U.S. EPA Coalbed Methane Outreach Program

Pre-feasibility Study for Coal Mine Methane Recovery and Utilization at Naryn Sukhait Mine

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PRE-FEASIBILITY STUDY FOR COAL MINE METHANE RECOVERY AND UTILIZATION AT NARYN SUKHAIT MINE

In Support of the Global Methane Initiative

Sponsored by: US Environmental Protection Agency, Washington, DC USA

Prepared by: Raven Ridge Resources, Incorporated

March 2013

Global Methane Initiative

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Acronyms and Abbreviations

CES	Central Energy System
CMM	Coal mine methane
CO_2e	Carbon dioxide equivalent
DAF	Dry ash free
GIP	Gas In Place
GMI	Global Methane Initiative
IRR	Internal Rate of Return
km	Kilometer
kV	Kilovolt
kWh	Kilowatt hour
LNG	Liquefied Natural Gas
m	Meters
m^3	Cubic meter
MAK	Mongolyn Alt Corporation
MCM	Million cubic meters
md	Millidarcy
MJ	Megajoule
Mpa	Megapascals
MW	Megawatt
MWh	Megawatt hour
NPV	Net Present Value
p10	Indicates a 10% chance that forecast will be ≥ to the p10 amount
p50	Indicates a 50% chance that forecast will be ≥ to the p50 amount
p90	Indicates a 90% chance that forecast will be ≥ to the p90 amount
t	Metric ton
MNT	Tugrik, Mongolian currency
USD	United States Dollar
USEPA	United Stated Environmental Protection Agency
VAT	Value Added Tax
VER	Voluntary Emission Reduction

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Executive Summary

With funding from USEPA, under the auspices of the Global Methane Initiative (GMI), Raven Ridge Resources, Incorporated performed a prefeasibility study examining the potential for employing vertically drilled wells to capture methane gas prior to mining for use as fuel to generate power at the Naryn Sukhait open cast coal mine. The Naryn Sukhait coal mine is located in remote southwestern Mongolia in the Gurvantes district of Ömnögovi Province, just 57 kilometers north of the Mongolian – Chinese border. The Naryn Sukhait mine, owned by Mongolyn Alt (MAK) Corporation is bordered by the Ovoot Tolgoi Complex, operated by South Gobi Resources. These mines are situated in a foreland basin filled with Mesozoic coal bearing sediments. The rank of the coal is high volatile C bituminous rich in vitrinite macerals, causing this coal deposit to be a significant source of methane with a high potential for storing gas. Gas desorption testing demonstrated that gas is present in depths as shallow as 150m and will be released to the atmosphere as surface mining takes place unless a program for draining gas prior to mining is adopted by mine operators. The coal basin in which the Naryn Sukhait deposit is located is similar to the Raton Coal basin located in the southwestern United States. Using information and data from this coalbed methane producing basin, Raven Ridge developed production profiles to forecast water and gas production and estimate the proposed pilot project could produce enough gas to fuel an 8.55 MW power generation facility. The capital costs are estimated to be $7.7 million USD with an IRR of 16.1 percent and a payback period of 6.75 years. Carbon emissions would be reduced by 187,900 tonnes over the project's 15 year life.

Introduction

This document reports the findings of a pre-feasibility study that was conducted as part of a larger initiative funded by the USEPA. This initiative supports USEPA's efforts under the Global Methane Initiative (GMI).

This work was conducted with the cooperation of Mongolyn Alt (MAK) LLC of Mongolia.

The present study is the result of investigations that entail:

- field visits to the mine;
- translation and review of technical documents;
- forecast of production based on statistical analysis of surface mine methane drainage; and
- economic analysis based on current energy markets and quotes from vendors.

Naryn Sukhait coal mine is MAK's flagship operation. The mine is located in Ömnögovi aimag (province) in southwestern Mongolia (**Figure 1)**. Groundbreaking for overburden removal at Naryn Sukhait started in December of 2007 and shipment of coal commenced in May of 2008. Minable coal resources estimated to be contained by Coal Seam 5 are 225 million metric tons from surface to -150m depth throughout the licensed area. Open pit production capacity is 3 million metric tons per year and is expected to increase to 5-8 million tons per year upon installation of a railway system to transport coal.

Location

The Naryn Sukhait coal mine is located in the Gurvantes district of Ömnögovi Province in southwestern Mongolia, just 57 kilometers north of the Mongolian – Chinese border as shown below in **Figure 1**. The mine is located in the remote south Gobi Desert and is accessible through travel by road or flying into the private Obooto Hural Northwest airport.

The Naryn Sukhait mine is bordered by the Ovoot Tolgoi Complex, operated by South Gobi Resources. The mines share the western, eastern and southern boundaries of the MAK mining area. The Chinese border crossing town of Ceke, shown to the south of the mine in **Figure 1**, is the main distribution center for the coal produced at both Naryn Sukhait and Ovoot Tolgoi.

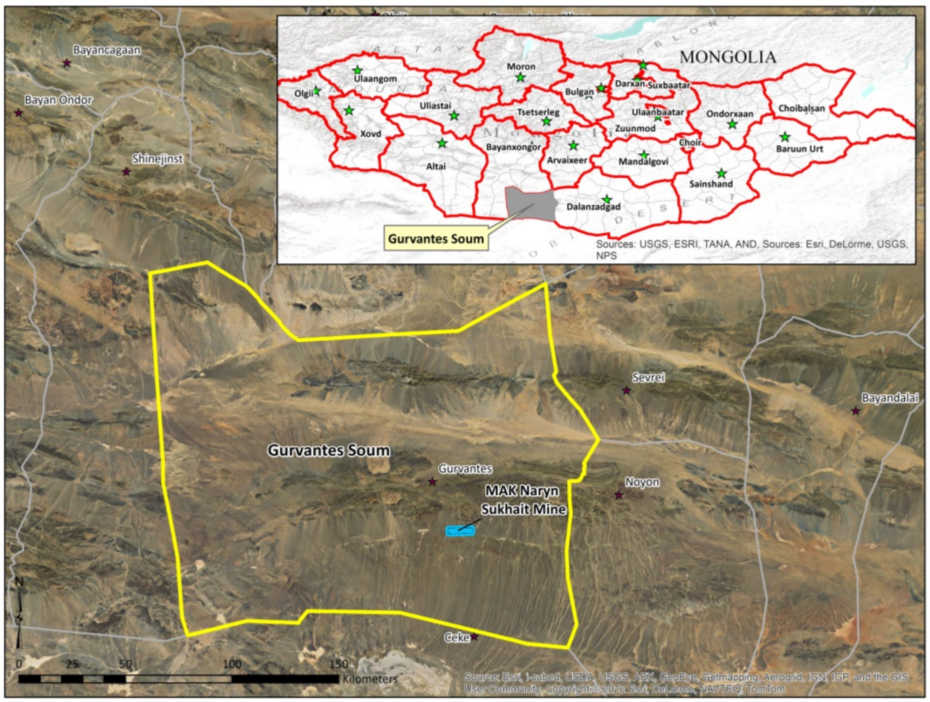

Figure 1: Overview Area Map

Background on Regional Geology

Extensive field studies conducted in Mongolia and North China have resulted in mapping large scale geologic features that provide clues to tectonic controls on evolution of depositional systems, burial history and subsequent deformation and collapse of basins where important coal deposits are found.

Many of these studies have been conducted and published describing the structural evolution of the Central Asian Orogenic Belt, the geologic terrain that comprises Precambrian and lower Paleozoic strata. In some locales, these strata have been subjected to episodes of plutonism and extreme deformation (Windley, et al 2007). Preserved structures bearing witness to this tortured history are the complexly folded, faulted, and in places, intensely metamorphosed stratigraphic sequences that host deposits of strategic minerals, oil and gas, and coal.

The Naryn Sukhait coal mine is situated in this complex geologic terrain. The mining property sits north of an extensive thrust fault system that roughly parallels the Mongolian border (Hendrix et al, 1996). The thrust front is evidence of a late Paleozoic intercontinental collision zone known as the Tian Shan suture and an element of the Tian Shan-Yin Shan suture (Heumann et al, 2012). During Permian time, well defined volcanic arcs formed which are recognized by the occurrence of thick accumulations of volcanic and volcaniclastic rocks. Remnants of these island arc eruptive and intrusive complexes are preserved as volcanic outflow facies and shallow intrusive rocks lying to the north of Naryn Sukhait. In the Late Jurassic, asymmetric basins formed in the East Gobi in response to what appears to have been wrenching and continental rifting along a north east southwest axis athwart the structural strike of the Tian Shan thrust front. Foreland-style basins lie on the flanks of the foundered volcanic arcs eventually filled with thick wedges of fluvial and lacustrine sediments derived from the adjoining highlands. The Naryn Sukhait coal and accompanying clastic sediments were deposited in such a foreland-style basin. Foreland basins characteristically form on the stable craton at the margins of a continent. In this case, a basin formed on the edge of a newly consolidating basin (Hendrix et al, 1996) in the early Mesozoic and continued to fill with sediment until the basin collapsed during the next stage of widespread deformation. The sedimentary basin filled with alternating beds of coarse and fine-grained clastic rocks and coal seams. Deformation of the sediment filled basin occurred in at least two episodes, the first during basin collapse occurring in Late Jurassic and the second during the Late-Cenozoic deformation associated with the collision of the Asian and Indian subcontinent.

Coal Bearing Strata of the Naryn Sukhait Area

MAK provided unpublished Mongolian language manuscripts documenting work that he and his team conducted on the lithology and paleontology of the coal bearing strata occurring in the area surrounding the coal mine. This work provides conclusive evidence that these strata were deposited during the Jurassic Period and can be subdivided into recognizable and mappable packages. Although the formation names have yet to be formally adopted, it is clear from satellite imagery that these units are extensive and traceable over a broad area. The geologic strata containing mineable coal reserves at the Naryn Sukhait mine range in age from Early to Middle Jurassic. Baatarhuyag's stratigraphic column shown in **Figure 2** depicts and describes the rock units that comprise the stratigraphic packages that were deposited in the Naryn Sukhait area. The Cretaceous strata that overlies the Jurassic sediments remains undifferentiated into subunits and is not named.

Baatarhuyag breaks the almost 300 meter thick Jurassic stratigraphic package into two coal bearing sequences informally named the Naryn Sukhait and MAK formations. Fossils taken from coals seams and intervening strata conclusively prove that these formations can be differentiated based on time of deposition. The formations exhibit striking differences in the lithologic makeup and overall coloration. The lowermost formation, the Naryn Sukhait, contains the most important mineable resource, Coal Seam 5. The MAK formation contains the bulk of the mine's coal resources, but these beds are generally thinner and become more discontinuous in the upper portion of the formation. Sandstone and siltstone strata deposited in higher energy environments separate Coal Seam 5 and coal seams 6 through 13.

Erdensogt (2009) states that Jurassic coal samples collected from coal deposits in Mongolia tend to be petrographically distinct from their Permian counterparts as they have higher vitrinite maceral content. Based on research conducted on high volatile B and C bituminous coals during the last three decades, it is now generally recognized that high vitrinite maceral content correlates with increased gas storage. Due to the increased gas storage capacity of high volatile bituminous coalbeds, coal miners in other parts of the world have had to deal with unwanted and dangerous gas emissions into workings where this rank of coal is extracted. The rank of the coal at the Nahryn Sukhait mine is high volatile C bituminous.

Johnson and others, (2003) have shown that the lower to middle Jurassic coal and coaly mudstone analyzed from samples taken in the South Gobi are important source rocks for hydrocarbon generation. These rocks contain type III and IV kerogen derived from vitrinite macerals which are prevalent in the bright coaly components of the Naryn Sukhait and MAK formation strata. These kerogen types tend toward hydrocarbon gas generation and based on the thermal maturation studies performed on the sediments contained in the foreland basins of the south Gobi, these coal bearing strata are still well within an active hydrocarbon generation stage. Clearly, the coalbeds and surrounding strata occurring at Nahryn Sukhait present the potential for generation and storage of hydrocarbons.

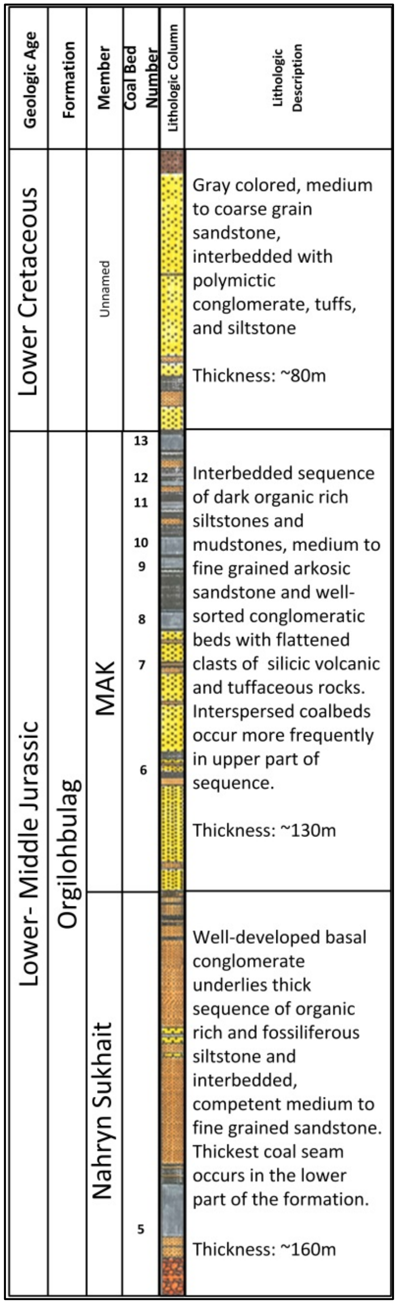

Figure 2: Stratigraphic Column

Mineable coal resources occurring in Coal Seam 5 were estimated using information supplied by MAK. Whereas detailed information exists for all coal occurrences lying within the eastern portion of the property, less detailed information exists for the geologically more complex western portion of the mining property. However, MAK has constructed 10 less detailed cross-sections that depict Coal Seam 5 mineable coal resources for mine planning purposes, with the extent of coverage shown on **Plate 1**. These cross-sections also include pit profiles depicting various phases of the development and the final depths to which open pit mining will extend. Since these are available for the entire property they were used to estimate the coal resource. These cross-sections are constructed such that the line of section is directly down dip, thus reducing the distortion that would occur if the section was constructed along a line oblique to the bedding dip. **Figure 3** is an example cross-section used in the coal resource calculations. AutoCAD™ was used to measure the cross-sectional area of the coal seam depicted on each of the cross-sections, segregated into 100 meter vertical intervals so that the team could apply the proper gas content value in the gas resource calculations discussed in the **Gas Resources** section of this report. Coal volumes were computed by taking the measured cross-sectional area of the coal, multiplying by the distance lying between the sections and dividing the product by two. The end section area calculations were arbitrarily limited to an up-dip depth of -150m and a down dip to depth of -450m. These limits comprise the limits of the coal resources that are likely to contain gas that will migrate up dip and be lost to the atmosphere if not pre-drained and used prior to dewatering and strata relaxation that will occur during the mining process.

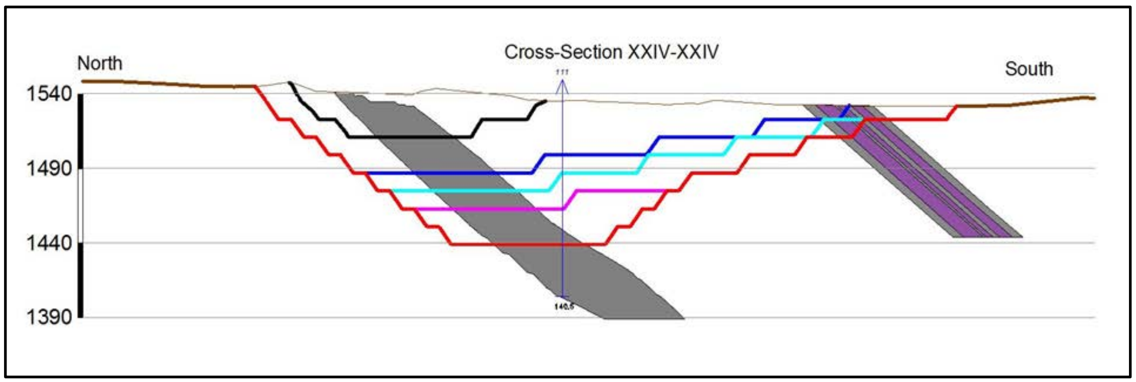

Figure 3: Example Cross-section Used in Coal and Gas Resource Calculations

The in-place coal resource mass (tonnage) was estimated by multiplying the volume of the coal by the density factor supplied by MAK. The values reported as coal resource include not only the coal, but the ash contained in partings or as finely distributed non coal material. In other words, the actual coaly material that is extracted for supplying customers will later be separated by washing or some other method to provide the customer with a suitable product. The average density of coal extracted from Coal Seam 5 is 1.4 metric tons per cubic meters. The results of these calculations are shown in **Figure 4**. The cumulative Coal Seam 5 resources calculated between -150m and -450m is 253.05 million tonnes.

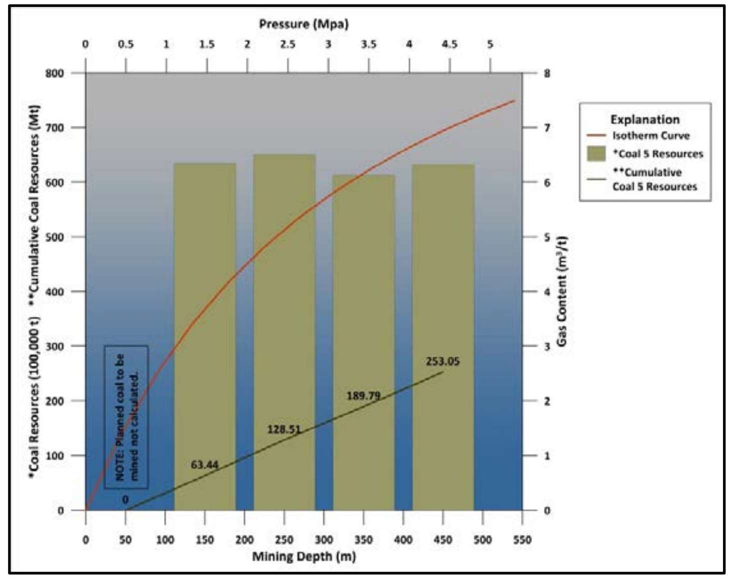

Figure 4: Calculated Coal Resources Shown by Depth, with Equilibrium Moisture Adsorption Isotherm

COAL RESOURCES

Testing conducted in the months of June, July and December of 2012 shows the presence of gas in coal seams being mined at Naryn Sukhait. Desorption tests were conducted in the field using equipment supplied by the Mongolia Nature and Environment Consortium during exploration drilling campaigns conducted in June and November. The results of the desorption tests are shown in **Table 1**, below with the location of these samples shown on **Plate 1**.

Table 1: Desorption Test Results

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

Adsorption testing was conducted at the Xi'an Research Institute of China Coal Technology & Engineering. Results from the testing were used to estimate the amount of gas that may be present and will otherwise be released during mining. Results of this test are shown in **Figure 5.**

The coal resource estimate described in the previous section served as the basis for calculating in-place gas resources at the Naryn Sukhait mine. A widely accepted way of estimating the gas resource associated to the coal is to multiply the coal mass by the gas content; however, other than the desorption testing conducted by the Raven Ridge team in 2012, verifiable in situ gas content measurements are not available for the Naryn Sukhait mine. A 2005 press release concerning work conducted by Storm Cat, a coalbed methane exploration and development company, reports drilling 12 stratigraphic tests at the Naryn Sukhait area. The coal strata were subjected to testing, and Storm Cat reports that the gas content of the coal seams ranged from 2.4 – 11.8 cubic meters per metric ton (Storm Cat, 2005).

Unfortunately, Storm Cat did not file maps, logs or other data with the Mongolian Petroleum Authority, so it is not possible to determine if these boreholes were drilled within the subject area of this report. Nevertheless, the maximum gas content value reported by Storm Cat is greater than the maximum used in this study.

A methane adsorption isotherm test was conducted to provide a broader frame of reference in which the results of the in situ gas content desorption testing could be evaluated. The adsorption test was conducted on a coal sample taken from corehole M12-284B (**Plate 1**) that penetrated Coal Seam 5. An adsorption isotherm mathematically describes the relationship between pressure and gas capacity under equilibrium conditions at a stable temperature representing the reservoir temperature of the coal seam at the depth of the sample. The Raven Ridge team recognizes that this adsorption isotherm indicates the gas capacity of one sample taken from the Coal Seam 5 and may not accurately depict the situation for other coal seams. However, the rank and coal quality of other samples analyzed by MAK as indicated by calorific value, carbon content, volatile matter and ash content are similar. Therefore, it is assumed that the isotherm may be broadly indicative of the gas capacity of Coal Seam 5 within the Naryn Sukhait mine.

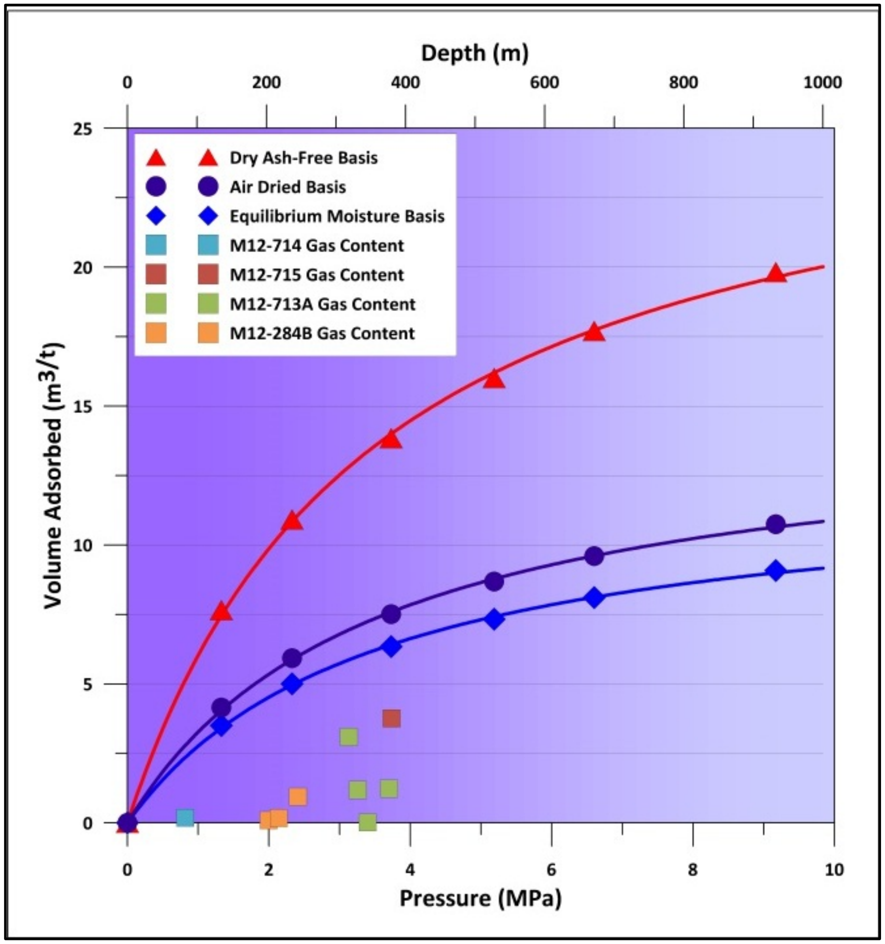

Figure 5: Adsorption Testing Results

For the purposes of this study, the team converted pressure into depth by assuming a normal hydrostatic gradient. The curves shown on **Figure 5** relate gas content of the coal sample to the expected content at a given mining depth. The red curve has been adjusted to reflect the gas capacity for the coal on a dry, ash free basis, allowing the results of this test to be compared to any other isotherm conducted on a coal sample from anywhere in the world. Ash content data is not readily available for the explored extent of Coal Seam 5 so the estimate of the coal resources and the gas resources is done on an uncorrected basis.

Therefore, for the purposes of this study the blue curve is considered to best represent the gas capacity of coal as it predicts the gas content at equilibrium moisture conditions without correcting for ash content. In other words, in order to represent the in situ conditions of the coal seam we used the gas content values reported on an as received-equilibrium moisture basis, thus accounting for the diminished gas content associated with the contained ash. In situ gas content measured from the field desorption tests are depicted by the colored squares beneath the lowermost isotherm curve in **Figure 5**.

As with the selected adsorption isotherm curve, the desorbed gas values are representative of raw conditions and not corrected for moisture and ash content. In situ gas content of the samples ranges from almost zero to a little over three standard cubic meters per ton, but as can be seen in **Figure 5**, the isotherm curve predicts substantially higher values.

As described in the **Coal Resources** section and related to coal resource calculations, the Raven Ridge team calculated the tonnage present in Coal Seam 5 at 100 meter depth intervals ranging from -150 to -450m below the surface. In order to estimate gas in place (GIP) contained by Coal Seam 5 within each depth interval, the coal resource contained therein was multiplied by a probability distribution representing the range of gas content values obtained from the adsorption isotherm and desorption tests.

The resultant estimates of GIP per depth interval, -150m -250m -350m and -450m, are shown in light orange on **Figure 6**. The total estimated GIP is 728.98 million cubic meters (MCM); the percentage of cumulative volume of the estimated GIP that each interval contributed is depicted by the yellow ribbon.

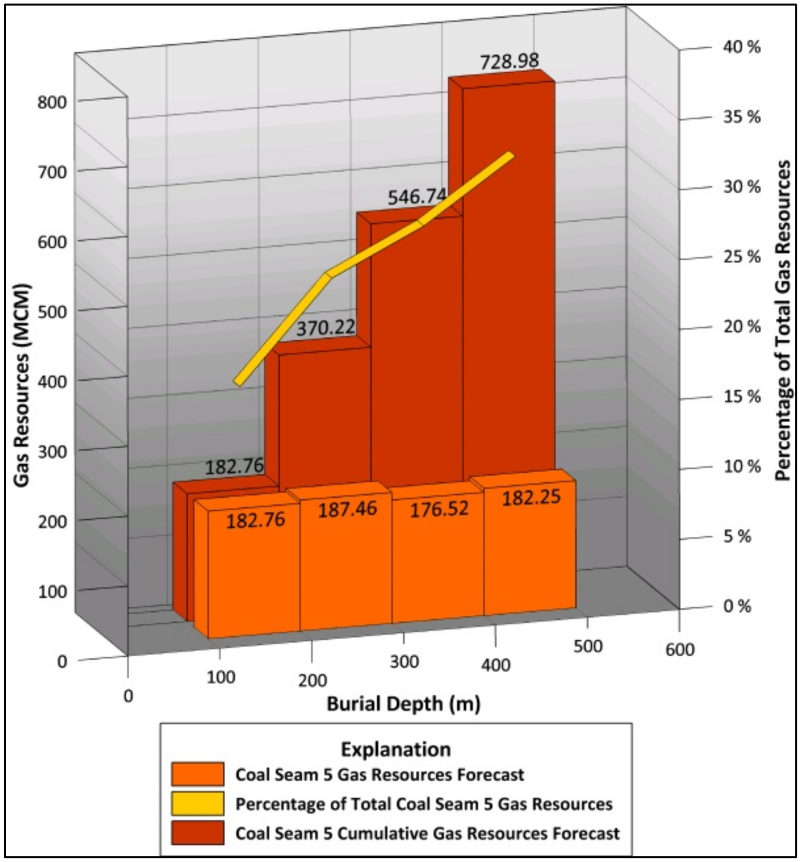

Figure 6: Estimated GIP by Depth Interval, Coal Seam 5

Figure 7 charts the probability based estimate of the GIP for each of the P10, P50, and P90 percentiles. The probabilistic approach to estimating the GIP takes into account the uncertainty of the gas content values of Coal Seam 5. The chart shows that the range in total GIP between the p90 to p10 gas resource forecasts is 505.61 – 954.88 MCM. The Raven Ridge team selected to use the p50 GIP resources estimate, totaling 728.98 MCM, because this is the mean and most likely value within the probability based estimate.

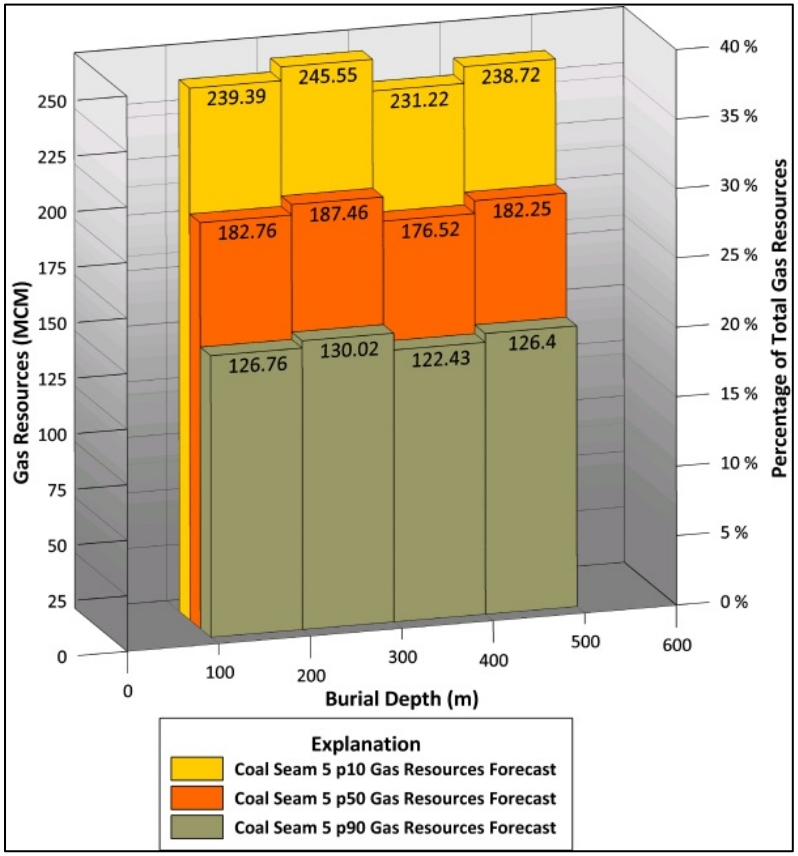

Figure 7: Probability Based Estimate of GIP by Depth Interval, Coal Seam 5

Coal Market

Mongolia has vast coal resources, occurring within 15 large-scale coal bearing basins. Within these basins are 80 well defined coal deposits and 240 coal occurrences according to the Geological Information Center of Mongolia. Total geological coal resources are estimated at approximately 150 billion metric tons (Tulga, 2009). Given Southern Mongolia's vast coal resources, sales of coal over the next decade or so are likely to be constrained by the extent of demand rather than by coal supply. The Naryn Sukhait coal deposit contains two mines, one owned and operated exclusively by MAK and another operated as a joint venture between MAK and the Chinese company Qinhua (Qinhua-MAK). Because of the remote location of the mine and lack of need within the immediate local market, the mines currently truck approximately two million metric tons of coal per year to the Chinese border at Ceke (World Bank, 2009).

China's domestic coal production and transport capacity has strained to keep pace with demand in recent years and as a result, China has been transformed from a net coal exporter into the world's largest importer, with net imports reaching 168 million metric tons, or 4.8 percent of total consumption on a physical quantity basis, and over five percent on a heating value basis in 2011. China has historically produced its own coking coal; however, growing demand for coking coal due to a rapid increase in steel production has led to demand for imports from Australia and Mongolia. In 2008, Mongolia supplied over half of China's coking coal imports. Though thermal power generation has been the most important driver for coal industry expansion in China, accounting for approximately half of total consumption in recent years, imports are consumed primarily in the southern and eastern coastal cities. Thus, the market for exports of thermal coal from Mongolia to China is not as significant, and in the future will be dependent on the particular grades of coal, the costs of transport, and the prices of coal and electricity within China.

Through the National Development and Reform Commission, the Chinese central government tightly controls most electricity wholesale prices and all wholesale, transmission and retail sales prices. Rapidly escalating coal costs have frequently put pressure on the electricity cost structure, with generators bearing the brunt of the burden in the absence of a mechanism to pass the increases onto grid companies and their end-users. Reforms to the pricing system – including competition among generators and separation of thermal tariffs into capacity and dispatch components, differential peak and off-peak pricing, among others – have been discussed or attempted on an experimental basis in isolated locations.

The World Bank reports three possibilities for development of a market for export of thermal coal from Southern Mongolia: possible increases in the price of electricity in China; possible exports beyond China; and conversion of coal into electricity in Mongolia, to support exports of electricity.

It may be possible to realize higher prices for Mongolian coal by exporting to Japan and Korea, or other international markets. This would depend on the price of rail freight through China or Russia.

Exporting electricity to China is another option for utilization of Mongolian thermal coal. The Mongolian Government has sought to develop a 3,600 MW power plant and transmission line at Shivee Ovoo, a coal mine in the central province of Govisümber, to export electricity to China (World Bank, 2009) with a memorandum of understanding in place with China's State Grid Corporation (IEEJ, 2012). Additional plants could be profitable as it is cheaper to export coal as electricity than by rail freight.

Mongolia's installed power capacity is 1,062 MW; however, only 836 MW (80 percent) is available due to aging power plants operating under capacity. Mongolia's electricity transmission network connects approximately 70 percent of the country's population, but is considered unreliable, causing frequent blackouts in major cities due to aging infrastructure. Coal accounts for 73 percent of Mongolia's energy consumption (IEEJ, 2012). Electricity demand has increased at an average annual rate of 2.9 percent since 2005, a trend that is expected to continue through 2020.

Mongolia's main electricity grid is the Central Energy System (CES) which covers 80 percent of Mongolia's electricity supply and includes five coal-fired power plants and an interconnection with Russia for import of electricity. Demand in the CES is expected to rise, reaching maximum import capacity from Russia of 255 MW (IEEJ, 2012). Increased imports from Russia are not considered an option for meeting demand as the Mongolian government is concerned about supply security risks attached to reliance on Russian imports as well as the increased expense of Russian electricity.

A large part of economic growth in coming years will be created by new mining developments concentrated in the southern province of Ömnögovi. These gold, copper, and coal mines will continue to rapidly increase electricity demand in Southern Mongolia, with consumption reaching 294 MW in 2012 and 650 MW by 2020 (World Bank, 2009). **Figure 8** shows the rise of energy demand in both the CES and South Gobi Areas.

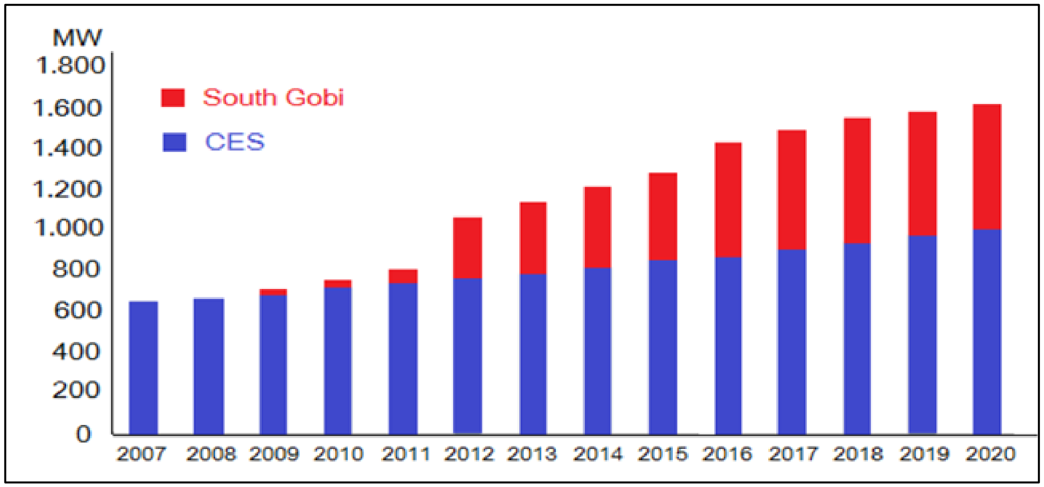

Figure 8: Mongolia's Energy Demand in the CES and South Gobi Areas (IEEJ, 2012)

Residential electricity demand in Southern Mongolia is small compared to the electricity demands of the mines. Because of the electricity demand created by the mines of Southern Mongolia, most of them generate their own electricity, including Naryn Sukhait. MAK plans to construct a 35kV interconnection from Naryn Sukhait to the Chinese grid in order to import electricity to meet growing demand. Production of additional electricity from CMM for onsite use is attractive provided regulatory and ownership barriers are overcome.

Mongolia has two ministries that control mining operations. The Ministry of Mining, which includes the Mining Authority and the Petroleum Authority, controls some coal mines while the Ministry of Energy maintains dominion over others, including Naryn Sukhait's resources. The Ministry of Energy has asserted that permission is required to explore for CMM resources; however, it is unclear at present how coal licenses are to be coordinated with gas production sharing contracts (PSCs) made through the Petroleum Authority. It is also unclear which environmental and safety regulations apply to CMM projects.

Despite undeveloped CMM exploration and licensing policies, Mongolia has several laws and resolutions that favor foreign investment in CMM projects. For instance, under the 1993 Law on Foreign Investment, an investor may request a stability agreement providing the investor a legal guarantee for a stable fiscal environment and protection from changes in taxation policy for 10 to 15 years. In addition, Parliament Resolution #140 (June 2001) includes oil and gas production and pipeline construction as “favored industries” for foreign investment. Mongolia’s Department of Fuel Regulation Policy has outlined various development goals which include extraction of petroleum products from coal (Ganbaatar, 2005).

Mongolia’s tax policy also appears to be favorable towards CMM project development. Materials and equipment necessary to conduct petroleum operations that are imported by contractors are exempt from customs taxes, value added taxes, and excise taxes. Contractors’ earnings from petroleum shares are exempt from income taxes.

Gas Production Forecast

Future gas production can be predicted using several approaches, the most common are: basing future production on actual past production of wells in the field being studied; reservoir simulation modeling using early production and/or geologic and engineering data acquired through field testing; or using production profiles from wells that were drilled in areas exhibiting similar geologic and reservoir conditions. There is no active coalbed methane production in Mongolia, and sufficient information was not available to allow reservoir simulation modeling; therefore, in order to develop gas production profiles for this project, an analogous field to the Naryn Sukhait Mine property with developed coalbed methane production was identified and used for production profile modeling. The coals of the Raton Formation along the western margin of the Raton Basin in south-central Colorado are similar in rank and depth to those found at Nahryn Sukhait, have comparable gas contents, and have been exposed to similar tectonic activities during its depositional history. The Raton Basin is an asymmetrical trough, a foreland basin, characterized by a steeply-dipping western limb intersected by thrust faulting and associated local areas of high folding with some overturned beds. The Upper Cretaceous through Paleocene Raton Formation is composed of interbedded sandstones, siltstones, and carbonaceous shales, with numerous coal beds ranging in total thickness from 3 to 20 meters, and gas contents ranging from 0.7 to 6.1 cubic meters per ton (Hemborg, 1998). The rank of the coals generally vary from medium to high-volatile bituminous, with localized areas containing higher rank coals due in part to a combination of deep burial during the Pliocene and their proximity to intrusions.

There is a long history of coalbed methane development in the Raton Basin with extensive production from the coals of the Raton Formation from which the Raven Ridge team developed a distribution of production profile outcomes (p10, p50, p90) for all the producing wells with similar characteristics. From this distribution, the p50 gas production profile and the associated water production was used in the economic analysis (**Figure 9**).

Pre-mine drainage is the only viable option for capturing and using gas that would otherwise be released during mining. Therefore the Raven Ridge team proposes drilling 12 vertical wells from which gas will be drained from the down dip extent of the planned mining area. The proposed wells are drilled on centers at 642 meter spacing between wells, providing for a drainage area of approximately 32.4 hectares. Locations for these proposed wells are shown on **Plate 2**. **Plate 3** is an example cross section showing the proposed placement of borehole RRR-09; the location of section, A-A', is delineated on **Plate 2**. The borehole placement with respect to the outcrop of Coal Seam 5 and the mining pit profile is also shown.

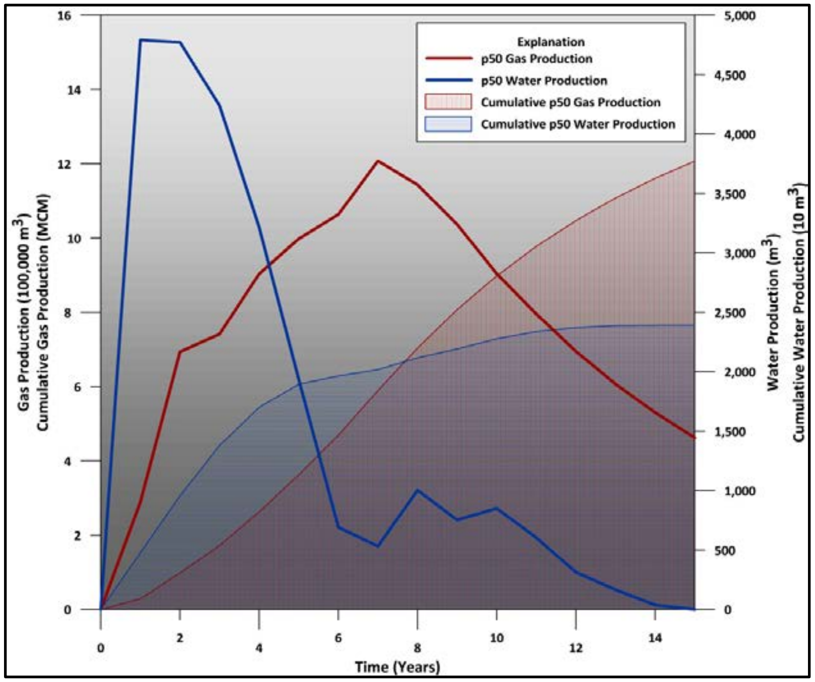

Figure 9: Gas and Water Production Forecast Based on p50 Decline Model

Original GIP was calculated for the presumed drainage area of approximately 32.4 hectares chosen to match the drainage area of 80 acres used as the spacing of the Raton Basin wells modeled for this study. In order to estimate GIP contained by Coal Seam 5 within the chosen drainage area, the RRR team multiplied the coal resource contained therein by a probability distribution representing the range of gas content values obtained from the adsorption isotherm and desorption tests. In order to validly represent the potential gas content of the coal seam, the probability distribution was constructed incorporating the potential range of values that may be encountered under in situ conditions. All of the field desorption tests resulted in measurement of in situ gas content values less than that predicted by the isotherm, suggesting that for at least in the areas and the depths that were sampled, Coal Seam 5 is gas undersaturated. In order to represent the in situ conditions of the coal seam we used the gas content values reported on an as received-equilibrium moisture basis, thus accounting for the diminished gas content associated with the contained ash. The gas resources estimated for the coal drained by the proposed 12 well program are 204.1 million cubic meters, and the forecasted drainage efficiency for the p50 percentile class is 57 percent, as shown in **Table 2**.

Table 2: Forecast GIP for Proposed Pre-mine Drainage Well Locations

Percentile Class	p90	p50	p10
GIP per 32.4 hectare well location	5,639,982	12,073,142	18,043,670
Potential Drainage Efficiency	37%	57%	85%

Power Generation Option

The end-use options for the CMM drained from the Naryn Sukhait mine are very limited as there is no existing infrastructure in the region that would enable the mine to transport produced gas to market. Given that MAK has plans to construct a 35 kV interconnection from Naryn Sukhait to the Chinese grid in order to import electricity to meet growing demand, the logical and only apparent option available is on-site use. This option is the case where CMM is produced in advance of mining and is used to fuel an internal combustion power generation facility located in close proximity to the mine's surface facilities. The mine's current electricity consumption was not available; however, with the projected growth of the mine in the next few years, it is assumed that all electricity generated would be consumed on-site, and supplant electricity that would be purchased from other sources. MAK management endorses this option.

The following sections discuss basic background information of the project as well as all inputs and assumptions used in the reservoir simulation and the economic analysis, followed by a discussion on the economic performance of the project.

Technology and Deployment

In the production modeling performed for this study, a series of 12 wells are proposed, placed approximately 640 meters apart along the southern rim of the pit, targeting Coal Seam 5 (**Plate 2**). Each well is drilled to a total depth just below the target seam (ranging in depth from 225 to 400m), at which point casing is set just above the seam and the well is completed openhole, relying on natural fractures to enable gas migration to the borehole. A downhole pump is placed at the bottom of the well and produced water is pumped to the surface facilitating the production of gas from the coal. Each well forecast to produce coalbed methane for 15 years, with individual well gas production peaking in year seven as the reservoir is de-watered. The produced water would have to be pumped to a local containment pond where it is stored and made available for use by the mine. All costs associated with both the gas and water production are incorporated into the economic analysis.

Power generating equipment from two western suppliers was evaluated based on price and performance. Average costs from the two systems (USD/kWh installed) were used in the analysis. This equipment has a fuel consumption factor of 0.2475 cubic meters per kWh installed. Operating 8,000 hours each year, once the project reaches peak production, 68,400 MWh of electricity would be generated annually. This equates to an installed capacity of approximately 8.55 MW of combined electrical and thermal generating capacity.

The unit costs for this equipment were derived from correspondence with a representative of a western company with offices in Asia. Included in the capital cost estimates are equipment purchase, installation and testing, gas gathering, as well as all drilling and completion costs. Installation of the internal combustion power generation facilities is scheduled in the first year.

Risk Factors and Mitigants

As with any project there are risks associated with developing a successful project. **Table 3** lists the risks that have been identified, an assessment of the level of risk, and possible mitigants to each identified risk. Overall, the Raven Ridge team has determined that the risks associated with technology and implementation are low to moderate, but other than using the electricity generated on-site, the risks associated with market issues is high.

Table 3: Risk Factors and Mitigants: Power Generation and Use Options

Risk	Assessment	Mitigant
Market:		
Access to and the ability to dispatch all available generated power to the national grid	High	Use power on-site, and avoid sale to national grid.
Ability to sell excess power to Ovoot Tolgoi Complex or to local villages	High	Laws regulating sale of electricity are not yet formulated; use power on-site.
Policy:		
Rights to CMM extraction and use	High	Careful planning, meetings with cognizant agencies, obtain the hydrocarbon rights along with rights to the coal
Technology:		
Reliability and dependability of equipment	Low	Very dependable equipment, train local technicians to monitor, maintain, and repair engines and associated systems.
Fluctuations in gas concentrations	Low	The concentrations of gas drained in advance of mining should not fluctuate significantly.
Implementation:		
Fluctuation in pricing of equipment and services	Moderate	Current trend for prices is downward; Procure contracts that lock in favorable prices.
Procurement of permits and rights-of-way	Low	Develop timeline that incorporates time necessary to secure all necessary permits and right-of-ways, allow for delays.
Delays in deliverability of equipment	Low	Detailed planning; incorporate necessary lead time into orders.
Delays in installation	Low	Detailed planning.

The project was modeled to determine the economic performance of this option. The subsections below list the assumptions and inputs used for the modeling, followed by a subsection reporting the resulting estimates of economic performance.

Inputs and Assumptions

Inputs and assumptions used to model this option are listed in **Table 4**. When available, actual costs and pricing are used in the model, otherwise reasonable estimates based on industry standards were used. The drilling costs used in the economic model were derived from an engineer with extensive drilling and oil and gas project management experience in Asia.

The project duration is designed for fifteen years, where drilling of all the wells is completed by the end of the first year, and installation of the gas gathering system is completed in the second year. Power generation equipment is scheduled for installation in the first year as well as in years two, three and five.

According to the p50 production forecast, 144.8 million cubic meters of methane could be drained and used to generate electricity; a total of 2.4 million barrels of associated water is also produced, which is stored in a containment pond on-site for use at the mine.

All electricity generated will be used by the mine, so the sales price of electricity used in this analysis is 105 Tugrik/kWh (0.076USD), which is the price that the mine would otherwise have to pay to the grid. Annual project operating costs are assumed to be twenty-five percent of the capital costs.

Table 4: Inputs and Assumptions Used in Economic Model

Project duration	15 years	
Gas production available to the project	Based on analogous p50 production forecast from the Raton Basin in the U.S.	
Drilling costs	140 USD / meter	Quote from drilling contractor with experience in Asia
Casing costs	80 USD / meter	
Production well operating costs	700 USD / well / month	
Drilling rig mob / demob	125,000 USD	
Gas hook-up lines	25,000 USD / km	Industry standard "rule of thumb" costs
Main gas gathering line	100,000 USD / km	
Water production costs	0.67 USD per cubic meter produced and transported 150,000 USD for construction of containment pond	Industry average costs
Plant construction	Site construction and installation is conducted in the first year, additional generator sets are installed in years two, three and five.	
Capital Investment for p50 scenario	Power Stations & auxiliary facilities includes drilling and completing 12 production wells: 7.77 million USD	Power station investment based on unit costs 916.23 $/kilowatt
Annual power sales	Electricity generated available to mine: 58,400 MWh	
Annual operating hours	8,000 per year	
Gas cnsumption efficiency	0.2475 m^3 per kWh generated Utilizes 5.0% of gas stream as fuel for compressors.	Based on manufacturer's representatives.
Power sales price, avoided cost	105 Tugrik per kWh (0.076 USD)	Avoided cost that mine would have paid to grid.
Annual project operating costs	25 percent of capital costs for gensets annually. 700 USD per well per month for producing wells.	Based on information provided by manufacturer's representative and drilling contractor
VER sales price	1.00 USD per ton of CO_2e	
Federal tax rate	10 percent	

Probabilistic Forecast Results

Table 5 below summarizes the results of the modeling performed to determine the economic performance of a power generation option. Using the p50 CMM production forecast, a series of internal combustion engines are installed at the mine, totaling 8.55 MW, fueled by all available CMM. At the p50 production rate, the project returns a positive value for the NPV at 3.31 million USD and an IRR of 16.1 percent.

Table 5: Power Generation Option Base Case Forecast Results

Power Generation Option	
Evaluation Scenario	Base Case
Annual Operating Hours	8,000
Gas Forecast-Project (million m^3)	144.9
Total CAPEX (million USD)	7.77
Tons of CO_2e (x thou.)	187.9
Carbon Sales Price (USD)	1.00
Plant Size (MW)	8.55
CAPEX/Tons CO_2e	0.04
Electricity Sales Price (MNT/kWhr)	105
NPV/Tons CO_2e	0.02
NPV (Million USD)	3.31
IRR (%)	16.1%

Conclusions and Recommended Next Steps

The Naryn Sukhait coal mine is located in remote southwestern Mongolia, just 57 kilometers north of the Mongolian – Chinese border town of Ceke, the mine's main distribution center for the coal it produces. The mine estimates coal production will be between seven to ten million tonnes per year for at least the next 15 years. The mine has resources of 220 million tonnes of high volatile C bituminous coal, rich in vitrinite macerals, causing the coal deposit to be a significant source of methane with a high potential for storing gas. Gas desorption testing demonstrated that methane is present in the coal at depths as shallow as 150m and will be released to the atmosphere as surface mining takes place, unless a methane drainage program is adopted by mine operators.

The Raven Ridge team evaluated the sparse data provided by the mine's

technical staff, as well as conducted an extensive internet search for geologic additional pertinent data and information in order to better understand the factors that controlled the distribution and size of CMM resources contained within the mine lease boundary. After constructing a relatively simplistic 3-D geologic model it was apparent that the geology was much more complex than originally anticipated; however the Raven Ridge team estimated there are 253.1 million tonnes of coal beneath the lowermost extent of mining which has the potential to produce 204.1 million cubic meters of gas by the proposed 12 well pilot drainage system. It is estimated that the proposed pilot project could produce enough gas to fuel a 8.55 MW power generation facility to be used by the mine. The capital costs are estimated to be $7.7 million USD with an IRR of 16.1 percent and a payback period of 6.75 years. Carbon emissions would be reduced by 187,900 tons of CO_2e over the project's 15 year life.

In order to minimize the geologic uncertainty which might affect the success of the coal mine methane drilling and recovery campaign, such as the proposed drilling program, a comprehensive data collection program should be carried out first. The different types of testing and sampling in this program should include:

- Gas desorption testing: currently, there is very little gas content data available. An extension campaign should be designed and carried out to collect gas content data for all coal seams at depths of 150m and greater over the entire license block.
- The desorbed gas from select desorption samples should be tested for gas composition.
- Injection fall-off testing should be carried out in one or more test drillholes to better understand the gas flow capacity (gas producibility) of the coal, average reservoir pressures, and the impacts that drilling and completion related stresses will have on the reservoir permeability.
- All exploration drillholes planned should be rotary drilled, rather than cored, and a full suite of geophysical logs should be run over the entire openhole section for each drillhole.
- A 3-D seismic acquisition program should be designed and carried out over the entire mine lease to identify and determine the extent and impact of faulting, fracturing, and folding on the coal-bearing strata.

Once this data is collected and integrated into the existing geologic model and interpreted, a methane recovery program can be carried out with a higher likelihood of success.

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