Pre-Feasibility Study for Methane Drainage and Utilization at the Pootkee Colliery, Damodar Valley

Jharkhand State, Dhanbad District, India

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Prepared by:

Advanced Resources International, Inc.

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Acronyms/Abbreviations

ARI	Advanced Resources International, Inc.
BCCL	Bharat Coking Coal Limited
Bcf	Billion cubic feet
Bcm	Billion cubic meters
Btu/cf	British thermal unit per cubic foot
CBM	Coal Bed Methane
CIL	Coal India, Limited
CIMFR	The Central Institute of Mining and Fuel Research
CMM	Coal Mine Methane
CMPDIL	Central Mine Planning and Design Institute, Limited
CMOP	US EPA Coalbed Methane Outreach Program
DAF	Dissolved Air Flotation
DGH	Directorate General of Hydrocarbons
EOGEPL	Essar Oil & Gas Exploration & Production Ltd
FEED	Front End Engineering and Design
FID	Final Investment Decision
GAIL	Gas Authority of India, Limited
GMI	Global Methane Initiative
IRR	Internal Rate of Return
JHBDGP	Jagdishpur-Haldia and Bokaro-Dhamra Gas Pipeline
LPG	Liquified Petroleum Gas
Mm^3	Million Cubic Meters
Mt	Million tonnes
MMcfd	Million cubic feet per day
NPV	Net Present Value
ONGC	Oil and Natural Gas Corp.
PB	Pootkee-Bulliary
PC	Pootkee Colliery
PFS	Pre-Feasibility Study
USEPA	US Environmental Protection Agency
Tcf	Trillion cubic feet

Executive Summary

Methane is both the primary constituent of natural gas and a potent greenhouse gas (GHG) 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 U.S. Environmental Protection Agency's (USEPA) Coalbed Methane Outreach Program (CMOP) works with coal mines in the United States to encourage the economic use of coal mine methane (CMM) gas that is otherwise vented to the atmosphere. The work of USEPA also directly supports the goals and objectives of the Global Methane Initiative (GMI), an international partnership of 45-member countries and the European Commission that focuses on cost-effective, near-term methane recovery and use as a clean energy source. These studies identify cost-effective project development opportunities through a high-level review of gas availability, end-use options, and emission reduction potential. This study assists mine operators in evaluating options for CMM capture and use while also presenting a preliminary financial analysis and laying the foundation for a more detailed feasibility study that will ultimately lead to CMM project development and GHG emission reductions.

Bharat Coking Coal Limited (BCCL), a subsidiary of the state-owned Coal India Limited (CIL) mining company, was selected by the USEPA for a pre-feasibility study to determine the viability of a CMM drainage project at the Pootkee Colliery in the Pootkee-Bulliary CMM block. Advanced Resources International, Inc. (ARI) was tasked with conducting the pre-feasibility study (PFS) for the proposed methane pre-drainage and utilization project, which is located in the northeastern section of the Jharia Coalfield.

The principal objective of this study is to determine the feasibility of a CMM capture and utilization project at the Pootkee Colliery. Industry experience, the geologic setting of the mine, and surface-level population density led the research team to conclude that a horizontal drilling strategy would be most feasible and yield the best results for the mine. The Pre-feasibility Study specifically aims, therefore, to evaluate the technical and economic viability of utilizing long in-mine horizontal boreholes drilled into Seam XII to drain methane in advance of mining, and to identify end-use options for the drained methane. To conduct the study, first, a gas production model was developed to identify the optimal spacing of boreholes and then an economic model was used to evaluate the options for CMM use.

While several potential options exist for the use of CMM at the Pootkee Colliery, onsite power generation is the most viable option based on comparable operations and preliminary market data provided by the mine. Given the small CMM production volume relative to surrounding CBM production blocks, constructing a pipeline to transport the gas to demand centers would be economically impractical. While there has been interest in compressed natural gas (CNG) for vehicle fuel, CNG at this time is not economically feasible as it requires significant capital costs to upgrade gas quality and compress the gas. Based on gas supply forecasts performed in association with this pre-feasibility study, the Project could be capable of supporting as much as 2,277,600 kwh of on-site electricity on an annual basis which is about 20% of the mine's annual consumption of 11,940,360 kwh of electricity.

For the CMM project at Pootkee Colliery, multiple reservoir models were developed to simulate long directionally drilled in-seam boreholes placed along the longitudinal axis of future longwall panels at various spacings. The intent of this exercise was to determine the drainage time required to achieve the 30 percent residual gas content reduction target as a function of borehole spacing. A total of six single-layer models were constructed in order to calculate gas production for a longwall panel located within the project area. The models were designed to simulate production from long directionally drilled boreholes drilled into virgin areas of Seam XII spaced according to six well spacing cases: 41.7 m, 50 m, 62.5 m, 83.3 m, 125 m, and 250 m. All boreholes are drilled into a coal block with a dip angle of 8 degrees and are assumed to be 800 m in lateral length. The models were each run for five years in order to simulate gas production rates and in-situ gas content reduction over time for a typical longwall panel within the study area.

The models predicted borehole gas flow rate and gas content reduction as a function of time for a five-year period. Exhibit 1 shows results derived from the reservoir simulation models, including the drainage time required to reduce the residual gas content by 30 percent (in years) and the average gas production rate for each in-seam borehole configuration during that period (m^3/day). The table is designed to give project developers an idea of the drilling strategy that best fits their needs—for example, if mine authorities wish to mine a panel as soon as possible, they will use the 41.7m spacing; if, however, the mine wishes to tap CMM from a panel that they do not intend to mine for several years, then they can use one of the larger spacing options.

Spacing (m)	Drainage Time (years)	Gas Content Reduction (%)	Average Methane Flow Rate (m^3/day)
41.7	0.5	30	1152
50	0.6	30	1046
62.5	0.9	30	925
83.3	1.4	30	778
125	2.8	30	593
250	5.0	20.75	452

Exhibit 1: Summary of Simulation Results and Borehole Production Rates.

For the purpose of forecasting CMM production at the mine, it is assumed that long, directionally drilled horizontal boreholes are drilled beginning in mid-2019 with the pre-drainage period extending through 2046. Since no mine development plan was provided by BCCL, a conceptual mine layout and development plan for Seam XII was created, with a total of 27 panels anticipated to be mined. All data for this report and the reservoir simulations was provided by CMPDI, the Pootkee Colliery, and Bharat Coking Coal Corporation. Based on a review of the data, and in consultation with the mine operator, it was determined that Seam XII would be the focus of the pre-drainage program. The in-seam drilling program for Seam XII requires a total of 50,400 m of drilling, with a total of 60 horizontal boreholes – all of which could be drilled from just 27 borehole collars. Using this strategy, the CMM project at the Pootkee Colliery is anticipated to reduce emissions of methane by more than 188,000 tonnes of carbon dioxide equivalent (tCO2e) over the 27-year life of the project.

Two economic scenarios were evaluated in this study. The two are differentiated by whether the mine will absorb the operational costs of the drainage system or not. In the first scenario, a “power plant only” scenario, the cost of the gas drainage system is considered a “sunk cost” and is absorbed by the mining operation as an operational cost; this is because the drainage system would be installed whether there is a CMM power plant or not. This may be the case if the pre-drainage of methane from the longwall panels is necessary before mining can be safely performed. It is also important to note that in the "power plant only" scenario, the cost of gas purchased is not included. It is assumed that the mining operation will provide the CMM for free to the power plant. Should the mining operation wish to internalize the price of gas as a revenue and charge a fee, then the power project would need to show a cost of gas purchased as an operating cost, which would reduce the IRR's.

In the second scenario, the "power plant and drainage system" development scenario, the cost of the gas drainage system is not absorbed by the mine operation. This may be the case if the drainage system is considered a part of the larger project as a whole and included in the capital expenditures of the CMM utilization project. The gas drainage system installation scenario involves in-seam directional drilling of horizontal pre-drainage boreholes, the installation of gas and water pipelines within the mine workings, and associated vacuum pumps and compressors which adds to the cost of the project and decreases returns.

The results of both economic scenarios evaluated in this study are shown in Exhibit 2. The two scenarios result in the same quantity of gas production, so maximum power plant capacity and net CO_2e reductions are the same for both project development scenarios. The IRR and payback periods differ depending on if the mine absorbs the operational costs of the drainage system or not. The first scenario, the "power plant only" scenario, yields the highest net present value (NPV) and internal rate of return (IRR). The discount rate used for all NPV calculations in the results tables is 10 percent.

Development Scenario	Max Power Plant Capacity (kW)	NPV-10 ($,000)	IRR (%)	Payback (years)	Net CO_2e Reductions (tCO_2e)
Power Plant (only)	260	372	18%	6.0	188,374
Power Plant and Drainage System	260	-4,557	na	Na	188,374

Exhibit 2: Summary of Economic Results (pre-tax)

As a pre-feasibility study, this report is intended to provide an initial assessment of project feasibility. Further site-specific analyses are required to develop a "bankable" feasibility study acceptable to project investors, banks, and other sources of finance. However, without performing the further "bankable" analysis required for a feasibility study, this report's analysis concludes that the most economically feasible path going forward is to utilize CMM for power production and to have the mine capitalize the cost of the drainage system as part of the mining operation.

1. Introduction

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 U.S. Environmental Protection Agency's (USEPA) Coalbed Methane Outreach Program (CMOP) is a domestic voluntary program that works with coal mines in the U.S. to encourage the economic use of coal mine methane (CMM) gas that is otherwise vented to the atmosphere. USEPA also directly supports the goals and objectives of the Global Methane Initiative (GMI), an international partnership of 45 member countries and the European Commission, that focuses on cost-effective, near-term methane recovery and use as a clean energy source. Under the auspices of GMI, USEPA collaborates internationally to promote methane mitigation in the coal mine sector.

An integral element of USEPA's international outreach in support of the GMI is the development of CMM pre-feasibility studies. These studies provide a 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. In recent years, USEPA has sponsored feasibility and pre-feasibility studies in such countries as China, Colombia, Kazakhstan, Mongolia, Poland, Russia, Turkey and Ukraine.

Bharat Coking Coal Limited (BCCL), a subsidiary of the state-owned Coal India Limited (CIL) mining company, was selected by the USEPA for a pre-feasibility study to determine the viability of a CMM drainage project at the Pootkee Colliery in the Pootkee-Bulliary CMM block. Advanced Resources International, Inc. (ARI) was tasked with conducting the pre-feasibility study (PFS) for the proposed methane pre-drainage and utilization project, which is located in the northeastern section of the Jharia Coalfield.

The Pootkee Colliery is labeled as a Degree II gassy mine, the middle category in the three-tier classification system for methane emitting mines in India.

BCCL has been mining this block since the nationalization of India's coal mines in 1972 and has developed seams XVIII, XVII, XVI, XV, XIV, XIII, XII, XI, and XA to varying extents with the room and pillar method of mining. The maximum depth of the bottom-most seam, II, is projected at 900 meters (m) and considerable coal reserves remain to be mined, however prognostics of coal seam methane content indicate the necessity of effective CMM drainage systems to access deeper seams. Seams X, IX, VIIIC, VIIIB, VIIIA, VIII, VII, VI, V, IV, III, and II, which have an average cumulative thickness of 55 m, are all being considered by the mine for CMM development. CIL and BCCL have therefore expressed an interest in pursuing a methane pre-drainage program to mitigate safety concerns to mine operations and to utilize CMM captured from the formation.

This PFS is intended to provide an initial assessment of project feasibility. A final investment decision (FID) should only be determined after completion of a full feasibility study founded on additional data, detailed cost estimates, thorough site investigations, well tests, and a possible Front-End Engineering Design (FEED).

2. Background

2.1 The Indian Coal Industry

India is the third largest coal market in the world, where coal represented 56.2 percent of the country's total primary energy consumption in 2017 (BP, 2018). In 2016, 62 percent of India's installed power capacity was dependent on coal and 61.8 percent of the country's coal consumption went toward power production, making coal the largest component of India's energy sector (MOSPI, 2018; EIA, 2016). Coal demand in India averaged a growth rate of 6.3 percent per year over the past decade, while coal production has fallen behind with an average 3.5 percent growth rate over the same period, leading to a significant reliance on coal imports (BP, 2018; USEPA, 2015). However, recent regulatory reforms have been enacted to increase domestic coal production to reduce imports and promote national energy security (EIA, 2016).

In 2017, as part of India's 3-Year-Action Plan (2017-2020), the country announced aggressive coal production targets that included exploring 25 percent of its 5,100 square kilometers (km^2) of untapped coal reserves, proving the definitive existence of indicated coal reserves, constructing three critical transportation railroads, and increasing the production of its state-owned coal producers (NITI, 2017). Additional thought was given to spinning off state-owned CIL subsidiaries in the hope of creating competition between state corporations, but no action has yet to be taken on this front.

India's 3-Year-Action Plan outlined that CIL, the world's largest coal producing company, was expected to produce 1 billion tonnes (1 gigatonne, Gt) of coal annually by 2019-2020, nearly double its output from 2015-2016. However, CIL fell well short of its original production goals in 2017-2018 due to transportation logistics issues, inflating stockpiles and decreasing power plant coal supplies (Singh, 2018). CIL has since updated its 1 Gt production target date to 2022 and has pledged to continue updating its mines and transportation infrastructure, but immediate power infrastructure demands coupled with continuing coal production shortages caused India's coal imports to increase 14 percent in 2017-2018 (PTI, 2018a; Sen, 2018). The immediate future of India's coal production capabilities therefore hinges on the ability of producers to transport coal from mines to consumers.

At the end of 2017, India's total proved reserves of coal were 97,728 Mt (ranked fifth globally), with 95 percent being anthracite or bituminous coal, and the remaining 5 percent being sub-bituminous or lignite (BP, 2018). The majority of India's coal reserves are located in the eastern half of the country, ranging from Andhra Pradesh, bordering the Indian Ocean, to Arunachal Pradesh in the extreme northeast of the country (USEPA, 2015).

In 2017, India ranked second only to China in global coal production with 716 Mt of coal produced (BP, 2018). Between 1981 and 2017, India's coal production capacity increased by 586 Mt (Exhibit 3). The country's largest coal producer, CIL, is responsible for producing over 80 percent of India's coal, with Singareni Collieries Company Limited (SCCL) responsible for another 10 percent of production (EIA, 2016). The remaining 10 percent of coal production is met by captive producers, which represent private industries mining coal for their own use. For decades, the Indian government portioned out coal production blocks to private companies for their own consumption, however, in 2014 India voided these contracts and planned to re-auction them for sale. The goal of the reform was to create a more transparent, competitive bidding system for coal production rights, which the government hoped would attract private investment in the coal sector and support domestic coal production (EIA, 2016). This bidding process has continued into 2019, although response among investors was more tepid than originally forecasted (Das, 2018). Reasons for this lack of interest range from perceived government over-exaggeration of block values to the improving economics of renewable energy deployment in the country.

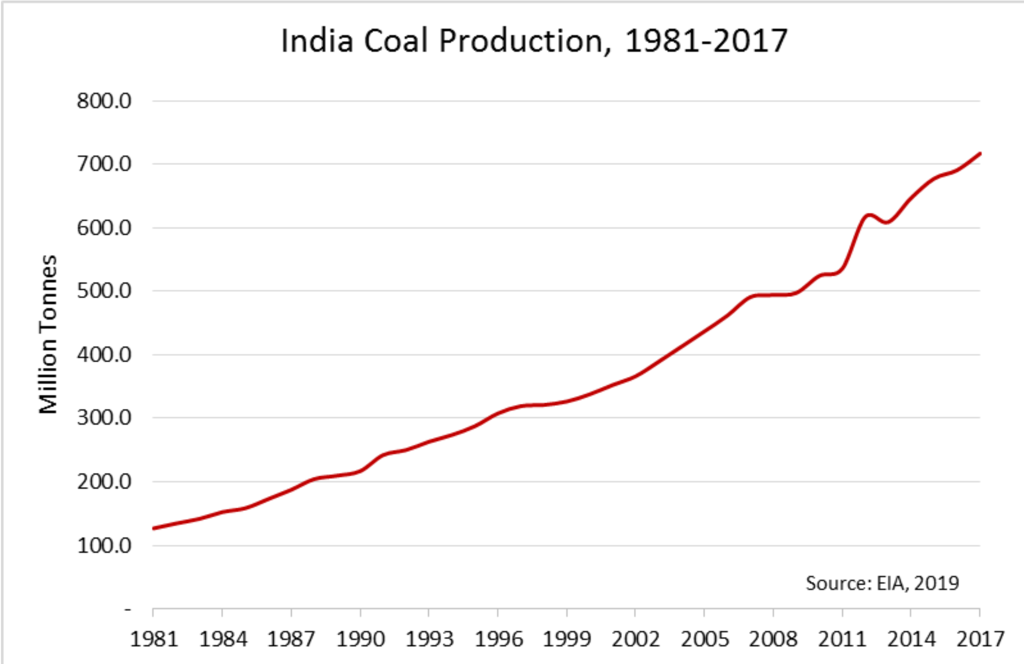

Exhibit 3: Coal Production in India

2.2 Coal Mine Methane in India

Most coal mines in India, including the Pootkee Colliery, are classified as Degree I or II gassy mines, indicating that they are moderately gassy as shown in Exhibit 4 (DGMS, 2015). However, India's growing demand for coal is expected to drive up production-associated CMM emissions as the country depletes its shallow, easily-accessible coal reserves and begins exploiting deeper, gassier seams. CMM emissions in India have risen from 35 billion cubic feet (Bcf) (1,007 million cubic meters, Mm^3) in 2000 to an estimated 49 Bcf (1,397 Mm^3) at the end of 2015 (USEPA, 2015).

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) (35.31 cubic 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 the rate of emission per tonne of coal produced does not exceed 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 4: Gassy Mine Classification System of India

India's current administration has called for an increase in domestic oil and gas production to reduce the country's dependence on fossil fuel imports. By 2020, the government hopes to reduce India's import dependence by 10 percent (PTI, 2016). Declining offshore oil and gas production is responsible for a 25 percent overall natural gas production decrease in India over the past five years, but CMM production, spurred by a 2013 government decision to allow CIL to produce gas from coal bed methane (CBM), saw an 8 percent increase in production over the period 2017-2018 (BP, 2018; PTI, 2013; Abdi, 2018). Disappointed with this lower-than-expected increase in CMM production, the Indian government took further policy steps in 2018 to allow CIL to extract natural gas from coal formations without receiving a permit from the oil ministry to do so (PTI, 2018b). The government expects the state-owned mining company to accelerate CMM/CBM exploration with a goal of ramping up its output to a minimum of 177 million cubic feet per day (MMcfd) (5 Mm^3/d) of natural gas from current levels of less than 35 MMcfd (1 Mm^3/d) (Saikia, 2015).

According to India's Directorate General of Hydrocarbons (DGH), a large portion of the country's prospective CBM resources have yet to be explored. In fact, exploration has only been initiated in about half of the 26,000 km^2 of potential CBM-producing areas (Saikia, 2015). CIL holds 20 percent of India's estimated 315 Gt of coal resources, and the company has coal mines in eight states, which are estimated to hold between 3.5 to 4 trillion cubic feet (Tcf) of CBM reserves. Furthermore, much of CIL's acreage is gaseous and considered safe to mine only after pre-drainage of methane. Extracting CBM/CMM before the mining of coal seams would grant CIL access to significant quantities of coal reserves in areas of Jharkhand and West Bengal (PTI, 2013). With 81 percent of the country's prospective CBM areas overlapping coal mining areas held by CIL, the continuing relaxation of government regulations hampering CMM capture and utilization development could help CIL unlock up to 100 Mt of medium grade coking coal and 1 Tcf of gas (PTI, 2013).

While recent policy changes appear favorable for state-owned CIL, the Ministry of Petroleum & Natural Gas (MOP&NG) recently clarified that existing private operators already undertaking CBM exploration and production projects at coal blocks allocated to them by the government would have to pursue new licenses from the government under the Hydrocarbon Exploration and Licensing Policy (HELP). The newly unveiled HELP calls for a composite uniform license for exploration and production of all forms of hydrocarbons from a single asset block, hampering private companies in the short term but giving them more freedom in developing hydrocarbon resources after getting licensed (Das, 2016). However, a recent decision by CIL to potentially open its coal fields for CBM extraction by global, third-party companies may facilitate the ability of private companies to execute CBM projects under the aegis of CIL's permit without having to apply for one of their own (Sengupta, 2018).

2.3 Bharat Coking Coal Limited

Bharat Coking Coal Limited (BCCL) is a subsidiary of Coal India Limited (CIL), a state-owned coal mining company. CIL is the largest coal producer in the world, operating in 81 mining lease areas spread across eight provincial states, through seven wholly owned mining subsidiaries and one mine planning and consulting company. CIL produces 84 percent of India's total coal, which accounts for 40 percent of India's total commercial energy requirements and 76 percent of its total utilities thermal power generating capacity (CIL, 2018). Its subsidiary, BCCL supplies 50 percent of the total prime coking coal requirements of India's steel sector (BCCL, 2009).

BCCL is situated in the states of West Bengal and Jharkhand, with operations in the Raniganj and Jharia Coalfields. BCCL currently holds an approximate mining lease area of 218 km^2 and operates 44 mines, of which 10 are underground, 20 are opencast, and 14 are mixed. As of 2009, BCCL reported owning a total estimated coal reserve of 17.5 Gt and the company produced an average of 31.6 Mt annually between 2009 and 2018 (BCCL, 2009; BCCL, 2018).

3. Mine Characteristics

3.1 Geographic Location

The Pootkee Bulliary CMM block covers an area of approximately 16 km^2 and is located in the east-central part of the Jharia Coalfield in the Damodar Valley of Jharkhand State (Exhibit 5). Mining of the Jharia Coalfield began in the 1890's when the East India Railway extended service to the region, making it possible to transport the coal to market—the field has since been recognized as India's largest coal reserve and the primary source of the country's coking coal supply (IBM, 2018). The Jharia Basin extends over 453 km^2 between latitudes 23°37'N and 23°52'N and longitudes 86°06'E and 86°30'E – within this space, the Pootkee Bulliary block exists between latitudes 23°43'17"N and 24°46'32"N and longitudes 86°20'12"E and 86°23'15"E.

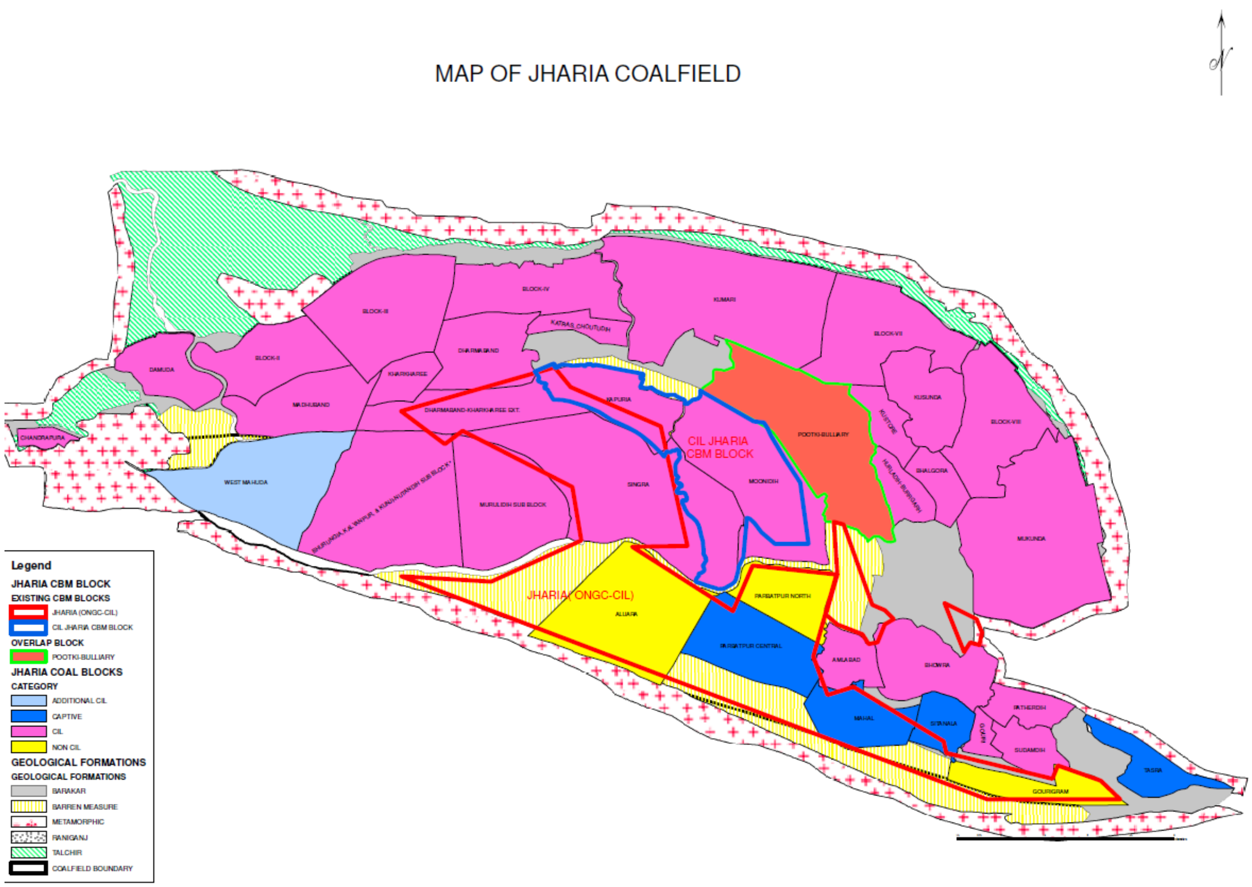

Exhibit 5: Jharia Coalfield. Pootkee Bulliary is shaded in orange and outlined in green.

3.2 Geologic Location

The Jharia Coalfield is a sickle-shaped outlier of the Gondwana group of Permo-Carboniferous sediments with a broad east-west major axis that plunges westward. The southern edge of the Jharia Basin is delineated by a major fault known as the Main Boundary Fault—a large part of the basin's original southern limb is therefore missing. Instead, south of the Main Boundary Fault are younger Permo-Carboniferous sedimentary formations juxtaposed against Archaean metamorphic bedrock. The fault gives the basin a half graben structure.

The northwestern, northern, and northeastern edges of the basin are fringed by well-exposed portions of the non-coal bearing Talchir Formation. The Barakar Formation overlays the Talchir and is well exposed in the northern, northeastern, and southeastern regions of the basin; the Barakar contains over 40 coal seams and is the formation responsible for producing the prime coking grade coal that drew mining interest to the region over a century ago. Atop the Barakar Formation rests the Barren Measures, whose exposures mainly occur in the central part of the basin. This, in turn, is overlain by the coal bearing Raniganj Formation in the southwestern corner of the basin. This sedimentary profile can be seen in Exhibit 6.

Age	**Formation**	**Thickness**	**Lithology**
Recent/Sub-Recent	Recent/Sub-recent	<30m	Alluvium/sandy soil, sandy clay, gravel etc.
^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^**Unconformity**^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^			
Tertiary	Block tectonics forming southern boundary and other faults		Tectonic Activities
Paleocene	Cross-folding along E-W axis; later folding along NNE-SSW axis from intrusion of dolerite dyke		Dolerite Dykes
Lower Cretaceous	Early folding along NW-SE axis forming zone of depression near Mohuda; intrusion of mica-periodites		Mica-peridoites
--**Time Lapse**--			
Upper Permian	Raniganj Formation	<725m	Coal bearing formation containing 24 coal seams, micaceous sandstone, shale, and carbonaceous shale
Middle Permian	Barren Measures Formation	375-625m	Massive sandstone traversed with ferruginous bands alternating with carbonaceous shale, gray shale, and sandstone.
Lower Permian	Barakar Formation	600-1250m	Coarse to fine grained sandstone interspersed with shale, carbonaceous shale, pebbly sandstones, and conglomerates. 18 correlatable coal horizons, but up to 51 coal seams including splits and locals
Upper Carboniferous	Talchir Formation	250m	Coarse grained green sandstone, greenish splintery shale, and basal boulder beds
^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^**Unconformity**^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^			
Archean	Metamorphics	Bedrock	Granite Gneisses and schists

Exhibit 6: Generalized stratigraphic sequence of Jharia Coalfield (adapted from CMPDIL data)

The Jharia Basin is widely considered to be the northern-most remnant of a cross-folded synclinal basin, preserved as a down-thrown block of the southern tectonic boundary fault. The Barakar Formation's changing regional strike in Jharia Coalfield shows an arc-shaped trend that is responsible for the overall sickle shape of the coalfield. Dip in the basin tends to be gentle and southerly except near faults where the dip can steepen drastically. The coalfield is traversed by a number of strike, dip, and oblique slip normal faults related to the major boundary fault to the south of the basin.

The basin is also traversed by dykes and sills of mica-peridotite and dolerite – the mica-peridotite igneous intrusions, in places, have metamorphosed coal seams into jhama (a high ash, low volatile coal with a high fixed carbon) and natural coke. The dolerite intrusions are confined to the western portion of the basin and have largely left the coal seams unaffected.

The Pootkee Bulliary block, located in the central part of the Jharia Coalfield, is completely covered by rocks of the Upper Permian Raniganj and Middle Permian Barren Measure Formation that overlay the Lower Permian Barakar Formation. The Barren Measures is a formation of massive sandstone traversed by ferruginous bands, grey to dark-grey shale, carbonaceous shale, and clay with ironstone bands. The Barakar Formation is composed of feldspathic sandstones and carbonaceous shales that are traversed by coal seams. The formations show a NW-SE strike with a south-west dip of 4^o to 12^o. Based off available borehole data and geologic reports, 21 faults are interspersed through the block with throws between 5 m and 190 m. Post-Gondwana orogeny mica-peridotite dykes and sills do intrude the area and have affected the seams—XVIII and XIV appear to be completely pyrolitized into jhama, XIII and XII are affected by intrusions throughout the block, and parts of XI have also been converted to jhama.

3.3 Topographic and Climatic Characteristics

The Pootkee Colliery within the block is situated directly north of the Damodar River at an elevation of 180 m (590 feet, ft) and has a humid, tropical climate. The Sendra-Bansjora ravine and Ekra Jore river near the western boundary of the block and the Kari ravine near the south-eastern border provide the main drainage for the block – these features ultimately drain into the Damodar River. Through the summer months (March through June) the temperature ranges from 18^o to 39^oC; through the winter months (November through January) the temperature can drop as low as 11^oC at night. Average rainfall in the area is 114 millimeters (mm) (4.5 inches, in), although, like many parts of northeastern India, the mine experiences monsoon cycles where the majority of its rain occurs between June and September (192 mm to 342 mm per month) and the rest of the year remains dry (5 mm to 17 mm per month). The region is often subjected to a cyclonic storm locally referred to as "Kalbaissakhi" from April through late May.

3.4 Transportation and Infrastructure Connectivity

The closest point of entry for a visitor to the mine would be the regional Dhanbad Airport, connected with regular flights from Calcutta and Patna (both of which can be easily reached by international travelers). From there, one would follow the Dhaiya Main Rd south for 15 kilometers (km) and then take Moonidih Road for the last 5 km, a drive that takes about 50 minutes. The nearest major airport is the Birsa Munda Airport in Ranchi, to the southwest of the mine – visitors would then need to drive 3 hours along the NH-320 before reaching the coalfield.

The region is well connected by road and rail – the Dhanbad-Chas section of the NH-32 road runs 0.5 km to the north of the mine and fair weather roads crisscross the coalfield. Dhanbad Railway Station on the

Grand Chord line of the Eastern Railway is 16 km to the northeast of the mine and connects the field to numerous major cities. A side rail-line 8 km to the northwest of the colliery connects the field to the Bhojudih-Chandrapura railway line via Mohuda Railway station.

3.5 Prognosticated Coal and Gas Reserves

Although up to 51 coal seams occur in the Barakar Formation of the block, only 18 are persistent and able to be correlated with each other (Exhibit 7). BCCL has been mining this block since the nationalization of India's coal mines in 1972 and has developed seams XVIII, XVII, XVI, XV, XIII, XII, XI, XI, X, IX, and VII to varying extents with room and pillar mining. The deepest seam, II, is projected to be 900 m deep and the cumulative thickness of the layers targeted for future mining, seams X to II, have an average cumulative thickness of 55 m. Seams X, IX, VIIIC, VIIIB, VIIA, VIII (A&B), VII, V, IV, III, and II are all being considered for CMM development.

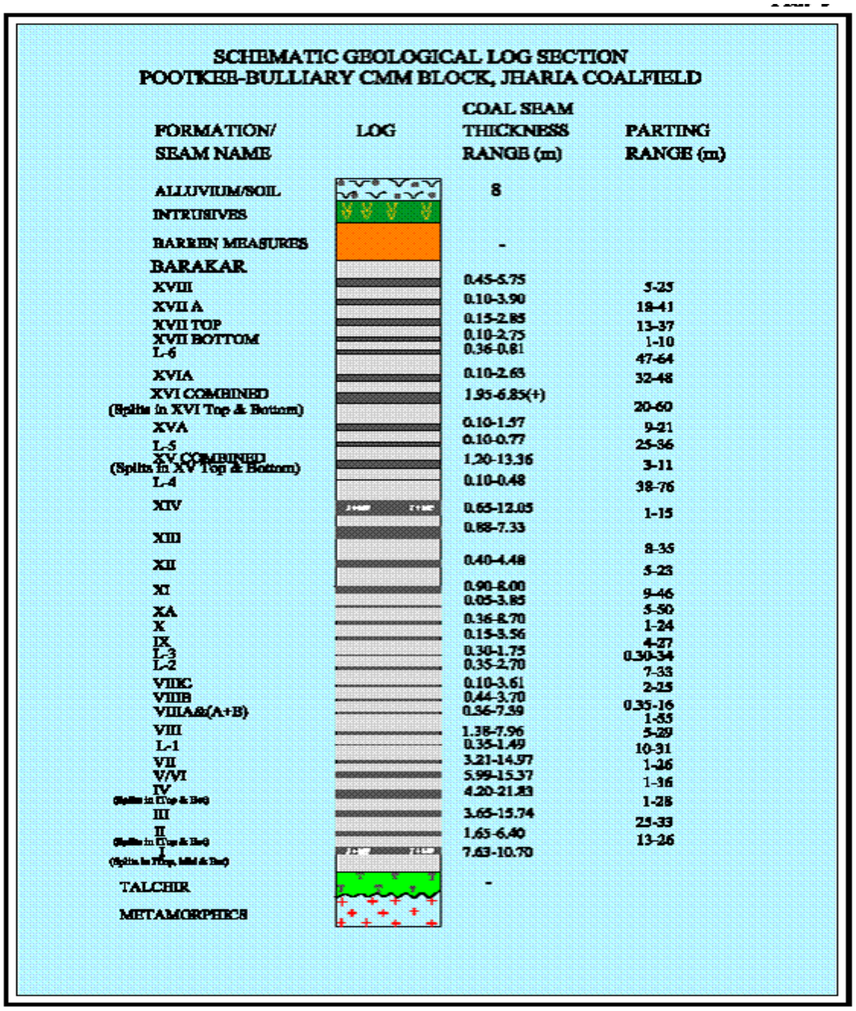

Exhibit 7: Geologic Log Section of the Pootkee-Bulliary CMM Block, Jharia Coalfield

Coal within the virgin seams is estimated at 1,116 Mt and desorption test results of seam samples taken from the Jharia CMM block, the block to the immediate southwest of the Pootkee-Bulliary CMM block, found that in-situ methane gas content ranged from 3.5 cubic meters per tonne (m^3/t) of coal to 16 m^3/t (Exhibit 8). The coal being mined ranks from low to medium volatile bituminous coal. The minimum recoverable gas is about 2.12 billion cubic meters (Bcm), or 30 percent of the total predicted resource.

Seams	**Coal Resource In million tonnes (Mt)**	**Average in-situ gas content (daf) of the seam M^3/T**	**Prognosticated CBM Resource in million cubic meters (Mm^3)**
XVIIIB	1.97	--	--
XVIIIA	2.82	--	--
XVIII	1.77	--	--
XVIIT	9.61	--	--
XVIIB	11.65	--	--
XVIT	15.62	--	--
XVICOMB	36.73	--	--
XV	35.4	--	--
XIV	18.52	--	--
XIII	16.71	--	--
XII	33.2	--	--
XI	70.48	--	--
XA	10.18	--	--
X	100.96	5.5	540.1
IX	37.77	5.6	183.4
VIIIC	45.42	6	259.74
VIIIB	33.84	6	180.6
VIIIA /VIII(A+B)	50.99	6	320.88
VIII	106.86	6	641.22
VII	218.14	6	1299.42
VI	55.55	6	333.3
V and V/VI	257.6	6	1545.6
IV	110.34	6	662.04
III	110.65	6	663.9
II	70.11	6	420.66
Total	**1462.89**		**7050.86**

Exhibit 8: Seam-wise Prognosticated CBM Resource of the Considered Coal Seams, Pootkee-Bulliary CMM Block, Jharia Coalfield

4. Gas Resources

4.1 Overview of Gas Resources

India's CMM emissions are estimated to be 2.6 trillion cubic meters (Tcm) (DGH, 2019). As of 2019, drainage of CMM in India is limited with no active commercial CMM recovery projects in the country. However, there are two CMM blocks currently being developed by CIL subsidiaries in the Jharia Coalfield, and initial research is being done on potential project sites in the Bokaro and Sohagpur Coalfields and in the Moonidih block of Jharia Coalfield (USEPA, 2015; CMPDI-CIL, 2017). As mentioned previously, recent legislation in 2018 has removed bureaucratic red tape from CIL's path to developing CMM recovery projects in its coal mines. If CIL's current CMM development projects and the Pootkee Colliery project are successful, they could be used as templates for CMM projects at future mines in the region. In terms of India's CBM resources from virgin coal seams, estimates vary depending on coal rank, burial depth, and geotectonic settings, with the DGH estimating that India's 44 major coal and lignite fields contain 120 Tcf, or 3.4 Tcm, of CBM resources (USEPA, 2015). Developing a strategy to harness these vast natural gas resources would therefore be in the government's self-interest for ensuring its energy security and fulfilling the emissions reductions it promised in the Paris Agreement.

4.2 Proposed Gas Drainage Approach

BCCL's current plans are to deploy equipment to mine the coking quality coal of Seam XII, which is situated at a depth ranging from 400 to 550 m. As of the preparation of this report (2019), the mining of other seams is not planned; however, future mining is envisioned as shallower coal resources are depleted and mining moves to deeper seams. The objectives of this pre-feasibility study are to perform an initial assessment of the technical and economic viability of methane pre-drainage utilizing long in-mine horizontal boreholes drilled into Seam XII to drain methane in advance of mining, and to utilize the drained gas to generate electricity for on-site consumption.

Long, in-mine directionally drilled boreholes that can be installed from main entries, significantly in advance of gate road developments, and drilled along the longitudinal axis of longwall panels are recommended. Directional drilling delivers an in-seam drainage solution that reduces the number of wellheads and potential points of air leakage into the gas drainage system and provides for longer drainage times to further reduce residual gas contents. The gas production profiles generated for the horizontal pre-drainage boreholes will form the basis of the economic analyses performed in Section 7 of this report. Additionally, estimating the gas production volume is critical for planning purposes and the design of production and end-use equipment and facilities.

4.3 Estimating Production from In-Mine Horizontal Pre-Drainage Boreholes

Directionally drilled boreholes should be planned based on the time available before mining takes place and the desired reduction in gas content prior to mining. For this study, a variety of well spacings were examined to determine how much time is required to achieve a 30 percent reduction in gas content prior to the mining of the seam. Multiple reservoir models were developed to simulate various borehole spacings. Larger spacing is generally less effective compared to more closely spaced boreholes over a given period of time, because it takes longer for the borehole drainage areas to overlap. All data used in these models were provided by CMPDIL, the Pootkee Colliery, and BCCL. The following sections of this report discuss the development of the gas drainage borehole models, the input parameters used to populate the reservoir simulation models, and the simulation results.

4.3.1 Simulation Model for Gas Production

A total of six, single-layer models were constructed in order to calculate gas production for a longwall panel located within the project area. The models were designed to simulate production from long, directionally drilled boreholes drilled into virgin areas of Seam XII. The six well spacing cases examined were: 41.7 m, 50 m, 62.5 m, 83.3 m, 125 m, and 250 m. All boreholes were modeled to bedrilled into a coal block with a dip angle of 8 degrees and are assumed to be 800 m in lateral length. The models were each run for five years in order to simulate gas production rates and in-situ gas content reduction over time for a typical longwall panel within the study area.

A typical longwall panel at the mine is estimated to have a face width of 250 m and a panel length of 800 m covering an aerial extent of 20 hectares (ha). The model grid setup consisted of 65 grid-blocks in the x-direction, 41 grid-blocks in the y-direction, and one grid-block in the z-direction. Zero-flow boundaries were created along the flanks of the borehole such that the width of the reservoir model was equal to the borehole spacing; this was accomplished by adjusting grid block sizes to correspond with each of the six well spacing cases. Side and top view illustrations of an example model developed to simulate the 800 m long 96 mm diameter directionally drilled boreholes are shown in Exhibit 9.

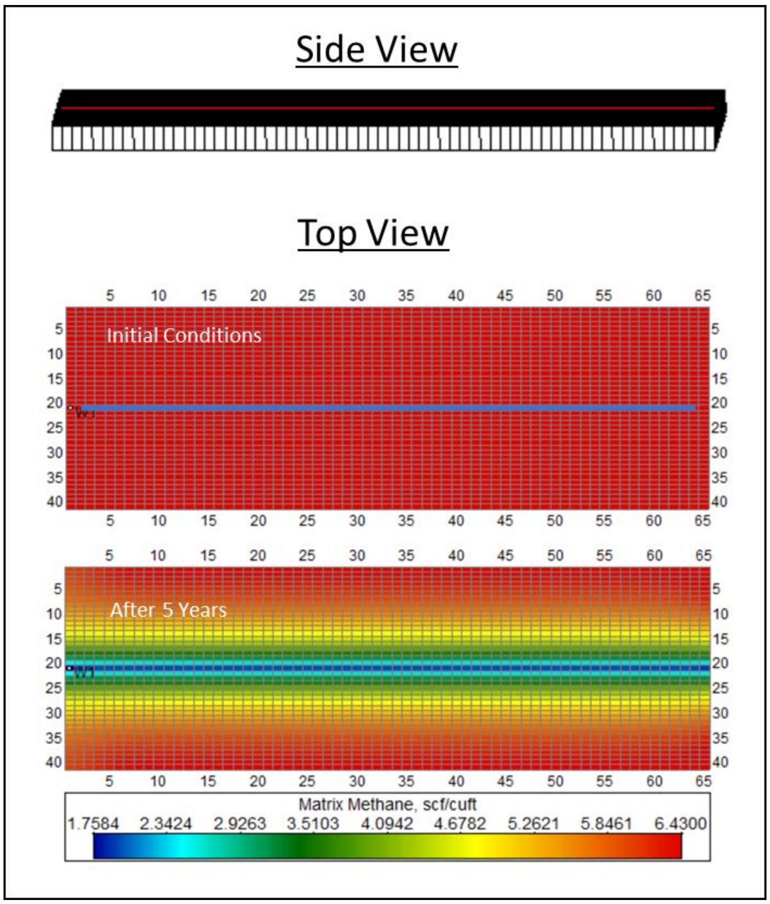

Exhibit 9: Example Model Layout for In-Seam Horizontal Pre-Drainage Borehole

4.3.2 Model Preparation and Runs

The input data used to populate the reservoir models were obtained from the geologic and reservoir data provided by CMPDI, the Pootkee Colliery, and BCCL. Where appropriate, supplemental geological and reservoir data from analogous projects, such as data from the neighboring Jharia CBM block, were also used. The input parameters used in the reservoir simulation study are presented in Exhibit 10, followed by a brief discussion of the most important reservoir parameters.

Reservoir Simulation Parameters for Pootkee-Bulliary CMM Block				
RESERVOIR PARAMETERS	**Imperial**		**Metric**	
COAL SEAM		XII		XII
PANEL DIMENSIONS				
LENGTH	ft	2,625	m	800
FACE	ft	820	m	250
AVERAGE COAL DEPTH	ft	1,558	m	475
DIP ANGLE OF COAL FACE	deg.	8	deg.	8
AVERAGE COAL THICKNESS	ft	10.2	m	3.1
COAL DENSITY	lb/ft^3	115.2	gm/cc	1.85
PRESSURE GRADIENT	psi/ft	0.433	kPa/m^3	9.80
RELATIVE PERMEABILITY		See curve		See curve
CLEAT POROSITY	%	0.5	%	0.5
CLEAT WATER SATURATION	%	100	%	100
CLEAT PERMEABILITY	md	0.5	md	0.5
INITIAL AVERAGE RESERVOIR PRESSURE	psia	689	kPa	4,753
LANGMUIR COEFFICIENTS				
LANGMUIR VOLUME	ft^3/ton	370	$m^3/tonne$	11.5
LANGMUIR VOLUME	scf/ft^3	21.3	sm^3/m^3	21.3
LANGMUIR PRESSURE	psia	270	kPa	1,863
GAS CONTENT	ft^3/ton	111	$m^3/tonne$	3.5
DESORPTION PRESSURE	psia	117	kPa	804
SORPTION TIME	days	1.5	days	1.5
CLEAT SPACING	in	2.6	cm	6.5
PORE VOLUME COMPRESSIBILITY	/psi	3.00E-06	/kPa	4.35E-07
MATRIX SHRINKAGE COMPRESSIBILITY	/psi	1.00E-06	/kPa	1.45E-07
BOREHOLE DIAMETER	in	3.8	mm	96
COMPLETION & STIMULATION	skin	+2	skin	+2
WELL OPERATION	psia	6	kPa	41

Exhibit 10: Reservoir Parameters for Horizontal Pre-Drainage Borehole Simulation

4.3.2.1 Permeability

Coal bed 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 is a critical input parameter for reservoir simulation studies. Absolute permeability data for the coal seams in the study area were not provided. For the current study, a permeability value of 0.5 millidarcy (md) was assumed based on permeability values used in previous studies performed on the Jharia CBM block (CMPDI-CIL, 2017).

4.3.2.2 Langmuir Volume and Pressure

Laboratory measured Langmuir volumes and pressures for the study area were not available. However, Langmuir volume and pressure values from methane isotherm analyses conducted on coal samples from Seam XII in borehole MKP-12 in conjunction with a CBM project in the Jharia block were utilized in the current study (CMPDI-CIL, 2017). The corresponding Langmuir volume used in the reservoir simulation models for the project area is 11.5 m^3/t and the Langmuir pressure is 1,863 kilopascal (kPa). The methane isotherm from borehole MKP-12, as reported on a dry, ash-free basis, was converted to an as-received basis using in-situ ash and moisture contents from the Pootkee-Bulliary block. Exhibit 11 depicts the methane isotherm utilized in the horizontal pre-drainage borehole simulations.

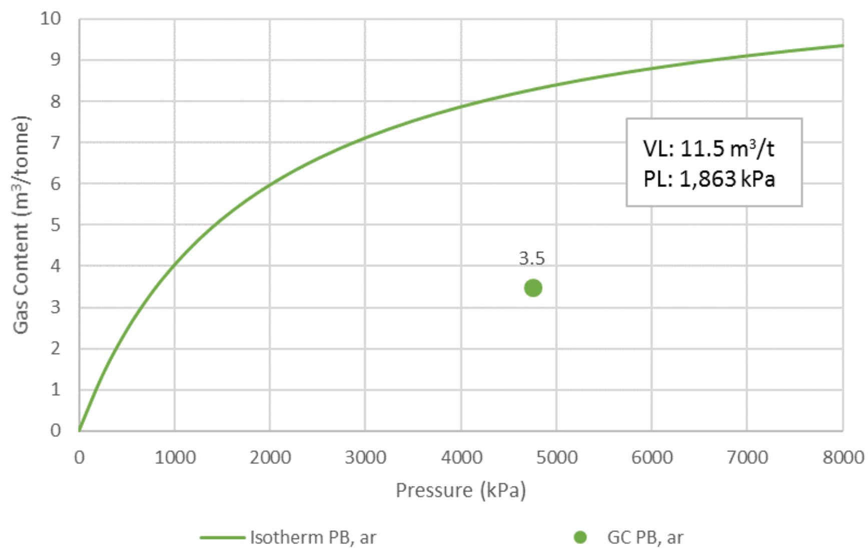

Exhibit 11: Methane Isotherm Used in Horizontal Pre-Drainage Borehole Simulation

4.3.2.3 Gas Content

No gas desorption analyses data were available for Seam XII within the study area. Based on the seam-wise gas content data as compared to the maximum methane storage potential from the Jharia CBM block isotherm, a gas saturation of 42 percent was calculated at Seam XII reservoir pressure. As a result, an initial gas content value of 3.5 m^3/t was used in the simulation study (Exhibit 11).

4.3.2.4 Relative Permeability

The flow of gas and water through coal seams is governed by permeability, of which there are two types, depending on the amount of water in the cleats and pore spaces. When only one fluid exists in the pore space, the measured permeability is considered absolute permeability. Absolute permeability represents the maximum permeability of the cleat and natural fracture space in coals and in the pore space in coals. However, once production begins and the pressure in the cleat system starts to decline due to the removal of water, gas is released from the coals into the cleat and natural fracture network. The introduction of gas into the cleat system results in two-phase fluid flow (gas and water) in the pore space, and the transport of both fluids must be considered in order to accurately model production. To accomplish this, relative permeability functions are used in conjunction with specific permeability to determine the effective permeability of each fluid phase.

Relative permeability data for the coal of the project area was not available. Therefore, a relative permeability data set was used, which is typical for coals of similar age and rank (CMPDI-CIL, 2017. Exhibit 12 is a graph of the relative permeability curves used in the reservoir simulation of the study area.

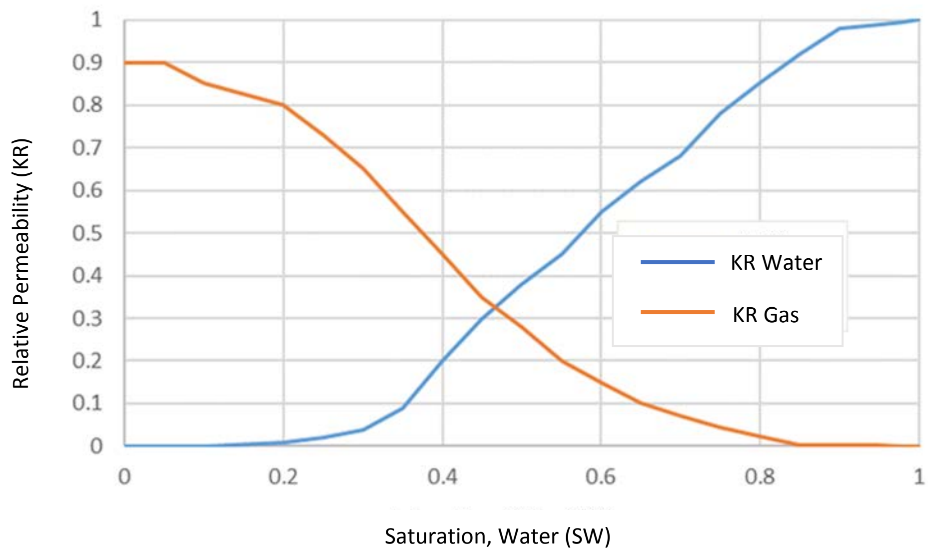

Exhibit 12: Relative Permeability Curve Used in Simulation

4.3.2.5 Coal Seam Depth and Thickness

Based on mine data, Seam XII ranges in depth from 400 m to 550 m with the seam averaging 3.1 m in thickness. For modeling purposes, the depth to the top of the coal reservoir was assumed to be 475 m, with the seam dipping an average of 8 degrees to the southwest (dip ranges from 4 to 12 degrees throughout the study area).

4.3.2.6 Reservoir and Desorption Pressure

Initial reservoir pressure was computed using a hydrostatic pressure gradient of 9.8 kPa/m and the midpoint depth of the coal seam. Because the coal seams are assumed to be undersaturated with respect to gas, desorption pressure is determined in COMET3® by the point of intersection of the gas content and isotherm. The resulting desorption pressure calculated by the model is 804 kPa compared to an initial reservoir pressure of 4,753 kPa.

4.3.2.7 Porosity and Initial Water Saturation

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 mine area were not available, a value of 0.5 percent was used in the simulations. Porosity values for coal typically range between 1 and 3 percent; however, the 0.5 percent porosity value was based on analog data from the Jharia Coalfield as provided by the Central Mine Planning and Design Institute (CMPDI). The cleat and natural fracture system in the reservoir was assumed to be 100 percent water saturated. This assumption is consistent with drilling information and well test data from analogous coal in the region.

4.3.2.8 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 a 1.5 day sorption time was used, which is consistent with the coals in the region. Production rate and cumulative production forecasts are typically relatively insensitive to sorption time.

4.3.2.9 Cleat Spacing

A cleat spacing of 6.5 centimeters (cm) was assumed in the simulations, which is consistent with data from field tests conducted at a nearby CBM project. In the model, cleat spacing is only used for calculation of diffusion coefficients for different shapes of matrix elements and it does not materially affect the simulation results.

4.3.2.10 Borehole Spacing

As discussed previously, six borehole spacing cases were modeled: 41.7 m, 50 m, 62.5 m, 83.3 m, 125 m, and 250 m apart.

4.3.2.11 Completion

Long in-seam boreholes with lateral lengths of 800 m will be drilled into the longwall panel. For modeling purposes, a skin value of +2 is assumed (formation damage).

4.3.2.12 Well Operation

For the current study, an in-mine pipeline with a surface vacuum station providing a vacuum pressure of 41 kPa was assumed. In coal mine methane operations, low well pressure is required to achieve maximum gas content reduction. The wells were projected to produce for a total of five years.

4.3.3 Simulation Results

Reservoir models were developed for 800 m in-seam boreholes for six different spacings between boreholes: 41.7 m, 50 m, 62.5 m, 83.3 m, 125 m, and 250 m. The models simulated borehole gas flow rate and percentage of gas content reduction over a five-year period as shown Exhibit 13. The drainage time required to reduce the residual gas content by 30 percent, and the average gas production rate for each in-seam borehole configuration during that period, were derived from the numerical models and are presented in Exhibit 14. This exhibit provides the drainage times that each borehole spacing strategy would require to decrease the in-situ methane level in a longwall panel methane saturation by 30 percent, allowing mine developers to tailor their drainage strategy depending on the amount of time they have before commencing mining operations on that panel.

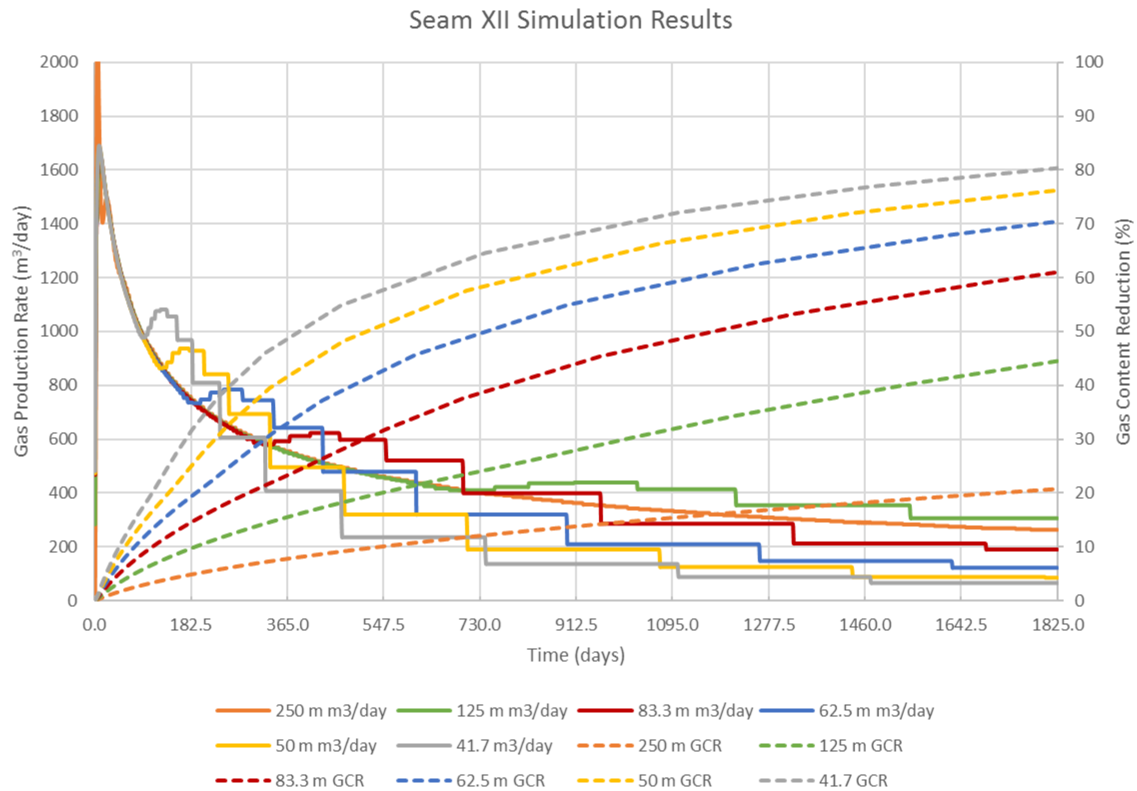

Exhibit 13: Results of Gas Content Reduction Versus Borehole Spacing Analysis in Seam XII

Spacing (m)	Time (years)	Gas Content Reduction (%)	Average Methane Flow Rate (m^3/day)
41.7	0.5	30	1152
50	0.6	30	1046
62.5	0.9	30	925
83.3	1.4	30	778
125	2.8	30	593
250	5.0	20.75	452

Exhibit 14: Drainage Time and Average Methane Flow Rates Versus Borehole Spacing in Seam XII

5. Market Information

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. 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 outbursts, increased production from underground mines cannot be realized without proper degasification precautions. If captured and utilized properly, CMM would help satisfy the demand for energy in the region while improving the local environment through the reduction of greenhouse gas (GHG) emissions.

India began awarding CBM blocks for exploration in 2001 and, after more than a decade, production is beginning to come online. According to the DGH, Jharkhand has significant potential for CBM production with 6.178 Tcf (175 Bcm) of CBM resources, or 24.7 percent of India's total CBM resources, located within the state. The Jharia Coalfield in Jharkhand has been developed and has an estimated gas potential of 2.4 Tcf (68 Bcm) (DGH, 2019). Total CBM production from India in 2016 amounted to 13.9 Bcf or 392.873 Mm^3 (DGH, 2016).

The Central Institute of Mining and Fuel Research (CIMFR) estimates that demand for natural gas in India has been increasing by 6.8 percent per year for the last decade, and natural gas consumption has increased annually by approximately 6 percent during the same period (EIA, 2016). Coal production in India is also struggling to keep up with the rapidly growing demand for coal causing power shortages and blackouts throughout the country. As a result, natural gas has traditionally been used to primarily supplement low coal supplies. However, as a cleaner and more efficient fuel than coal, natural gas has recently made major inroads in the power, transport, fertilizer, chemicals, and petrochemical industries. The majority of natural gas demand in 2014 came from the power sector (23 percent), the fertilizer industry (32 percent), and for the replacement of liquified petroleum gas (LPG) for cooking oil and other uses in the residential sector (14 percent) (EIA, 2016).

By 2022, India plans for natural gas to make up 15 percent of its primary energy consumption, up from 6 to 7 percent currently (Kar, 2018). The ability to market CMM as a viable way of feeding this increase is dependent on the ability for pipelines to transport the gas to market—despite the 11,092 km of pipeline that exists in the country and the 13,489 km of pipeline currently being built, pipelines continue to be underutilized, hampering efficient operation and further expansion. A central reason behind this underutilization is the lack of domestic natural gas production in India and the higher price of imported gas. Increasing pipeline coverage in gas-producing regions, like Jharkhand and neighboring West Bengal, will help improve this imbalance.

As of the beginning of 2018, there was a complete absence of pipeline infrastructure in the vicinity of the Jharia Coalfield for transporting and marketing natural gas. Jharkhand and the cities neighboring the mine are virgin markets devoid of natural gas or the infrastructure necessary for it. Consequently, if CMM resources are inadequate to fuel local demand, then consumers are exposed to uncertainty in natural gas supply. This situation was addressed by the 2016 Indian Cabinet Committee on Economic Affairs' decision to fund 40 percent of the $1.8 billion Jagdishpur-Haldia and Bokaro-Dhamra Gas Pipeline (JHBDPL) project, thereby expediting construction of a pipeline that would run through the Jharia Coalfield (PIB, 2016) (Exhibit 15).

Phase I of the pipeline, running 753 km from Phulpur to Dobhi, was completed in December 2018 and work immediately began on Phase II, running 667 km from Dobhi to Bokaro, which passes within 10 km of the Pootkee Colliery. The portion of the pipeline passing by Pootkee Colliery will have a design capacity of 16 Mm^3 natural gas per day and will connect the project to a pipeline network running through seven cities, forty districts, and 2,600 villages in eastern India (HT, 2019). This section is due to be finished by December 2020 and will connect the Jharia Coalfield to India's overall natural gas infrastructure. CIL confirmed it was in talks with the Gas Authority of India Limited (GAIL), the state-owned pipeline company operating the JHBDPL, about a possible partnership to connect and further develop the CBM/CMM resources of the Jharia and Raniganj coalfields (HT, 2019).

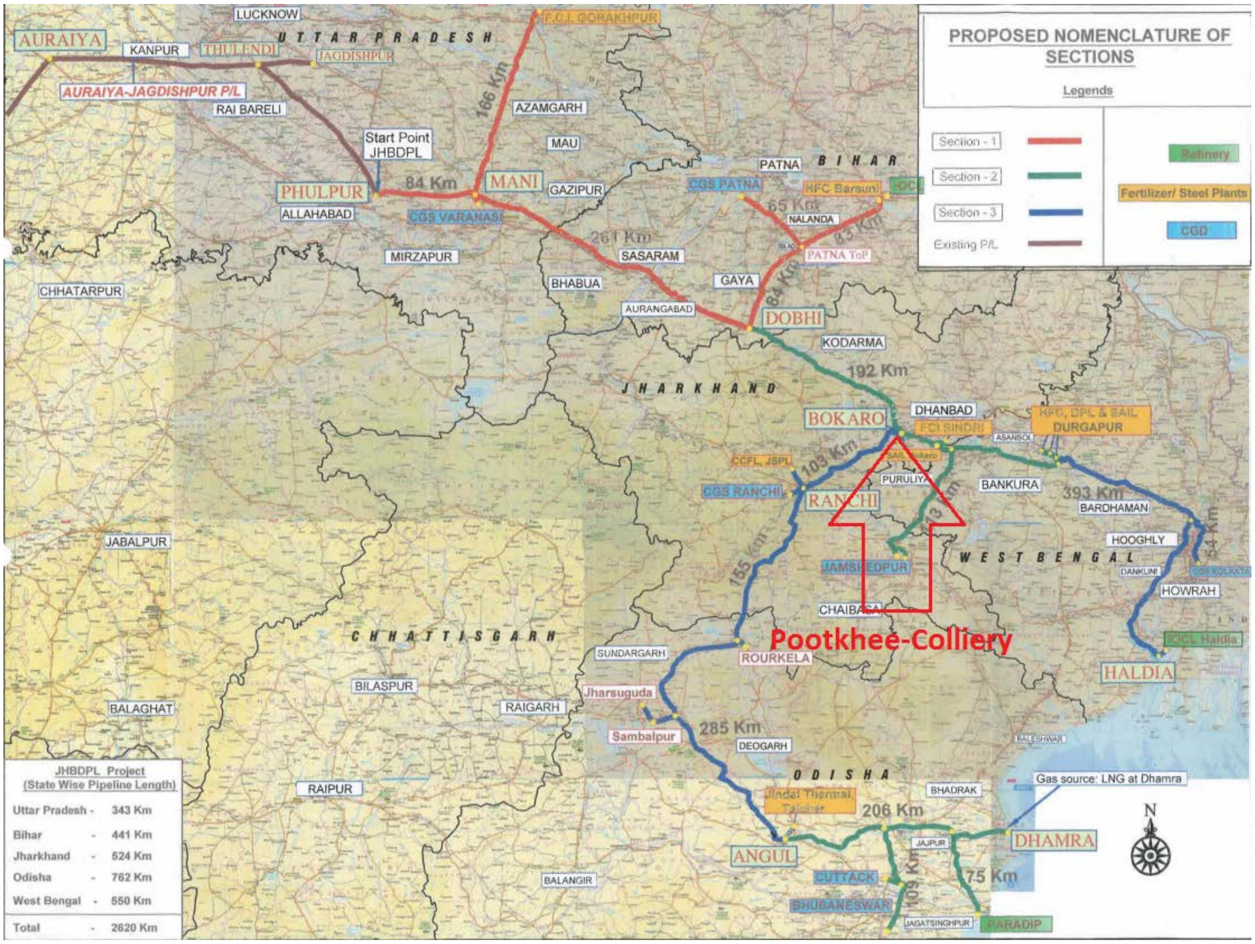

Exhibit 15: Jadishpur-Haldia & Bokaro-Dhamra Pipeline Project in Relation to the Pootkee Colliery. Source: (PNGRB, 2018)

India is currently the fourth largest liquefied natural gas (LNG) importer in the world and has four LNG import terminals all located in Gujarat Province in western India: Dahej, Mundra, Hazira, and Jafrabad (Corkhill, 2018a). There are additional projects currently being developed in Ennore, Kakinada, and Dahmra on India's east coast, although these projects have developed at a slower pace than anticipated and will not run at 100 percent capacity until over a year after completion (Corkhill, 2018b). None of these terminals are close to the Jharia Coalfield, meaning that CBM/CMM would likely not directly compete with imports of LNG.

Additionally, Essar Oil & Gas Exploration & Production Ltd (EOGEPL) signed a 15-year supply contract with GAIL in August 2018 whereby the company would be able to monetize its entire CBM production from the Raniganj East block at a globally competitive price (Essar, 2018). The prices that GAIL will pay for the gas are linked to the three months' daily average price of Brent crude (Equation 5.1) and will hypothetically feed a 20 Mm^3/d demand in the region with a floor price of \$5.22 per million British thermal unit (MMBtu) and a ceiling price of \$13.45/MMBtu. Under this pricing scheme, the gas price in February 2019 was \$7.96/MMBtu. Four fertilizer plants and 25 municipalities have already signed contracts to receive CBM gas from the GAIL JHBDPL. GAIL is committed to getting 100 percent usage of its pipeline, so CMM gas sales would be a feasible utilization option for the Pootkee-Bulliary block, which will be evaluated in the Economic Analysis section of this report (Section 7).

$$Sales\ Price\ \left(\frac{USD}{MMBtu}\right) on\ GCV\ basis = 12.67\% * Brent_{(n)} + 0.780 + (V) \quad \text{(Equation 5.1)}$$

Where:

$Brent_{(n)}$ = arithmetic average price of Brent crude oil over a period of 3 months.

GCV = Gross Calorific Value

V = (-) 1.89

The state-owned Oil and Natural Gas Corp (ONGC) sold CBM from its Bokaro CBM block assets (also located in the Jharia Coalfield) in 2018 for $5.77 to $6.12/MMBtu to private industries and GAIL pipelines. CMM sold as low as $5.56/MMBtu to GAIL and as high as $6.12/MMBtu to Positron Energy Pvt Ltd, a private energy company (PTI, 2018c). The prices BCCL would be selling its CMM at would likely be within these ranges.

Jharkhand State's gross state domestic product (GSDP) expanded at a compound annual growth rate (CAGR) of 10.8 percent from 2011 to 2018, and now represents India's 19th largest state economy with a current GSDP of US$ 43.36 billion (IBEF, 2018). Despite the modest size of its local economy, the Pootkee-Bulliary CMM block is located only 30 km away from the border of West Bengal, which is India's 6th largest economy with a GSDP of US$ 163.67 (IBEF, 2018). The services sector is responsible for 57 percent of West Bengal's economic output while the agricultural and industrial sectors contributing 23 and 19.8 percent each, respectively (IBEF, 2018). The state's favorable location gives it a market advantage and it is a traditional market for eastern India, northeast India, Nepal, and Bhutan. Most importantly West Bengal State offers great connectivity to the rest of India through a developed network of railways, roadways, sea ports, and airports (IBEF, 2018).

Jharkhand State itself is also economically attractive given its huge mineral wealth (40 percent of India's overall mineral wealth) and the local manufacturing and energy related industries that naturally concentrate in mineral rich areas (IBEF, 2018). More specifically, the Pootkee Colliery is located near the heavily developed industrial areas of Bokaro Steel City and Dhanbad – the terrain between these areas is smooth and only has a topographic relief of 20 m between the mine and the towns, so transportation of CMM to these markets via pipeline would be theoretically feasible.

6. Opportunities for Gas Use

Drained methane can be used to fire internal combustion engines that drive generators to make electricity for sale to the local power grid. The quality of methane required for use in power generation can be less than that required for pipeline injection. Internal combustion engine generators can generate electricity using gas that has heat content as low as 300 Btu per cubic foot (Btu/cf) or about 30 percent methane. Mines can use electricity generated from recovered methane to meet their own on-site electricity requirements and can also sell electricity generated in excess of on-site needs to utilities. Coal mining is a very energy-intensive industry that could realize significant cost savings by generating its own power. Nearly all equipment used in underground mining runs on electricity, including mining machines, conveyor belts, ventilation fans, and elevators. Drained methane can also be used as a transportation fuel, as a petrochemical and fertilizer feedstock, as fuel for energy/heating requirements in industrial applications, and for on-site boilers that provide hot water or space heating to mine facilities (USEPA, 2013).

On-site power generation is typically the most economic option for methane utilization at mines around the world because low quality gas can be used, which minimizes gas processing costs, and the gas is used on-site, which eliminates pipeline and compression costs. Coal mines are major power consumers with substations and transmission lines near large mining operations and accessible to CMM-based power projects. However, there are other potential uses for drained gas in the region of the Pootkee Colliery that could be economic if other mines in the region pooled their gas production which would allow them to amortize the cost of the added infrastructure over a larger gas volume. One such option would be sending the gas to the JHPDL pipeline, scheduled to be completed in 2019. This pipeline would allow for CBM/CMM delivery to large customers in the area like FCI, Sindri, Jamshedpur, Ranchi, and the Bokaro Steel Plant. Recent liberalizing of CBM pricing approved by the Cabinet Committee on Economic Affairs in 2017 allows for CBM/CMM to be sold at market driven rates. It remains to be determined the effect that the JHBDPL will have on local gas pricing; however, if the pipeline allows for the cheap transport of natural gas to cities and townships, then marketing gas directly to consumers would be a viable option.

BCCL is developing a similar CMM drainage project at the nearby Moonidih Mine, located just south of Pootkee Colliery, where it intends to install pre-drainage boreholes into coal seam XVI. In September 2018, the company tendered an offer to contractors requesting bids for a degasification job of the seam via any combination of long-hole directional drilling, surface drilling, and underlying strata drilling. The bidder would have to collect enough gas to feed a 2-megawatt (MW) generator capable of producing at least 1 million kilowatt-hours (kWh) of electricity per month.

7. Economic Analysis

7.1 Economic Assessment Methodology

The economic and financial performance of the proposed CMM drainage and utilization project were evaluated using key inputs discussed in the following sections of this report. A simple discounted cash flow model was constructed to evaluate project economics of CMM drainage and power sales. Key performance measures that were used for evaluating the project included net present value (NPV) and internal rate of return (IRR). The results of the analyses are presented on a pre-tax basis.

7.2 Project Development Scenario

Long directionally drilled boreholes were planned in advance of mains, gate roads, and longwall panels using the aforementioned mining schedule presented for the Seam XII workings through the year 2046. The spacing requirements for the in-seam boreholes were derived by comparing the time available for gas drainage based on the mining schedule (and directional drilling schedule) with the time required to reduce the residual gas content by 30 percent per the reservoir modeling results (Exhibit 13 and Exhibit 14).

This pre-feasibility study assumes that directional drilling will initiate in mid-2019 in panels PB-001 and PB-002, with mining of the panels beginning in 2020 and 2021, respectively. Based on the mining and drilling schedule, minimal drainage time is available, and a borehole spacing of 41.7 m and 83.3 m will be required for panels PB-001 and PB-002, respectively. Similarly, drilling at panel PB-003 will begin in mid-2020 with mining initiated in 2022, which necessitates a borehole spacing of 83.3 m. As directional drilling begins to outpace mining and more drainage time is available, borehole spacing increases, minimizing annual drilling requirements during the later years. Panels PB-004 through PB-027 are assumed to utilize borehole spacing of 125 m as shown on the drilling schedule in Exhibit 17. Overall, the Seam XII pre-drainage drilling plan requires a total of 50,400 m of drilling, with a total of 60 horizontal boreholes – all of which could be drilled from just 27 borehole collars.

Exhibit 17 also summarizes the projected annual gas collection pipeline requirements for the drainage plan proposed for the Project. It is assumed that 300 m of gathering pipeline will be needed as each panel is developed. As a result, a total of 8,100 m of gathering pipeline will be laid over the life of the Project.

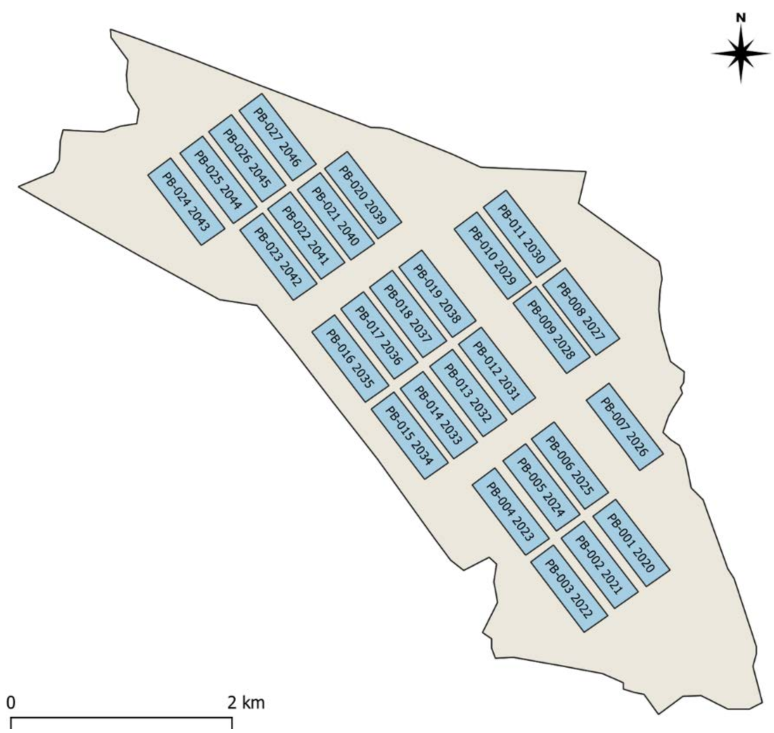

Exhibit 16: Conceptual Mine Layout and Development Plan for Seam XII at Pootkee Colliery

Panel	Year Drilled	Year Mined	Drainage Time (years)	Borehole Spacing (m)	Boreholes Per Panel	Meters Drilled	Gathering Pipeline Laid (m)
PB-001 2020	2019.5	2020	0.5	41.7	6	5040	300
PB-002 2021	2019.5	2021	1.5	83.3	3	2520	300
PB-003 2022	2020.5	2022	1.5	83.3	3	2520	300
PB-004 2023	2020	2023	3	125	2	1680	300
PB-005 2024	2021	2024	3	125	2	1680	300
PB-006 2025	2022	2025	3	125	2	1680	300
PB-007 2026	2023	2026	3	125	2	1680	300
PB-008 2027	2024	2027	3	125	2	1680	300
PB-009 2028	2025	2028	3	125	2	1680	300
PB-010 2029	2026	2029	3	125	2	1680	300
PB-011 2030	2027	2030	3	125	2	1680	300
PB-012 2031	2028	2031	3	125	2	1680	300
PB-013 2032	2029	2032	3	125	2	1680	300
PB-014 2033	2030	2033	3	125	2	1680	300
PB-015 2034	2031	2034	3	125	2	1680	300
PB-016 2035	2032	2035	3	125	2	1680	300
PB-017 2036	2033	2036	3	125	2	1680	300
PB-018 2037	2034	2037	3	125	2	1680	300
PB-019 2038	2035	2038	3	125	2	1680	300
PB-020 2039	2036	2039	3	125	2	1680	300
PB-021 2040	2037	2040	3	125	2	1680	300
PB-022 2041	2038	2041	3	125	2	1680	300
PB-023 2042	2039	2042	3	125	2	1680	300
PB-024 2043	2040	2043	3	125	2	1680	300
PB-025 2044	2041	2044	3	125	2	1680	300
PB-026 2045	2042	2045	3	125	2	1680	300
PB-027 2046	2043	2046	3	125	2	1680	300
TOTAL					**60**	**50400**	**8100**

Exhibit 17: Pre-Mining Directional Drilling Schedule and Gathering Pipeline Laid for Seam XII

7.3 Mine Methane Drainage Production Forecast

Gas production rates were derived for each in-seam borehole by considering the implementation schedule and the borehole spacing and denoting the corresponding gas production from the methane flow rate prediction curves presented in Exhibit 13. Exhibit 18 presents the annual methane production forecast from degasification of the Mine using the recommended methane drainage plan over the 27 year period between 2019 and 2045. The forecast predicts recovery of an average of 0.6 Mm^3 of methane per year.

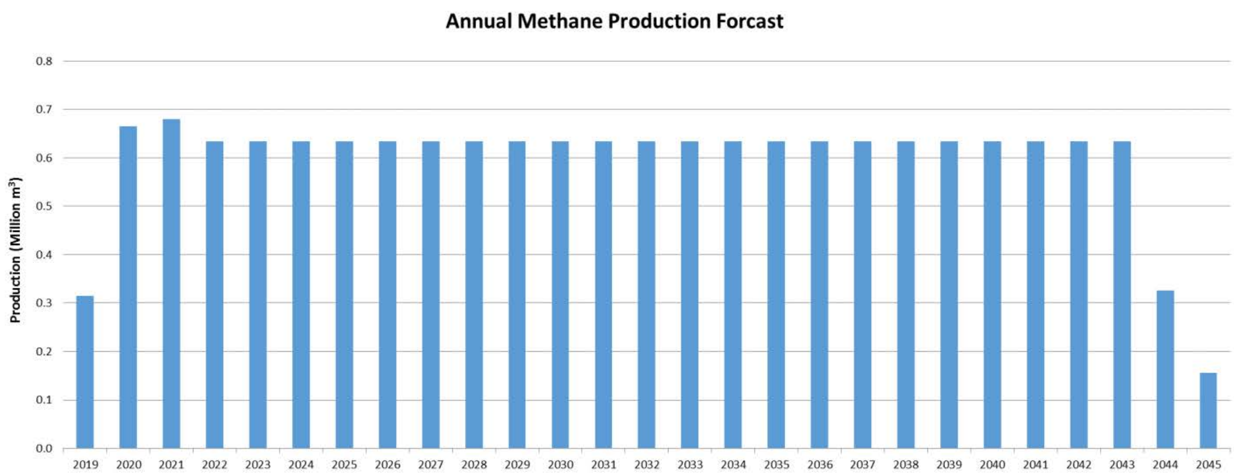

Exhibit 18: Methane Production Forecast for the Proposed Methane Drainage Plan for Seam XII

7.4 Economic Assumptions

Cost estimates were developed for goods and services required for the development of a CMM project at the Pootkee Colliery. These estimates were based on a combination of known average development costs of analogous projects in the region, and other publicly available sources. All economic results are presented on a pre-tax basis. The input parameters and assumptions used in the economic analysis are summarized in Exhibit 19. A more detailed discussion of each input parameter is provided below.

PHYSICAL & FINANCIAL FACTORS	Units	Value
Royalty	%	10
Price Escalation	%	3
Cost Escalation	%	3
Heating Value of Drained Gas	Btu/cf	928
Electricity Price	$/kWh	0.071
Generator Efficiency	%	35
Run Time	%	85
Global Warming Potential of CH_4	tCO_2e	25
CO_2 from Combustion of 1 ton CH_4	tCO_2	2.75
CAPITAL EXPENDITURES	**Units**	**Value**
Drainage System		
In-Seam Drilling Cost	$/ft	40
In-Seam Drilling Length	ft	165,312
Surface Vacuum Station	$/hp	1000
Vacuum Pump Efficiency	hp/Mcfd	0.035
Gathering & Delivery System		
Gathering Pipe Cost	$/ft	40
Gathering Pipe Length	ft	26,568
Contingency Fee (capex)	%	10
Power Plant	$/kW	1300
Development Fee	%	15
OPERATING EXPENSES	**Units**	**Value**
Field Fuel Use (gas)	%	5
Drainage System O&M	$/Mcf	0.1
Water Treatment/Disposal	$/Bbl	0.05
Power Plant O&M	$/kWh	0.03
Contingency Fee (opex)	%	10

Exhibit 19: Summary of Economic Input Parameters and Assumptions.

7.4.1 Physical and Financial Factors

Royalty

Under the permission granted by the Government of India (GoI) to BCCL, royalty at prevailing rates at par with payments required to be made for natural gas and as revised from time to time is to be paid by BCCL which at present are set at 10%.

Price and Cost Escalation

All prices and costs are assumed to increase by 3 percent per annum based on analogous projects in the region.

Heating Value of Drained Gas

The drained gas is assumed to have a heating value of 928 Btu/cf. This is based on a heating value of 1,020 Btu/cf for pure methane adjusted to account for lower methane concentration of the CMM gas, which is assumed to be 91 percent for drained gas in the Pootkee Colliery area.

Electricity Price

According to the most recent data available (2017-18), BCCL's average purchase price for electricity was $0.071/kWh (BCCL Annual Report 2017-18).

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 (USEPA, 2011). For the proposed power project an electrical efficiency of 35 percent and an annual run time of 85 percent, or 7,446 hours, were assumed.

Global Warming Potential of Methane

A global warming potential of 25 is used. This value is from the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC, 2013).

Carbon Dioxide from Combustion of Methane

Combustion of methane generates carbon dioxide (CO_2). Estimating emission reductions from CMM projects must account for the release of CO_2 from combustion when calculating net CO_2 emission reductions. For each ton of CH_4 combusted, 2.75 tCO_2 is emitted, resulting in a net emission reduction of 22.25 tCO_2e per ton of CH_4 destroyed.

7.4.2 Capital Expenditures

Capital expenditures include the cost of horizontal pre-drainage boreholes, as well as surface facilities and vacuum pumps used to bring the drainage gas to the surface. The drained methane can be used to fuel 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 major input parameters and assumptions associated with the project are as follows:

Borehole Cost

In-seam borehole costs are estimated at $40 per foot ($131/m) with a total of 165,312 ft (50,387m) drilled.

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 per thousand standard cubic feet per day (Mscfd) are assumed. 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).

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:

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 ($131/m) and 26,568 ft (8,100 m) of gathering lines.

The delivery system consists of the satellite compressor and the pipeline that connects the compressor to the sales system leading to the utilization project. We assume the power plant is located within the mine area resulting in a delivery system cost of zero.

Power Plant Cost Factor

The power plant cost factor, which includes capital costs for gas pretreatment, power generation (including combustion engines), and electrical interconnection equipment, is assumed to be $1,300 per kilowatt (kW).

CAPEX Contingency Fee

A 10 percent contingency is fee is added for unforeseen additional costs.

Development Fee

A fee is included to account for the cost of project development including staff costs, equipment, office space, transportation, and other resources necessary to plan and develop the project. The fee is estimated at 15 percent of the cost of the power plant based on experience in the field.

7.4.3 Operating Expenses

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 5 percent, which is deducted from the gas delivered to the end use.

Drainage System Operating and Maintenance Costs

Operating and maintenance costs for vacuum pumps and compressors associated with in-mine horizontal pre-drainage boreholes are assumed to be $0.10/Mscf.

Water Treatment/Disposal

The cost associated with water treatment and disposal is $0.05/Bbl.

Power Plant Operating and Maintenance Cost

The operating and maintenance costs for the power plant are assumed to be $0.03/kWh.

OPEX Contingency Fee

A 10% contingency is fee is added for unforeseen additional costs.

7.4.4 Economic Results

There are two different economic scenarios evaluated in this study as shown in Exhibit 20. The two are differentiated by whether the mine will absorb the operational costs of the drainage system or not. The first scenario is the power plant only scenario and in this project scenario, the costs of the gas drainage system will be absorbed by the mining operation as operational costs. Higher NPV and IRR values are present in the power plant only scenario because of this cost absorption. It is also important to note that in the power plant only scenario, the cost of gas purchased is not included. It is assumed that the mining operation will provide the CMM for free to the power plant. Should the mining operation wish to internalize the price of gas as a revenue and charge a fee, then the power project would need to show a cost of gas purchased as an operating cost, which would likely reduce the IRR's.

In the second scenario, the gas drainage system costs are not absorbed by the mine operation. The gas drainage system involves in-seam directional drilling of horizontal pre-drainage boreholes, which adds to the cost of the project and decreases returns. Max power plant capacity and net CO_2e reductions are the same for both project scenarios because those values are largely reliant on the quantity of gas production, which is the same for the different project scenarios because the same two development scenarios are used to calculate results from the two economic scenarios. The discount rate used for all NPV calculations in the results tables is 10 percent.

Development Scenario	Max Power Plant Capacity (kW)	NPV-10 ($,000)	IRR (%)	Payback (years)	Net CO_2e Reductions (tCO_2e)
Power Plant (only)	260	372	18%	6.0	188,374
Power Plant and Drainage System	260	-4,557	na	na	188,374

Exhibit 20: Summary of Economic Results (pre-tax)

8. 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 Pootkee Colliery. The project as proposed will use long in-mine horizontal boreholes to drain methane in advance of mining, and to utilize the drained gas to generate electricity for on-site consumption. The analysis performed reveals that methane drainage using long in-mine horizontal boreholes 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.

As the analysis shows, pre-drainage using long, directionally drilled horizontal boreholes can effectively lower the residual gas content of coal seams prior to future mining. As proposed in this study, the CMM project at the Pootkee Colliery is anticipated to reduce emissions of methane by more than 188,000 tonnes of carbon dioxide equivalent (tCO_2e) over the 27-year life of the project.

The next step in proceeding forward is a full feasibility study, which, at a minimum, should be prepared before any investment decision is made. To prepare a full feasibility study, USEPA recommends the following next steps:

- Conduct a detailed engineering study, conduct additional monitoring of gas drainage and ventilation to provide a robust data set on which to evaluate project feasibility and identify important data gaps with respect to gas drainage and mine ventilation data and address;
- Secure additional geologic data to develop a more accurate gas resource assessment;
- Further refine the reservoir simulation and gas production forecast based on newly available or revised data;
- Contact drilling contractors to obtain estimates of drilling costs for directional drilled boreholes;
- Conduct additional market research and investigate more thoroughly all utilization options including power production to confirm the economic and technical feasibility of CMM-to-power and the viability of alternatives and their competitiveness with power generation;
- Conduct outreach to suppliers of equipment and services and compile equipment pricing, terms of sales and product specifications;
- Scope out engineering and construction requirements for the CMM plant;
- Develop a detailed project development and implementation schedule and determine internal costs for project development;
- Refine the financial analysis and develop a detailed project-specific model sufficient for internal or external financing entities.

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