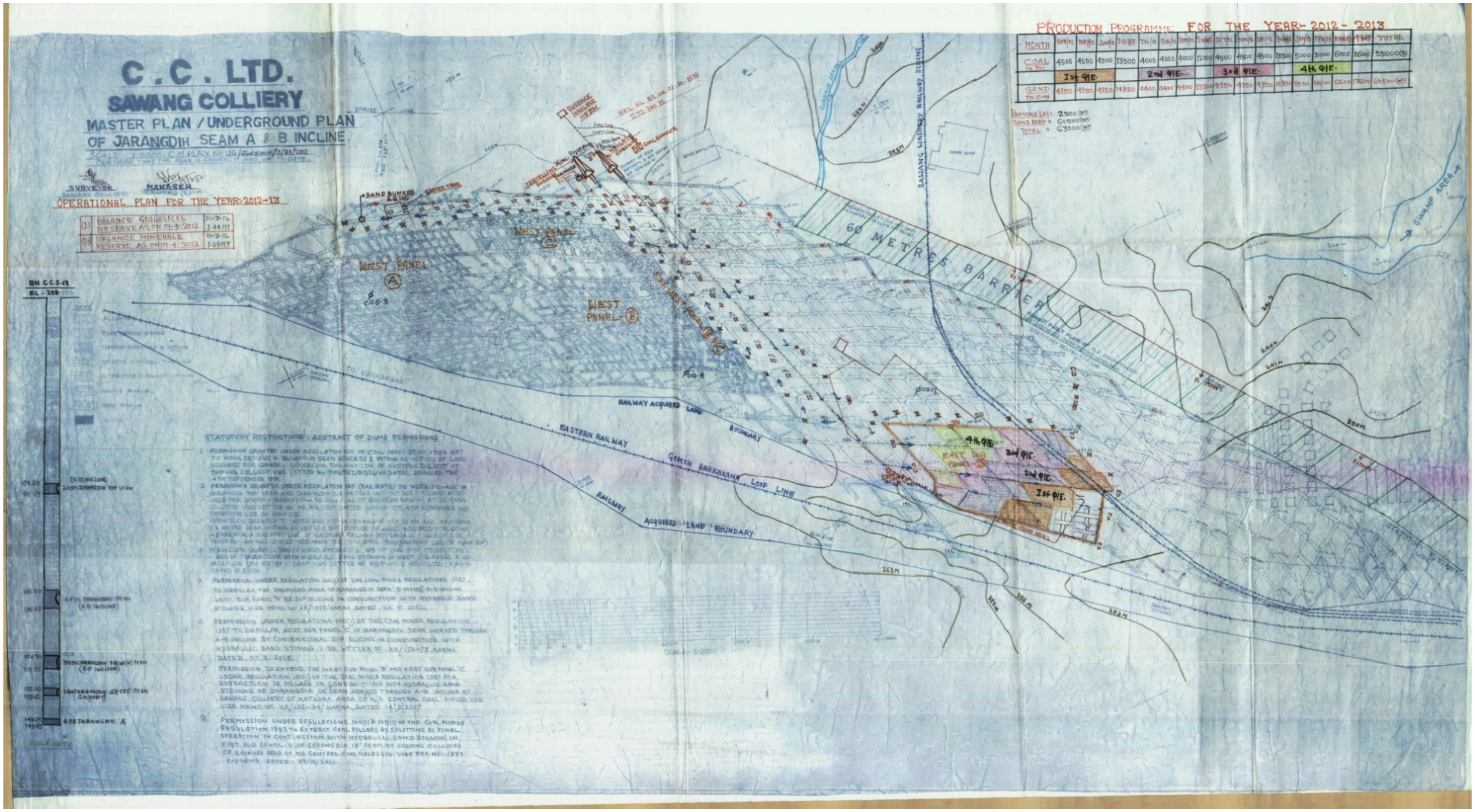
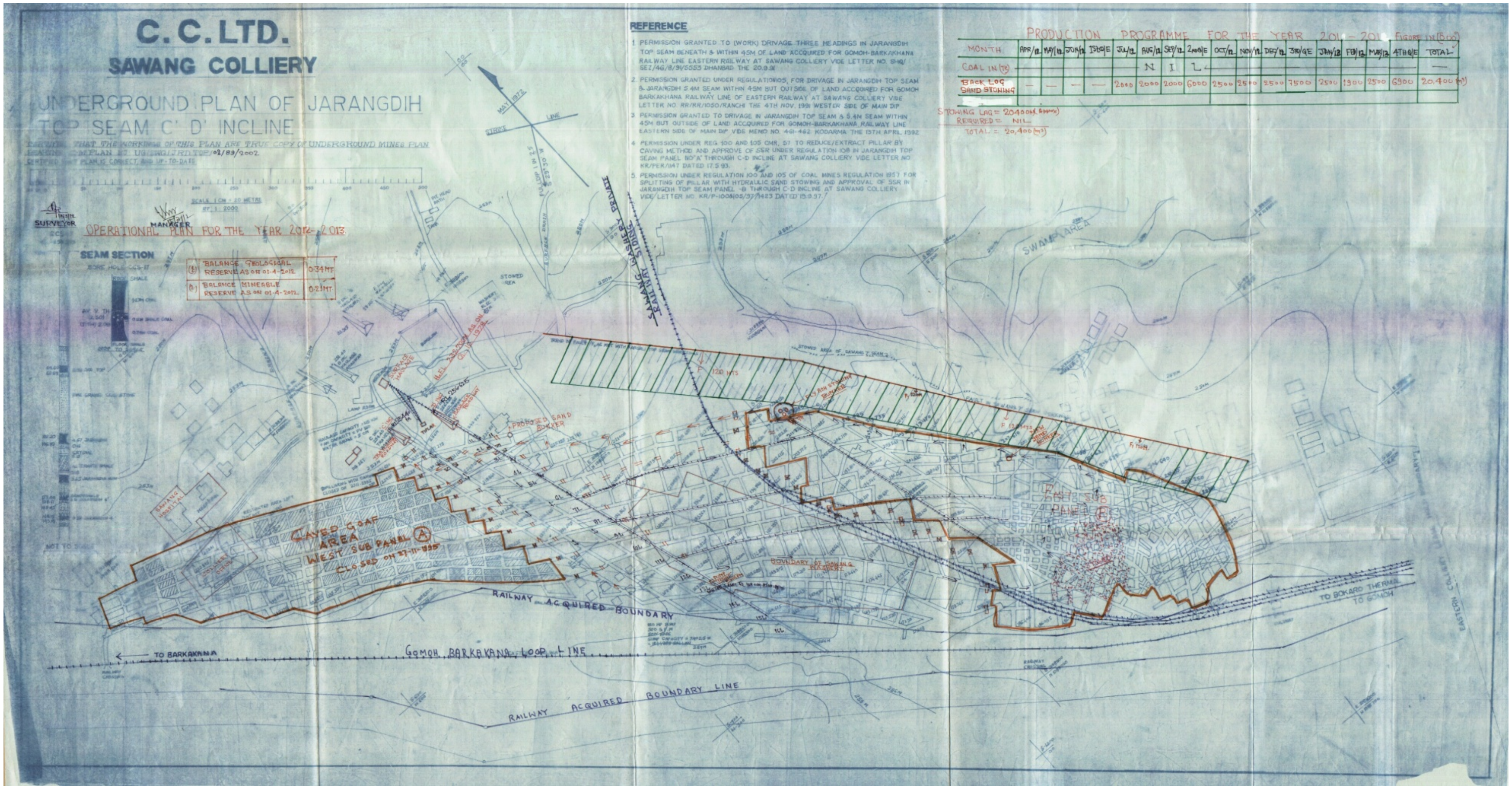


Exhibit 68: Underground Plan of the Jarangdih Seam in the A&B Incline



C. C. LTD.

SAWANG COLLIERY

UNDERGROUND PLAN OF JARANGDIH TOP SEAM C' D' INCLINE

CERTIFIED THAT THE WORKINGS OF THIS PLAN ARE TRUE COPY OF UNDERGROUND MINES PLAN BEARING PLAN NO. UG/SWG/JRD TOP/02/89/2002

CERTIFIED THAT PLAN IS CORRECT AND UP-TO-DATE

SCALE 1 CM = 20 METRE

RF 1 : 2000

SURVEYOR

MANAGER

OPERATIONAL PLAN FOR THE YEAR 2012-2013.

SEAM SECTION

BORE HOLE CCS-17

(1)	BALANCE GEOLOGICAL RESERVE AS ON 01-4-2012	0.34 MT
(2)	BALANCE MINEABLE RESERVE AS ON 01-4-2012	0.21 MT

REFERENCE

1. PERMISSION GRANTED TO (WORK) DRIVAGE THREE HEADINGS IN JARANGDIH TOP SEAM BENEATH & WITHIN 45M OF LAND ACCQUIRED FOR GOMOH-BARKAKHANA RAILWAY LINE EASTERN RAILWAY AT SAWANG COLLIERY VIDE LETTER NO. SHQ/SEZ/46/8/91/5553 DHANBAD THE 20.9.91
2. PERMISSION GRANTED UNDER REGULATION 105, FOR DRIVAGE IN JARANGDIH TOP SEAM & JARANGDIH 5.4M SEAM WITHIN 45M BUT OUTSIDE OF LAND ACCQUIRED FOR GOMOH BARKAKHANA RAILWAY LINE OF EASTERN RAILWAY AT SAWANG COLLIERY VIDE LETTER NO. RR/RR/1050/RANCHI THE 4TH NOV. 1991 WESTER SIDE OF MAIN DIP
3. PERMISSION GRANTED TO DRIVAGE IN JARANGDIH TOP SEAM & 5.4M SEAM WITHIN 45M BUT OUTSIDE OF LAND ACCQUIRED FOR GOMOH-BARKAKHANA RAILWAY LINE EASTERN SIDE OF MAIN DIP VIDE MEMO NO. 461-462 KODARMA THE 13TH APRIL 1992
4. PERMISSION UNDER REG 100 AND 105 CMR, 57 TO REDUCE/EXTRACT PILLAR BY CAVING METHOD AND APPROVE OF SSR UNDER REGULATION 108 IN JARANGDIH TOP SEAM PANEL NO "A" THROUGH C-D INCLINE AT SAWANG COLLIERY VIDE LETTER NO KR/PER/1147 DATED 17.5.93.
5. PERMISSION UNDER REGULATION 100 AND 105 OF COAL MINES REGULATION 1957 FOR SPLITTING OF PILLAR WITH HYDRAULIC SAND STOWING AND APPROVAL OF SSR IN JARANGDIH TOP SEAM PANEL -B THROUGH C-D INCLINE AT SAWANG COLLIERY VIDE LETTER NO. KR/P-100&105/97/1423 DATED 19.9.97.

PRODUCTION PROGRAMME FOR THE YEAR 201 - 201 FIGURE IN (000)

MONTH	APR/12	MAY/12	JUN/12	1ST Q/E	JUL/12	AUG/12	SEP/12	2ND Q/E	OCT/12	NOV/12	DEC/12	3RD Q/E	JAN/13	FEB/13	MAR/13	4TH Q/E	TOTAL
COAL IN (Te)						N	I	L									—
BACK LOG SAND STOWING	—	—	—	—	2000	2000	2000	6000	2500	2500	2500	7500	2500	1900	2500	6900	20,400 (m³)

STOWING LAG = 20400 (Approx)

REQUIRED = NIL

TOTAL = 20,400 (m³)

Exhibit 69: Underground Plan of the Jarangdih Top Seam C&D Incline