Pre-Feasibility Study for Methane Drainage and Utilization at the Liulong Coal Mine, Liuzhi District Liupanshui, Guizhou Province, China

U.S.Environmental Protection Agency

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This publication was developed at the request of the United States Environmental Protection Agency (USEPA), in support of the Global Methane Initiative (GMI). In collaboration with the Coalbed Methane Outreach Program (CMOP), Advanced Resources International, Inc. (ARI) authored this report based on information obtained from the coal mine partner, Guangxi Baise Mining Group Co Ltd., the China Coal Information Institute (CCII), and REI Drilling Inc.

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Acronyms/Abbreviations

ARI	Advanced Resources International, Inc.
Bcf	Billion cubic feet
Bcm	Billion cubic meters
CMOP	US EPA Coalbed Methane Outreach Program
CMM	Coal Mine Methane
CH_4	Methane
CO_2	Carbon Dioxide
ft	Feet
GMI	Global Methane Initiative
km	Kilometer
kW	Kilowatt
kWh	Kilowatt hour
m	Meters
m^3	Cubic meters
m^3/h	Cubic meters per hour
m^3/min	Cubic meters per minute
m^3/t	Cubic meters per metric tonne
Mcf	Thousand cubic feet
MMBtu	Million British Thermal Units
MMcf	Million cubic feet
MMSCF	Million Standard Cubic Feet
MSCFD	Thousand Standard Cubic Feet per Day
Mta	Million (metric) tonnes per annum
MtCO2e	Metric tonnes of CO_2 equivalent
MW	Megawatt
PL	Langmuir pressure (psia);
psi	Pounds per square inch
psia	Pounds per square inch absolute
SCF	Standard Cubic Feet
Sub-bit	Sub-bituminous coal
Tons	Tons
Tpa	Tons per annum
USEPA	US Environmental Protection Agency
VAM	Ventilation air methane
VL	Langmuir volume (scf/ton)

Executive Summary

The U.S. Environmental Protection Agency's (USEPA) Coalbed Methane Outreach Program (CMOP) 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. 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 work of USEPA also directly supports the goals and objectives of the Global Methane Initiative (GMI), an international partnership of 42 member countries and the European Commission that focuses on cost-effective, near-term methane recovery and use as a clean energy source. An integral element of the USEPA's international outreach in support of the GMI is the development of CMM pre-feasibility studies. These studies identify cost-effective project development opportunities through a high-level review of gas availability, end-use options, and emission reduction potential.

The Liulong Coal Mine, owned and operated by the Guangxi Baise Mining Group Co Ltd. (BMG) was selected as the recipient for a pre-feasibility study for CMM drainage and utilization because of the difficult gas conditions at the mine and expected increases in gas production in coming years as the mine expands. The mine was ultimately selected for this pre-feasibility study based on the level of commitment BMG and provincial authorities in Guizhou Province have demonstrated to implement methane drainage and utilization projects, and the high likelihood of project implementation and resulting methane reductions.

The mine is located on the western margin of Guizhou Province in the Liuzhi Coalfield in Liupanshui City. Like many other mines in Guizhou Province, the Liulong Mine faces challenging mining conditions with targeted coal seams having high gas contents. The mine, which is formally classified as a coal and gas outburst mine, currently employs a gas drainage system using short, cross-panel boreholes, but this method of degassing the mine has not been effective. BMG has considered an alternative drainage method used by other mines in Guizhou Province where inseam boreholes are drilled vertically up into the target seam from an underlying gallery. This method, however, can be very expensive. The company is, therefore, interested in alternatives that could improve gas drainage in a cost effective manner. In addition, BMG would like to use the CMM produced at the mine for power generation. To date, the Liulong Mine has not implemented a gas utilization project.

Aside from the current mining operation, BMG is planning a large reserve addition, called the Dayong Coalfield, with geologic conditions that mirror existing operations. The Dayong Coalfield is scheduled to commence operations at the beginning of 2018. The same seams that are mined in the current mine plan will be mined in the Dayong addition.

Based on the stated objectives of BMG and the conditions at current and future workings, the objectives of this pre-feasibility study are to:

- Identify and assess alternative methane drainage options that can improve gas availability (gas quality and gas quantity);

- Produce reservoir models simulating gas production from the mined seams based on geologic data provided by the Liulong Mine;
- Forecast gas production over the life of the project at the Liulong Mine and Dayong Coalfield reserve addition by applying the results of the reservoir simulation to the mine layout and future production schedule;
- Identify and assess CMM utilization options potentially available to the Liulong Mine, including CMM-based power production;
- Determine the power plant capacity based on the gas production forecasts and prepare a preliminary financial analysis of CMM-to-power; and
- Outline recommended next steps for BMG and the Liulong Mine to support their pursuit of a CMM recovery and use project.

There are two working seams for coal production at the Liulong Mine, the No. 7 seam and the No. 3 seam. The No. 3 seam is closest to the surface. The No. 18 seam is also permitted for coal production, but the seam is not currently mined. Based on a detailed review of mine data provided by BMG and the China Coal Information Institute (CCII), two directional drilling concepts for methane drainage at the Liulong Mine are proposed, which can be applied to both the panels in the existing mine and also in the Dayong reserve addition.

The first proposed drainage method is the application of in-seam boreholes implemented from the rock gallery (or other lower elevation gallery) that penetrate up into the mining seam at intervals of 30 meters (m). The objectives of this approach are to provide additional reach, potentially eliminate the underlying drainage galleries, and provide for more drainage time, which could possibly enable larger borehole spacing. The second proposed drainage method is the application of horizontal gob boreholes (HGBs). Although there is no available data that quantifies that gob gas emissions are significant relative to methane emissions from the mined seam, the data provided by the mine indicates all surrounding strata are gassy.

Inseam boreholes were initially modeled at 30 m spacings. However, gas production was very low and in-situ gas content in the coal seams after 10 years of degassing was still around 80 percent of original gas content in the No. 3 seam, and 70 percent in the No. 7 seam. This led to a second simulation with 10 m spacings, which increased gas production significantly. However, the in-mine HGBs appear to be the most effective option for gas drainage at Liulong, as shown in Figure ES-1.

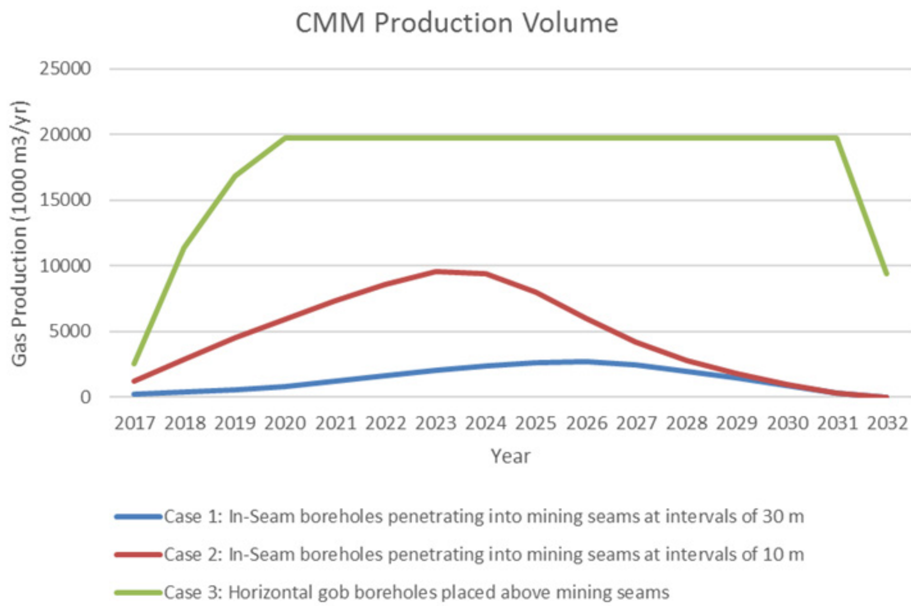


Figure ES-1: CMM Production Forecast

Although several potential options exist for use of CMM at the Liulong Mine, power production is the most viable option based on preliminary market data provided by BMG and CCII. Chinese coal mines have significant experience implementing CMM power generation projects, including mines in Guizhou. In China, the knowledge, expertise and experience to support cost-effective implementation, operation and maintenance of a CMM power plant are widely available. Industrial power prices are also attractive for CMM-to-power projects at US$0.14 per kilowatt-hour (kWh) with subsidies. Power plants are modular and can be easily expanded if gas availability increases or decreases. Additionally, the technical challenges of wheeling excess power to the grid are easily overcome because mines are large users of electricity with access to high voltage interconnects or even electricity substations at the mine. Other possibilities include sales to the local natural gas distribution network, compressed natural gas or liquefied natural gas (CNG/LNG) production, and use as boiler fuel. However, all of these potential end uses have additional barriers that must be addressed. For example, the local gas network, operated by the Liupanshui Natural Gas Corporation, is currently inaccessible to the mine. A pipeline must be constructed from the mine over difficult terrain to give the mine access to the local gas network. In addition, the current and projected gas sales price is low and not economic. CNG/LNG requires costly infrastructure, and LNG production, in particular, has very high operating and maintenance costs. Use as boiler fuel at the mine is a possibility although the mine is in a temperate area and heating needs are very limited in Guizhou Province.

This study focuses on the most likely utilization option, power production, to evaluate project economics. The financial analysis considers the entire capital and operating costs of the project including the cost of drilling boreholes, the gathering system, and the power plant. The economic results for the power project are summarized in Table ES-1. Cases 2 and 3 both have a positive net present value discounted using a yearly discount rate of 10 percent (NPV-10). However, the HGBs case, Case 3, which has an NPV-10 of over US$30 million and an internal rate of return (IRR) of 43 percent, is preferable to Case 2, in-seam boreholes with 10 m spacing, which has a NPV-10 of just under $1.3 million and an IRR of 12 percent. Case 3 delivers the largest CMM production to maximize the capacity of the power plant. In addition, net emission reductions associated with the destruction of drained methane from the optimal development scenario are estimated to total 2.9 million metric tons of carbon dioxide equivalent ($MtCO_2e$) over the life of the project. Case 1, using in-seam boreholes, is unviable.

Case	Description	Max Power Plant Capacity	NPV-10 US$000	IRR	Payback (Year)	Net CO_2e Reductions (Million metric tons)
1	In-seam boreholes penetrating mining seams at intervals of 30 m	2 MW	-5,722	-3%	-	0.32 Mt
2	In-seam boreholes penetrating mining seams at intervals of 10 m	6 MW	+1,278	+12%	8	1.1 Mt
3	Horizontal gob boreholes placed above mining seams	9 MW	+30,054	+43%	3	2.9 Mt

Table ES-1: Summary of Economic Results

As a pre-feasibility study, this report is intended to provide an initial assessment of project feasibility. Further site-specific analysis is necessary to develop a "bankable" feasibility study acceptable to project investors, banks, and other sources of finance. Section 6 provides further guidance for BMG to aid in their assessment of a CMM capture and use project. Foremost among these recommendations is the need to clearly define the geology, gas content data, prospective mine layout, and mine production plan for the Dayong addition. The existing workings provide limited potential for a large-scale CMM project, but the prospects improve considerably with the very large Dayong addition.

1 China's Coal Industry and Coal Mine Methane

1.1 China's Coal Industry

In 2016, China ranked first in global coal production with 3,411 million tonnes (Mt) of production, accounting for 46 percent of the global share (BP, 2017). Between 1981 and 2016, China's coal production increased by 2,789 Mt (Figure 1-1). In 2014, coal production began stabilizing due to decreased demand (BP, 2017).

At the end of 2016, China's total proved reserves of coal were 244,010 Mt (ranked second globally behind the U.S.), with 94 percent being anthracite or bituminous coal and the remaining 6 percent being sub-bituminous or lignite (BP, 2017). China's coal reserves are located throughout the country with the majority located in Shanxi, Inner Mongolia, Xinjiang, Shaanxi, and Guizhou provinces, with Guizhou ranking fifth in total reserves (GZICCEP, 2011).

As shown in Figure 1-1, coal production has grown rapidly from 2.2 billion tons (Gt) in 2005 to 3.75 Gt in 2015, although coal production in 2015 is down from peak production of 3.97 Gt in 2013. Total coal consumption in China was 3.97 Gt in 2015. By the end of 2015, the total annual coal consumption in China accounted for 64 percent of total energy consumption, but the Chinese Government is targeting a consumption level of 62 percent by 2020 in the latest energy development strategy plan released by the State Council (He, 2016) .

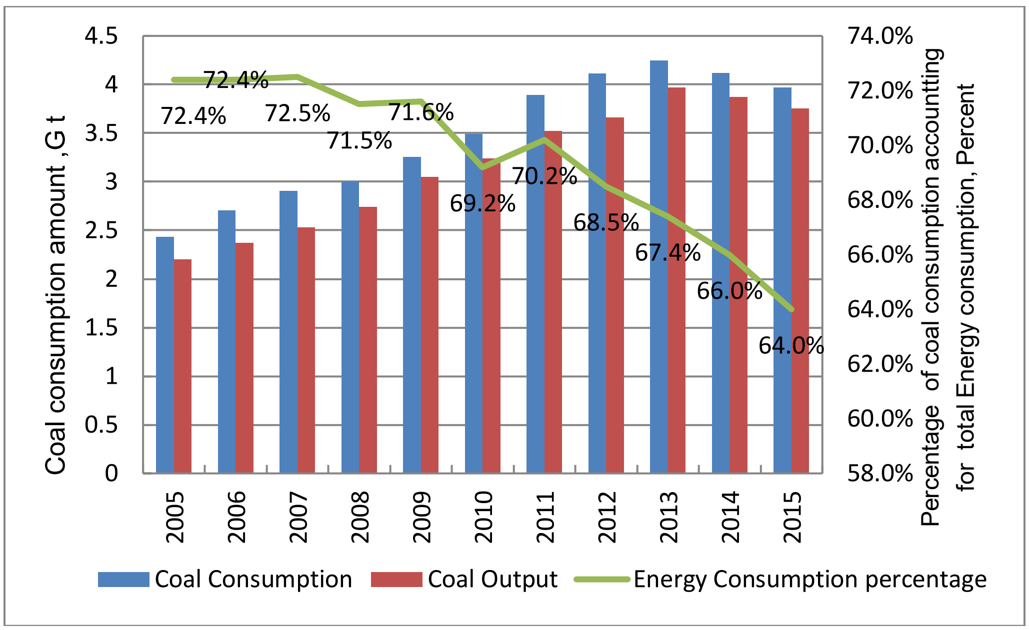


Figure 1-1: China Coal Production, 1981-2014

The Chinese government is currently attempting to consolidate the nation's coal mines in order to improve industry economics, reduce pollution, make the national coal industry more efficient, and improve safety (USEPA, 2015). Currently China has 12,000 coal mines and has implemented a policy of phasing out coal mines producing less than 90,000 tons of coal per year (EIA, 2015) (USEPA, 2015). Existing coal and gas outburst mines, an official classification by China's State Administration for Coal Mine Safety Supervision, must produce at least 450,000 tons per annum (tpa).

Although smaller mines are closing, large scale coal mines are still being constructed. In some cases, production capacity at smaller mines is being expanded, as is the case with the Liulong Mine. According to the CCII, approximately 400 large-scale coal mines with annual output over 1.2 Mt were added in 2015. The minimum size for a new coal and gas outburst mine is 900,000 tpa (CCII, 2016). Thus, large scale coal production will continue in China for many years to come. With many well-established coal industries in northern and eastern provinces, the Chinese Government has turned its focus to newer mining prospects – including Guizhou and neighboring provinces in southwest China – by supporting increased investment in these areas.

1.2 Coal Mine Methane in China

The USEPA estimated China's CMM emissions to be 22,490 million cubic meters (Mcm) in 2015 (USEPA, 2015). Coal producers continue to face significant challenges related to CMM management and mine safety. In 2015, 13.6 billion cubic meters (Bcm) of CMM were drained in China, of which 4.77 Bcm were utilized. Total installed CMM power generation capacity is almost 3000 megawatts (MW), including a 120 MW power project and a 30 MW ventilation air methane (VAM) power project both in Shanxi Province (Wenge, 2016).

The "China Petroleum Resource Assessment" indicates that the total coalbed methane (CBM) resource in China is about 36.81 trillion cubic meters (Tcm). The burial depth of most CBM resources is less than 2,000 m with 39 percent of the total resource between depths of 1000 m to 1500 m (Figure 1-2).

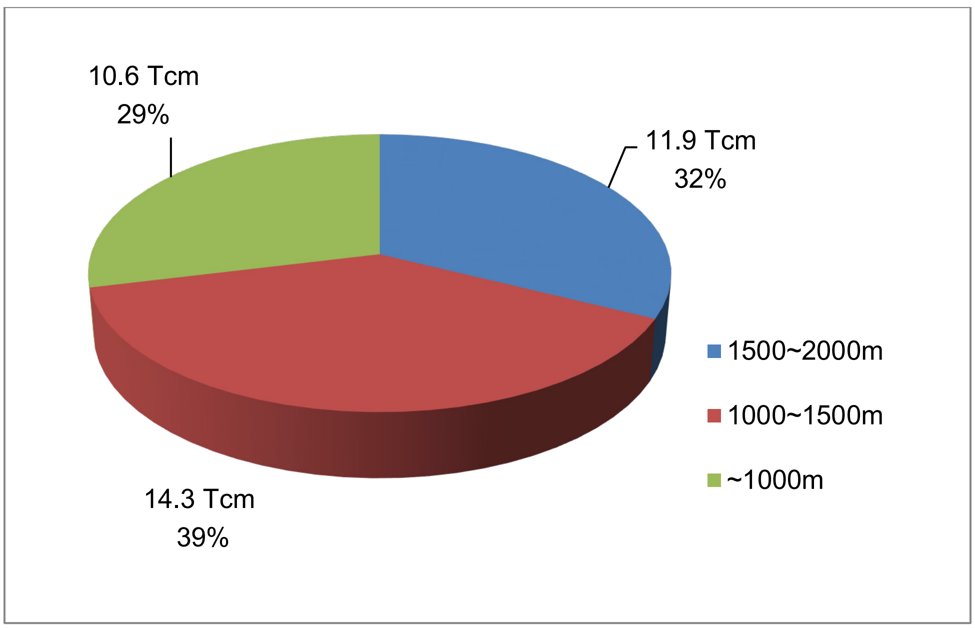
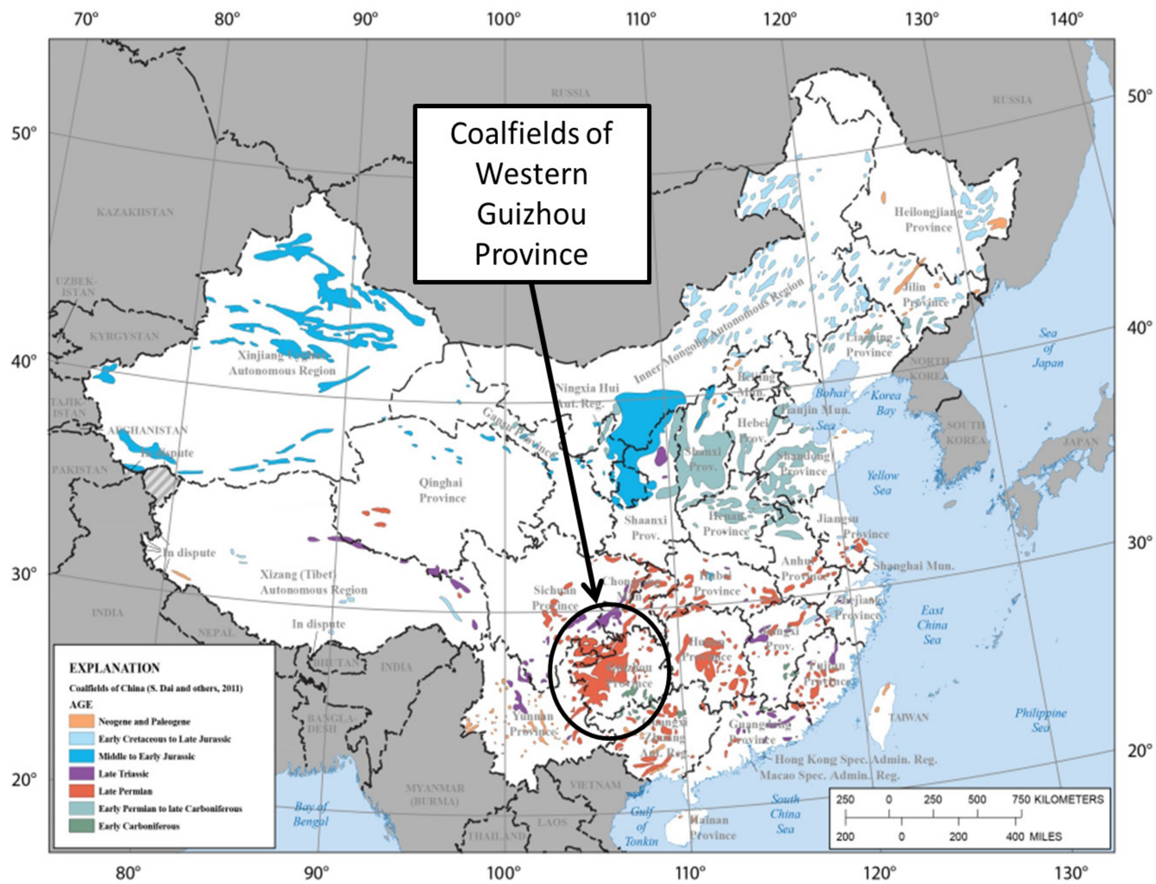


Figure 1-2: Depth of Coalbed Methane Resources in China

Despite the slight reduction in total coal production from its peak, the volume of drained and utilized CMM is expected to continue increasing as shallower coal reserves become exhausted and mines begin to develop deeper, gassier coal seams to meet demand. CMM drained and utilized is also expected to increase as mines develop more experience with gas capture and use, as gas drainage methods improve, and as coal production becomes concentrated in large-scale gassy mines. Capture and use of CMM is also a provincial and national priority in coal mining provinces, including Guizhou.

1.3 Coal Mine Methane Resources in Guizhou Province

Reserve estimates for Guizhou Province indicate that there are 3.15 Tcm of total CMM reserves in the province (Yuguang, 2004), of which approximately 45 percent are in the Liupanshui Coalfield (GZICCEP, 2011). Out of the total Provincial CMM reserves, 434 Bcm are held by mines with a capacity of over 300,000 tpa, of which 264 Bcm is extractable (GZICCEP, 2011). Historically Guizhou province has had an average gas utilization rate of 16 percent (GZICCEP, 2011), with gas utilized for power generation and civil use.



Source: (U.S. Geological Survey, 2014)

Figure 1-3: Coal Map of China Highlighting Coalfields of Guizhou Province

Figure 1-3 shows the coalfields of Guizhou Province. Most of the coal and gas resources in Guizhou Province are found in the Late Permian strata. The entire province can be separated into southeastern and northwestern gas bearing areas. The southeastern area is a low gas zone and the northwestern area is a high gas zone. The gas resources are rich at the Panguan syncline in the Panjiang coal mine area, Gemudi syncline in the Shuicheng coal mine area, Bide-Santang syncline in the Liuzhi coal mine area, and Jinlong syncline in northern Guizhou. Among the coalfields in Guizhou, the gas content of the Liupanshui Coalfield is the highest.

1.4 Liulong Coal Mine

The Liulong Coal Mine is in the Liupanshui Coalfield of Guizhou Province. The mine is a coal and gas outburst mine currently permitted to produce 600,000 tpa with the potential for annual production of 1.5 million tpa after a reserve addition, the Dayong Coalfield, is added to the existing operation. The reserve addition is scheduled to be integrated at the beginning of the 2018 calendar year.

1.4.1 Selection of the Liulong Coal Mine

The Liulong Mine was selected for this pre-feasibility study for the following reasons:

- The coal seams in western Guizhou Province are very gassy and prone to outburst; therefore, the Chinese Government and the Guizhou Provincial Government have made CMM drainage a very high safety priority;
- Gas drainage and utilization are lagging behind other major coal producing regions in China, and regional authorities and the mine owner and operators welcome technical assistance;
- The Chinese Central Government and local Guizhou Government have also placed a high priority on CMM utilization. Economic development targets in Guizhou Province will require continued reliance on coal, so it is likely that coal production will continue to grow. Successful early development of gas drainage and utilization projects can lead to sector-wide growth, and more effectively leveraging USEPA's technical support;
- The Liulong Mine is currently draining CMM, but has requested technical assistance to improve drainage practices and to develop a CMM power project; and
- The Liulong Mine's reserve addition means that initial efforts at gas capture and use in the current mine workings will be expanded to a much larger operation, resulting in greater emission reductions.

1.4.2 Location of the Liulong Mine

The mine is located in southwestern China's Guizhou Province, situated along the western border of the province in Yangfeng Village, Pingzhai Town, Liuzhi Special District of Liupanshui City. Liupanshui is in the Liuzhi Coalfield, one of the three most productive coalfields in Guizhou Province. The mine is bounded by a coal seam cropline in the east, the F146 fault in the south, the newly-delimited 3 and 4 turning points in the west, and the F141 fault in the north. The length of the existing mine permit (pre-Dayong addition) from east to west is 1.4 kilometers (km), the width from south to north is about 1.6 km, and the existing mine boundary covers 7 square kilometers (km^2). The mine portal and mine buildings are located in the small village of Mitangtian at an elevation of 1500 m above sea level. The mining portal is conveniently located 8 km from the Pingzhai Town Government, 8 km from the Liuzhi railway station, and 8 km away from the An-shui highway. The reserve addition, called the Dayong Coalfield, will increase the mine's footprint by a total of 45 km^2. Figure 1-4, Figure 1-5, and Figure 1-6 show the locations of Guizhou Province, Liupanshui City, and the Liulong Mine, respectively.

Figure 1-4. Map of China Highlighting Guizhou Province

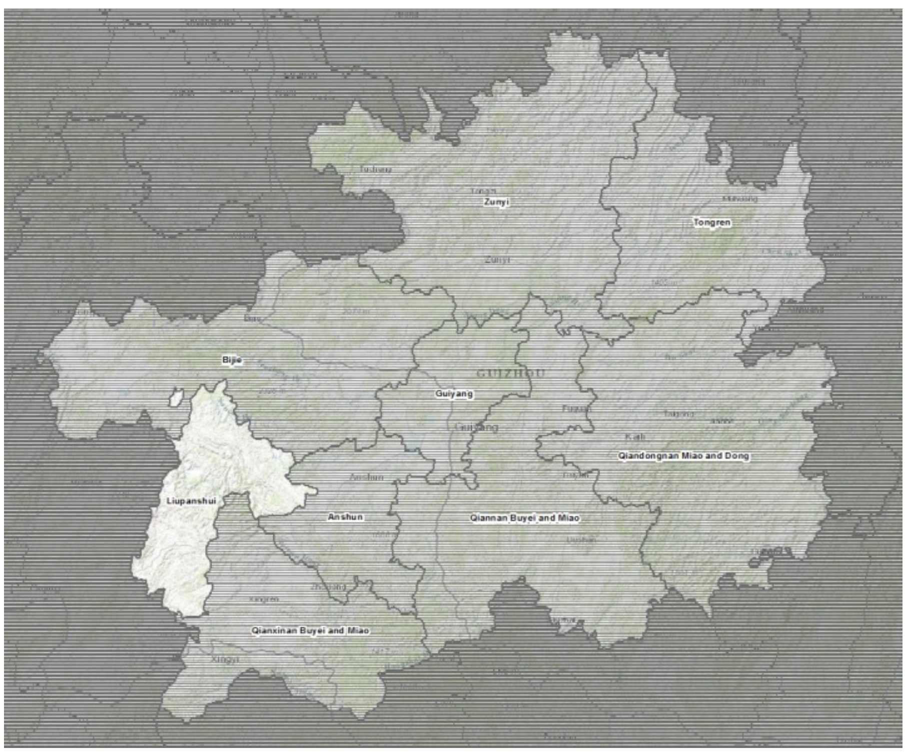


Figure 1-5. Map of Guizhou Province Highlighting Liupanshui City

Figure 1-6. Location of Liulong Mine relative to Liuzhi District, Liupanshui City

Guiyang is the capital of Guizhou Province and the likely point of entry into the province for anyone visiting the Liulong Mine from outside of Guizhou. Pingzhai Town, Liuzhi Special District of Liupanshui City, where the mine is located, is easily accessible by a recently constructed major highway from Guiyang; the trip by automobile is approximately two hours from central Guiyang. It takes approximately 20 minutes to reach the mine from the town center. Accessing the mine's surface facilities requires travel up a hillside on a steep and narrow, but paved, road through a small village over a ridge and then down a short and steep road to the mine offices and main portal.

The offices and portal of the Liulong Mine are located in a valley abutting several large hills. A conveyor brings coal up to the processing plant, which is located adjacent to the road from Liuzhi District to the mine. Larger transport vehicles may have difficulty navigating the road; however, large scale equipment has been delivered to the mine for mine development and coal production, and mobile drilling rigs have been deployed at the mine for coring. One other mobility challenge is a tunnel underpass from the city to the mine. It is necessary to use the underpass to access the mine road and proceed up the hill through the village to the mine. Navigating the underpass with a relatively low ceiling and narrow width may require special consideration in transporting power generation equipment, gas upgrading equipment, or other utilization equipment. The photograph in Figure 1-7 shows an example of the local terrain.

Figure 1-7: Mine Workers at the Liulong Mine with Example of Local Karst Terrain in the Background

1.4.3 History of the Liulong Mine and Planned Reserve Addition

The Liulong Mine was constructed in the 1990's and was originally a private mine. The mine operator, Mr. Peng Yanhui, developed the mine including the construction of the paved road from the local village, over the hillside, to the mine. The originally licensed coal production was less than 100,000 tpa. In June 2008, the Liulong Coal Mine was granted a mining license for production of 150,000 tpa by the Department of Land and Resources of Guizhou Province, and this was further increased to 300,000 tpa in January 2012. BMG, a state-owned company, purchased a majority share of the Liulong Mine in February 2014, partnering with the original mine owner. Today BMG owns 73 percent of the shares and Mr. Peng Yanhui controls the remaining 27 percent. In February 2014, BMG received authorization to increase the production capacity of Liulong Coal Mine to 600,000 tpa. Target coal production for the Dayong Coalfield reserve addition is 900,000 tpa by 2020, thus the expanded Liulong Mine will have a combined production capacity of 1.5 million tpa.

1.4.4 Topography and Climate

The terrain of Guizhou Province where the Liulong Mine and many other coal mining operations are located is a karst terrain characterized by steep, rounded hills and mountains that have been carved out of limestone over time. The hills and mountains in the area are heavily forested. The undulating karst terrain has several impacts for coal mining and gas management. The sudden changes in overburden can place significant stresses on coal seams, putting mining development and production under risk of coal and rock outbursts. Karst terrains can also hold pockets of subterranean water that can flood mine workings if breached; however, this has not been an issue for the Liulong Mine. For surface operations, the steep, undulating terrain can present challenges transporting and mobilizing equipment. Although there are significant vertical stresses, the mine reports that horizontal stresses are not a concern.

Guizhou Province has a humid monsoon climate and is located in the subtropical climate zone. The area has neither a severe winter nor hot summer. Guizhou has an average annual temperature between 14^oC to 16^oC (57^oF to 61^oF). January, Guizhou's coldest month, has average temperatures of between 4^oC to 9^oC (39^oF to 48^oF) and July, Guizhou's warmest month, has average temperatures between 22^oC to 26^oC (72^oF to 79^oF). Annual average precipitation in Guizhou is between 900 to 1500 millimeters (mm) (China Today, 2015). Project construction is unlikely to be affected by cold, ice, or snow, but may be impacted by rainy weather.

1.4.5 Regional Geology

The Liuzhi Coal mine area is a part of Liupanshui Coalfield in western Guizhou Province. The total area of the Liupanshui Coalfield is 24,869 km^2, of which the coal-bearing area is 14,587 km^2. The coal-bearing strata are transited from continental facies to interactive marine-terrigenous facies from the west to the east. The upper Permian series strata are the main coal-bearing strata. The Changxing Formation and Longtan Formation contain the main minable strata and the major target strata for CBM development.

In terms of regional structure, this area is located at the fourth-order tectonic element below the passive margin fold thrust belt south of the Yangtze continental block, Zhijin relieved folded zone, and Liupanshui complex deformation zone. The main faults in the area are the Nayong-Weng'an Fault, Shizong-Guiyang Fault, Shuicheng-Ziyun Fault, Wangmo-Dushan Fault, Panxian-Shuicheng Fault, and Zunyi-Huishui Fault. The area successively went through the Indosinian movement, Yanshan movement, and Himalaya movement. The Yanshan movement has the strongest influence on the area, generating structural feature combinations with different directions and forms in different areas, and controlling the preservation degree and occurrence status of coal-bearing strata.

The structural pattern of the Liupanshui Coalfield contains widely spaced anticlines, and can be divided into three groups according to distribution direction and morphological characteristics. The three groups consist of northwest folding anticlines located toward the northeast of the coalfield, northeast folding anticlines located south of the Panxian-Qinglong line, and brachy-anticlines located at the center of the coalfield. Normal strike folds are common in the coalfield and are distributed along the anticline axis or wings.

The late Permian epoch coal-bearing strata in Liupanshui Coalfield mainly consists of a delta, wad, and lagoon sedimentary system, formed by terrestrial rivers from the west, and coastal tidal forces from the ocean in the southeast. Main sedimentation types are tidal distributary channel facies, distributary tideway facies, and distributary bay facies. Sedimentary patterns in this region are as follows: the continental side mainly develops upper delta plain systems with active rivers; the central area develops transitional delta plain systems controlled by river and tide activity; the coastal area develops lower delta plain systems with tide activity and wad-lagoon systems. This region was undergoing a transgression progress in the early Longtan period. The main sedimentary pattern is a wad-lagoon sedimentary system. A delta system developed in the line of Shuicheng and Panxian. During the late Longyuan period, this region was controlled by a regressional geologic process, the delta sedimentary system developed extensively, and the lagoon-wad system moved eastwards. In the Changxing period a new transgression process started, and the delta system shrunk towards the continental side, but still developed at a large scale.

1.5 Guangxi Baise Coal Mining Group – Owner/Operator of the Liulong Mine

The Liulong Coal Mine is majority-owned and managed by the Baise Mining Group Co Ltd. (BMG), a large state-owned enterprise based in Baise City in Guangxi Zhuang Autonomous Region, adjacent to Guizhou Province. BMG's holdings include 22 enterprises, and the company has total assets of RMB 8 billion (USD 1.2 billion). Its primary industry is coal, but it is involved in other industries including manganese ore production, power generation, aluminum production, coal logistics, coal conveyor manufacturing, building materials, real estate, and professional engineering services for coal mines. BMG is the primary lignite producer in Guangxi, and is also a leading manganese carbonate producer in China. The company has over 5,000 employees.

The coal business of BMG is spread throughout the southeastern and southwestern provinces of China and other Southeast Asian countries. BMG's subsidiary that owns and operates the Liulong Mine, Guangxi Baise Coal Mining Group, is one of the top 100 enterprises in Guangxi Province. The Liulong Mine is BMG's first investment in the Guizhou coal sector. The coal produced from the Liulong Mine is used as steam coal, for chemical manufacturing, and for civil uses. BMG requested assistance to improve gas drainage and develop a CMM utilization plan for the Liulong Mine because it has limited experience with gassy mines; none of BMG's eight mines in Guangxi are gassy.

2 Summary of Liulong Mine Characteristics

2.1 Coal Reserves

Currently, the Liulong Mine has coal reserves of 6.8 Mt, of which 5.1 Mt are recoverable. However, as noted previously, BMG is in the process of integrating the coal reserves of the Dayong Coalfield, which would increase the Liulong Mine's reserves to approximately 80 Mt (see Figure 2-1).

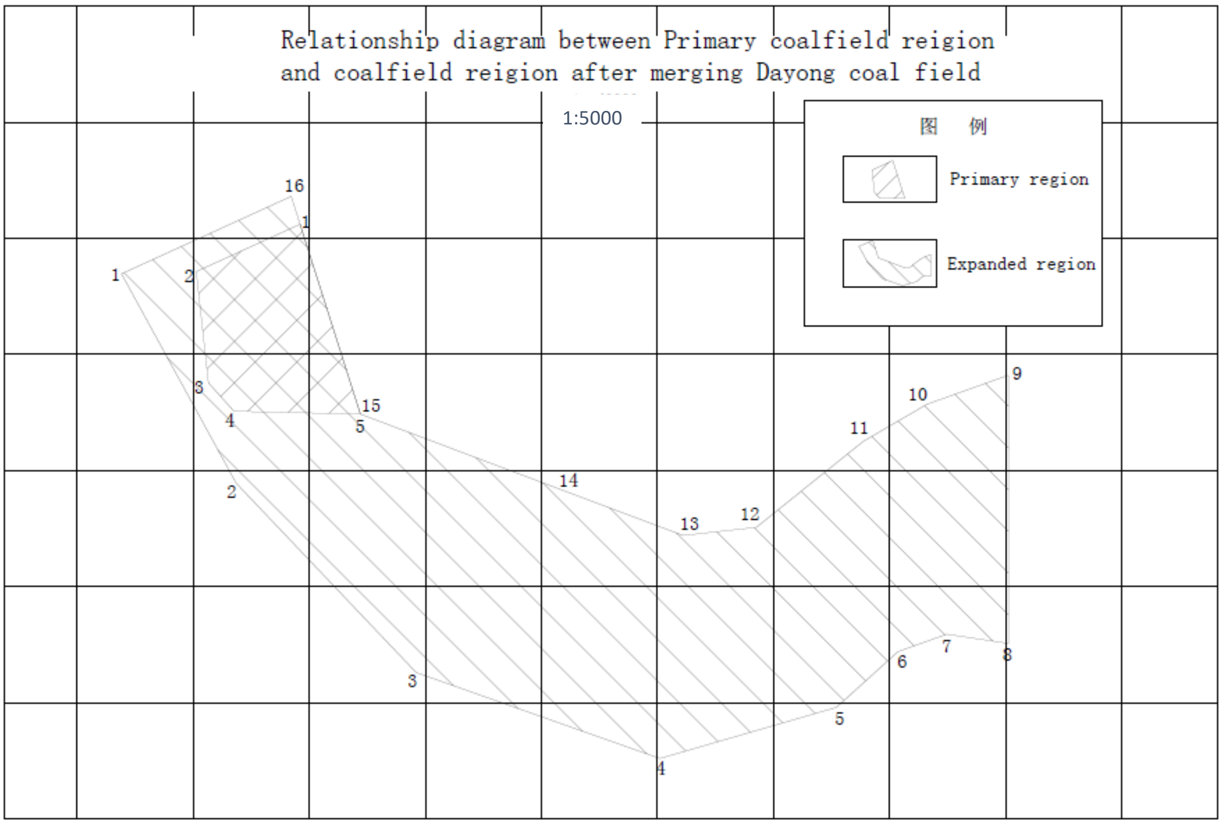


Figure 2-1: Relationship of the Existing Workings to the Dayong Coalfield Reserve Addition

2.2 Coal Production

Historic coal production figures were not provided by the mine for this study. The mine's coal production was small relative to future production and is not a good indicator of future production. The permitted production capacity of the mine has risen quickly from less than 150,000 tpa in 2007 to 600,000 tpa currently, and will reach 1.5 million tpa when the Dayong field comes online.

The two working seams for coal production at the Liulong Mine are the No. 7 seam and the No. 3 seam. The No. 18 seam is also permitted for coal production, but the seam is not currently mined. The elevation of the No. 3 seam is between 1350 m to 1600 m above sea level, the elevation of the No. 7 seam is between 1200 m to 1350 m above sea level, and the elevation of the No. 18 seam is between 1020 m to 1200 m above sea level.

The existing mine is divided into east and west wings. BMG uses the adit method for development and the retreating longwall mining method to extract coal.

Figure 2-2. Mine Portal (or main adit) to the Liulong Mine

2.3 CMM Emissions

BMG provided data on CMM characteristics from historic and current operations. Pure methane (CH_4) flow in gas drainage ranges from 160 cubic meters (m^3) to 763 m^3 per hour, roughly enough CH_4 to support electricity generation capacity ranging from 500 kilowatts (kW) to 3 MW. The historic average CH_4 concentration is 21 percent, but has reached 30 percent.

Although Liulong Mine's historic absolute gas emission rate is relatively low, the mine has a high specific emissions rate of 40.3 m^3 of gas per ton of coal mined (equivalent to 1,422 cubic feet per ton, ft^3/t), showing that CMM production from the mine could be significant with improved degassing methods and increased coal production. For example, 600,000 tpa of production would generate 24.2 Mcm of CMM, or enough to generate up to 8 MW of electricity with a consistent gas source.

The relative gas emission rates for the working seams, Seams No. 3 and No. 7, are shown in Table 2-1:

Coal Seam No.	Working face gas emission rate (m^3/t)		Tunneling gas emission rate (m^3/min)		Gas emission rate in the mining area (m^3/t)	Gas emission rate in the mine	
	q_1	q_2	q_3	q_4		Relative (m^3/t)	Absolute (m^3/min)
3	10.2	21.9	0.66	1.04	37.65	56.47	36.65
7	7.73	0.00	3.50	1.30	25.75	38.63	24.39

Table 2-1 Statistical Table of Gas Emission Rate before Extraction

Currently, the mine employs short cross-panel boreholes for degassing the No. 3 and No. 7 seams; however, this method has proved to be relatively ineffective. The coals are friable, and a potential borehole collapse could be problematic. BMG has considered an alternative approach to draining gas that would entail driving galleries in the underlying No. 18 seam, and then drilling boreholes vertically into the higher elevation No. 7 and No. 3 seams. However, this option is prohibitively expensive.

BMG has also considered surface pre-drainage wells and surface gob vent boreholes (GVBs), but these methods are not practical alternatives at this time. The terrain makes it very difficult to mobilize and service surface drilling equipment, wellheads, and gathering systems. Two proposed alternatives that should improve drainage are discussed in Section 3: (1) in-mine directionally drilled boreholes from an underlying gallery, similar to the alternative preferred by BMG, and (2) long in-mine directionally drilled gob boreholes.

In addition to technical challenges, title to the produced gas is another barrier for pre-drainage wells. Although BMG could use any CMM produced from surface pre-drainage wells for up to five years after a borehole is drilled, it must have a CBM license to use or sell gas after the initial five-year period. A party other than BMG currently holds the CBM license within the permitted mine boundary and within the Dayong Coalfield, likely adding potential legal hurdles and costs to obtain rights to the gas after the five-year license concludes.

2.4 Mine Geology (Stratigraphy, Lithology, Tectonics)

The mining area is located in the northwest section of the northeast wing of the Liuzhi Syncline. The strata of the Liuzhi Syncline have a strike to the northwest between 40° and 45°. The strata generally dip between 16° to 36°, and in the southwest, strata generally dip 25° to 30°, increasing from the northwest to southeast. The Syncline is slightly inclined, and faults in the mining area are mainly transverse normal faults. Oblique and flat normal faulting along with rare reverse faulting has also been observed. No faulting, folding or problems with the cleat structure in the existing mine is expected to affect the flow of gas. There is a major fault in the Dayong Coalfield, but the mine management does not believe this will impact the mining operation or gas management.

The three minable coal seams found within the Liulong Mine are seams No. 3, No. 7, and No. 18. Currently, only seams No. 3 and No. 7 are being exploited by the mine. Seam No. 3 has a mean mining elevation of 1386 m above sea level and a thickness ranging from approximately 0.1 m to 2.86 m, with an average thickness of 1.05 m. Seam No. 7 has a mean mining elevation of 1463 m above sea level and a thickness that ranges from approximately 1.06 m to 14.24 m, with an average thickness of 6.39 m. Seam No. 18 has an approximate thickness range of 0.11 m to 2.53 m, with an average thickness of 1.40 m. The coal is generally soft, and boreholes are prone to collapse.

The exposed strata in the Liulong Coal Mine area contains the Quaternary Sequence (Q), Yongning Town Formation (T1yn), and the Yelang Formation (T1y) of the lower Triassic series; Dalong Formation (P3d), Longtan Formation (P3l), and Mount Emei Basalt Formation (P3β) of the upper Permian series; and Maokou Formation of the middle Permian series (P2m). The characteristics of each stratum and rock association are described, from most recent to oldest, as follows:

(1) The Quaternary System (Q): Mainly slide rock, alluvial deposit, diluvium, stacked up in valley and gentle slope of coal series.
(2) Yongning Town Formation of lower Triassic series (T1yn): The upper is light grey medium stratiform limestone, intercalated by three to four layers of greyish yellow dolomite limestone; the middle is light grey medium-thick stratiform limestone, intercalated by purple and greyish-green mudstone; the lower is off-white and light grey thick-layer to massive limestone, with local oolitic texture.
(3) Yelang Formation of lower Triassic series (T1y): The upper is off-white and light grey medium and thick-layer to massive limestone, mainly oolitic limestone and purple thin stratified argillaceous limestone, intercalated by thin burgundy mudstone; the lower is grey and greyish green thin stratified siltstone and calcareous siltstone.
(4) Dalong Formation of upper Permian series (P3d): Dark grey to grey black mudstone, siltstone, intercalated by three to five layers of thin to medium and thick stratiform limestone (or argillaceous limestone), the middle is a layer of stable siliceous limestone (or limestone), which is the marker bed.
(5) Longtan Formation of upper Permian series (P3l): Mainly grey to dark grey sandstone, siltstone intercalated by sandy mudstone, mudstone, carbonaceous mudstone and clay rock.
(6) Mount Emei Basalt Formation of upper Permian series (P3β): Dim gray and grayish-green basalt with cryptocrystalline to fine grained texture, vesicular structures, and columnar jointing structures; the top and bottom commonly develops tuff and tuff sandstone.
(7) Maokou Formation of middle Permian series (P2m): Light grey fine grained thick stratiform to massive limestone. Karst structures are present.

The faults in the area of the Liulong Mine are mainly lateral normal faults, followed by oblique and flat normal faults, with few reverse faults. The F18, F20, and F21 have the greatest potential impact, and are described below:

(1) F18 lateral normal fault: Extends from the axis of the Liuzhi syncline towards the northeast via Longzhaodi and Zhengjiazhai across the coal series and extends outside of the region near Shabao. The trend is 65°NE with a dip of 49° to 57°SE. The largest fault displacement is located near the No. 7 coal seam. The fault passes through Triassic limestone towards the southwest with a 20 m to 70 m wide fracture zone. The vertical fault displacement in Yongning Town Formation, Longzhaodi, is only 150 m, and ground horizontal displacement is 330 m. The fault is branched in the NE section near Yejialan Dam into F140, F138, and subsidiary faults F139 and F147. The fault displacement reduces rapidly and disappears to Maokou limestone near Shabao.

(2) F20 oblique normal fault: Starts from Xiaobadi in the northeast, and crosses with the F21 fault. Based on trenching and drilling data, the vertical fault displacement is 115 m, and the horizontal displacement is 173 m.

(3) F21 oblique normal fault: Starts from the coal series in the east of Dayutang, extends to Guanling Formation towards the southwest, and then disappears. The trend of the southwestern section is 74°NE, then turns to the NW as it extends southwards after Dayutang with a dip angle of 50° to 63°. Vertical fault displacement is about 200 m, and horizontal displacement is about 450 m. The fault displacement suddenly becomes smaller in the northeastern part of the coal series. Vertical fault displacement in the northeastern part of the coal series is 20 m to 60 m, and the horizontal displacement is 100 m, and disappears towards the east.

2.5 Gas Resources

Currently, under the permitted mine plan the CBM resources are 100 Mcm. Table 2-2 shows the gas contents for the three seams. After the Dayong coalfield reserve addition, the mine boundaries will have an estimated CBM resource of 2 Bcm.

Coal Seam	No. 3	No. 7	No. 18
Original gas content (m^3/t)	12.63	15.06	15.62

Table 2-2: Reported Gas Content of the Coal Seams in the existing mining area (m^3/t)

2.6 Mine Operations

The Liulong Mine is designated as a coal and gas outburst mine. Under Chinese regulations the minimum size for an existing coal and gas outburst mine is 450,000 tpa, an increase from the 2014 standard of 300,000 tpa. Current coal production at the Liulong mine is 1,500 tons per day (tpd), or 547,500 tpa.

The industrial plant and mine offices for the Liulong Coal Mine are located in Mitangtian village in the hills above Liuzhi District, Liupanshui City. The surface plant includes an office building with dormitories, a bathhouse, and a material storage yard. The mine employs the adit incline shaft, a multilevel mining development method. Three shafts are used within the mine layout – the main adit, an intake shaft, and a return-air exhaust shaft. A steel rail is laid inside the shaft for the transportation of coal, materials, equipment, and for ventilation and pipe installation. The elevation of the main adit is 1,502 m above sea level. The intake shaft has an elevation of 1,565 m above sea level, with a net cross section of 8.5 square meters (m^2) and a base cross section of 9.5 m^2. The return-air exhaust shaft is at an elevation of 1,580 m above sea level, with a net cross section of 8.5 m^2, and an excavated section of 9.5 m^2.

The mining elevation of Liulong Mine is between 1,000 m and 1,600 m above sea level. In addition to the three coal seams that are mineable – the No. 3, No. 7, and No. 18 seams – the No. 9 seam can be used for drainage galleries, but coal production is not feasible. The No. 3, No. 7, and No. 9 coals seams in the existing mining operation extend to the Dayong Addition. At present, there are two coal faces in production, panels 1033 (No. 3 Seam) and 1071 (No. 7 Seam), and two tunneling faces including 1071 and 1074. The 1074 return airway is under reconstruction, and the drainage ways for panels 1076 and 1075 are being prepared for tunneling.

Because of the coal seam dip angle and the characteristics of the coal structure, the Liulong Mine has adopted the strike and retreat long wall mining methods. For the No. 3 Seam, the mine uses the gob-side entry retaining strike long wall retreat mining method, and the No. 7 seam uses the strike long wall inclined layering retreat mining method.

2.7 Mine Ventilation and Methane Drainage

The Liulong Mine maintains a gas drainage system to supplement the ventilation system.

2.7.1 Mine Ventilation

The main adit and inclined shafts are used as intake shafts, and there is one exhaust shaft. The independent exhaust system is set in the mining section and along the development face. At the working faces, the mine employs the common U-shape ventilation method. Nominal air flow is 42 to 93 cubic meters per second (m^3/s), air pressure is 625 to 2,360 pascals (Pa), and the two reversible exhaust fans are rated at 110 kW each. The average VAM concentration is 0.12 percent. The ventilation flow rate is expected to increase significantly as the existing operation increases coal production and mining expands to the Dayong Addition. Methane concentrations in mine ventilation air will be heavily dependent on the rate of mining, the ventilation flow rates, and success in implementing an extensive and effective gas drainage program.

2.7.2 Gas Drainage System for the Current Mining Operation

The Liulong Mine utilizes short cross panel boreholes for degassing, which can be a very effective method; however, the coals in Liupanshui are very friable and susceptible to borehole collapse. As a result, this method has met limited success at the Liulong Mine. As an alternative, BMG has been considering utilizing in-seam boreholes drilled from an underlying gallery below the mined seam. According to presentations delivered at the Guizhou Gas Exploration and Development Workshop held in Guiyang, Guizhou, China in December 2015, there is growing interest in this degasification approach in Guizhou (GICCEP, 2015). This method, though, is more expensive than traditional gas drainage approaches, and can be cost-prohibitive. Figure 2-3 presents a side-view of the underlying drainage gallery concept now being considered at the Liulong Mine and some other mines in Guizhou Province. BMG is also interested in vertical pre-drainage boreholes drilled from the surface. BMG reports that Liupanshui City has previously drilled two or three pilot CBM wells although the results were not made public. However, as noted in Section 2.3, logistical and legal barriers limit the potential use of surface pre-drainage and, as such, this pre-feasibility study does not consider surface pre-drainage as a viable degassing technology for the near-term.

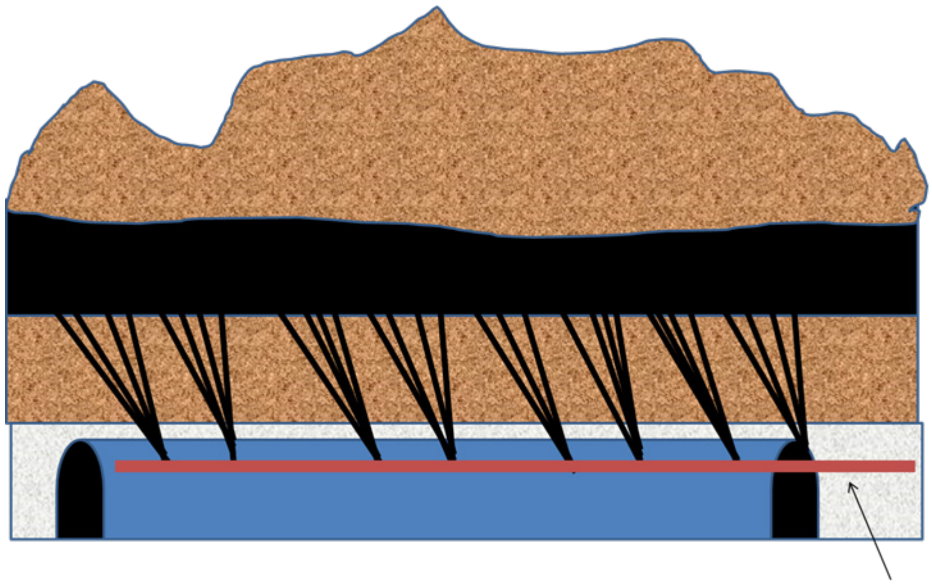


Figure 2-3: Cross-Measure Boreholes Drilled from a Gallery below the Mined Seam

The mine maintains a permanent drainage system. The system is normally active when mine development and coal production is occurring. The drainage system consists of two 2BEC-420 high negative pressure drainage pumps with 160 kW of motor power, a maximum pressure of 16,000 Pa, a revolving speed of 390 rotations per minute (rpm), and a maximum pumping speed of 126 cubic meters per minute (m^3/min). Additionally, there are two 2BEA-303 low negative pressure drainage pumps with 75 kW of motor power, a maximum pressure of 3,300 Pa, a revolving speed of 590 rpm, and a maximum pumping speed of 52 m^3/min. The system also consists of high and low negative pressure drainage pipelines with diameters of 400 mm. The high negative pressure drainage pipeline travels from the exhaust rise to a horizontal level of 1,350 m above sea level and to the drive surfaces. Placement of the low negative pressure pipeline is in the exhaust airway at the surface with an elevation of 1,033 m above sea level. In 2014, the gas drainage volume from the mine was 2.76 Mcm with a CH_4 concentration ranging from 8 percent to 30 percent, and an average concentration of 21 percent CH_4. A new working face in 2016 has reportedly increased gas production to 500,000 m^3 per month, effectively doubling the volume of CMM produced.

The coal mine has installed a sophisticated KJ90NB CMM monitoring system, comprised of two dedicated monitoring computers along with one standby KJ90NA system (Figure 2-4). The system includes gas sensors, negative pressure transducers, equipment on/off transducers, air velocity transducers, and water level sensors that provide mine staff with real-time continuous monitoring. The control room includes a large monitor where continuous data is shown (Figure 2-5). Alarms are triggered if any readings are outside of expected ranges. The system also includes cameras throughout the mine to provide live feedback from underground operations to the control room, and a diagram of the mine layout showing the location and movement of all staff underground (Figure 2-6).

Figure 2-4: Liulong Mine State-of-the Art Control and Monitoring Room

Figure 2-5: Screen Providing Real-Time Feedback on CH_4 percent, Air Velocity, Etc.

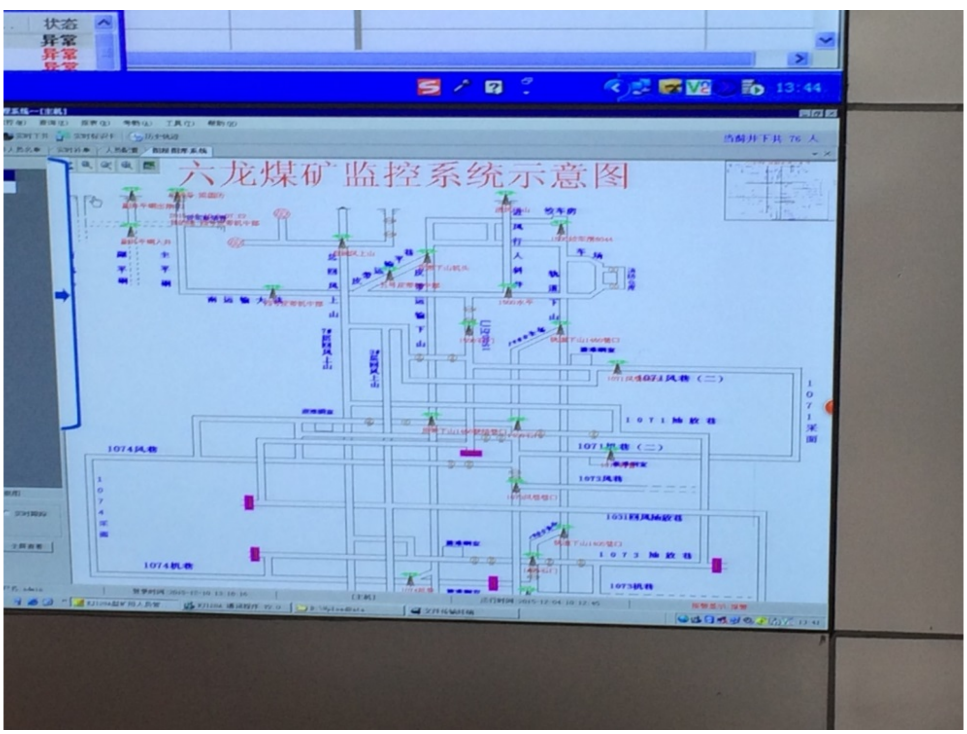


Figure 2-6: Real-time Tracking System for Workers in the Underground Operations

3 Evaluation of Methane Drainage Concepts and Gas Forecast

The purpose of this pre-feasibility study is to determine the technical and economic viability of a CMM capture and utilization project at the Liulong Mine. After an initial assessment of the site geology and consideration of various drainage options, the recommended design incorporates the use of either in-seam pre-drainage boreholes or horizontal gob boreholes, and utilizes the drained gas to generate electricity for on-site consumption. The forecasted gas production profile for each methane drainage scenario is presented below, forming the basis of the economic analyses performed in Section 5.

3.1 Proposed Gas Drainage Concepts

Based on a detailed review of available mine data, several directional drilling concepts for methane drainage at the Liulong Mine are proposed. The proposed gas drainage concepts focus on the current mining district with examples applied to the No. 7 Seam, from which most of the coal is currently produced. However, it is envisioned that the proposed drilling concepts could also be applied to the panels in the Dayong reserve addition.

For modeling purposes, the longwall panels are short on all mining levels, approximately 250 m long with 100 m wide faces. Longwall mining is in retreat, with the panels developed on strike with the faces dipping 29 degrees. The mine's current methane drainage practice is to use short cross-panel boreholes drilled in a parallel pattern from a side gallery. However, this method has not proven effective because the coals are friable, leading to borehole collapse. The proposed drainage concepts for the CMM project at the Liulong Mine are outlined below. While these concepts, as shown, apply to the No. 7 Seam only, it is assumed that similar concepts will apply to the No. 3 Seam as well.

3.1.1 In-Seam Pre-Drainage Boreholes

As illustrated in Figure 3-1 and Figure 3-2 (plan and profile view, respectively), the first concept is the application of in-seam boreholes implemented from the rock gallery (or other lower elevation gallery) that penetrate up into the mining seam at intervals of 30 m. The objective of this concept is to provide additional reach, potentially mitigate the underlying drainage galleries, and provide for more drainage time, which could possibly enable larger borehole spacing. The boreholes that penetrate the seam can be drilled into the seam as drilling allows (high pressure, soft, or friable coal). These boreholes could be developed from mains or other adjacent galleries and drilled significantly in advance of mining or rock drainage gallery development.

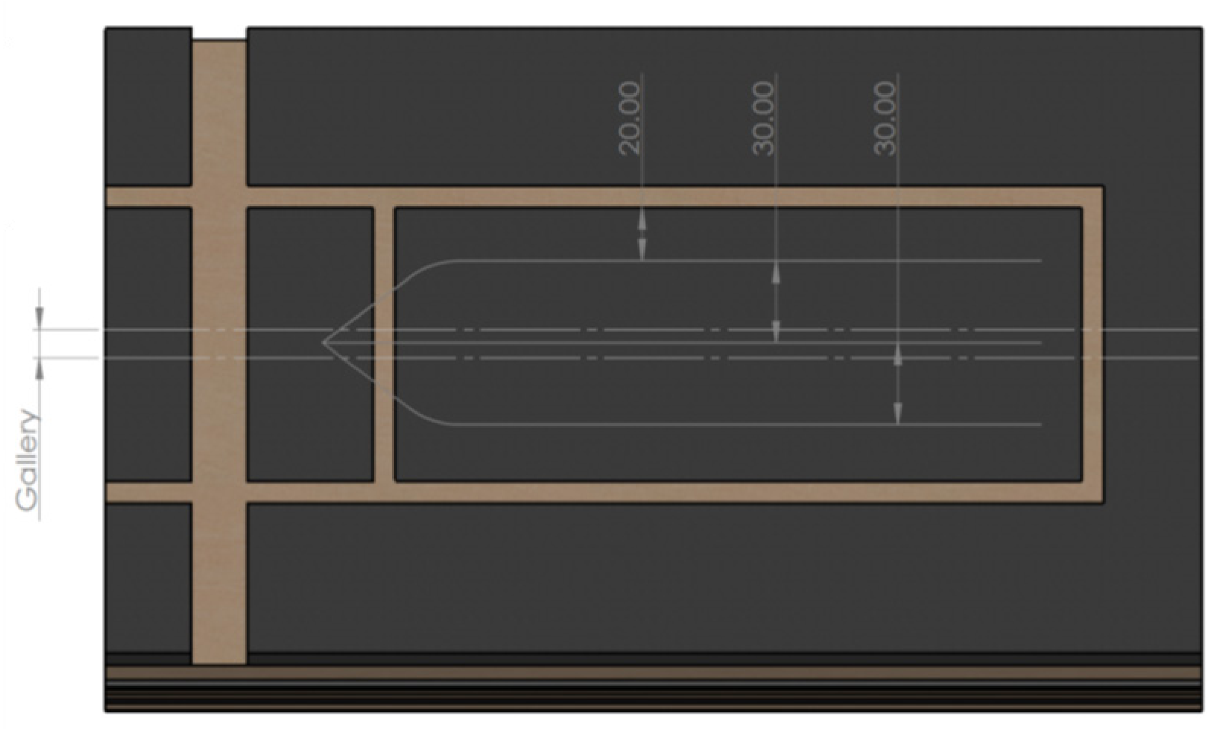


Figure 3-1: Horizontal Trunkline Boreholes Drilled from Underlying Gallery with Branchline Boreholes Drilled Upwards into Coal Seam (Plan View)

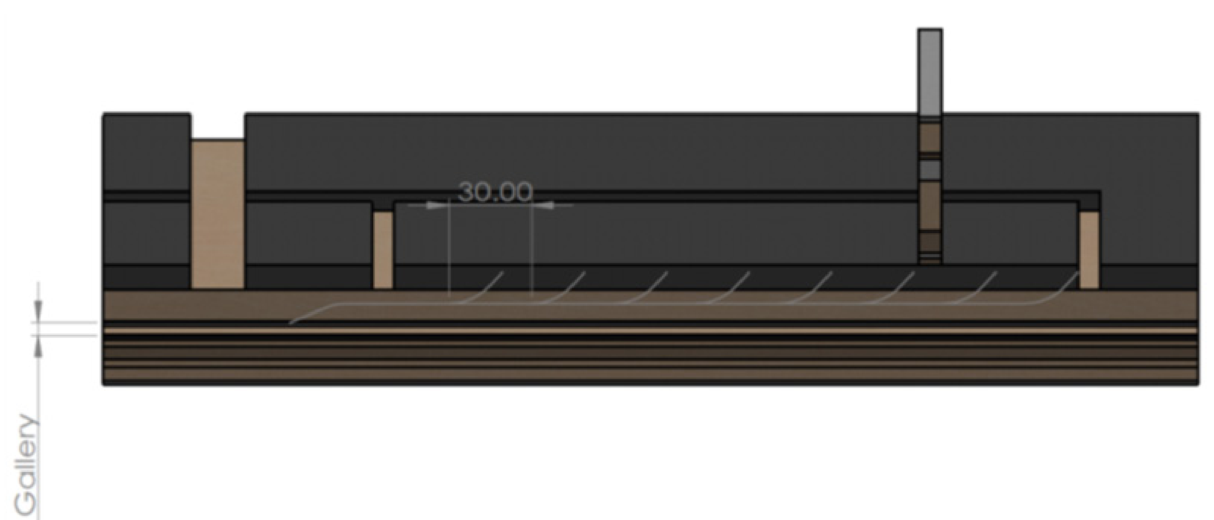


Figure 3-2: Horizontal Trunkline Boreholes Drilled from Underlying Gallery with Branchline Boreholes Drilled Upwards into Coal Seam (Profile View)

3.1.2 Horizontal Gob Boreholes

The second concept is the application of horizontal gob boreholes (HGBs). Although there is no information that quantifies that gob gas emissions are significant relative to methane emissions from the mined seam, the data indicates that all surrounding strata are gassy. Because the panels in the current mining district are short, drilling can originate out of the gateroads, from mains, or as shown on the concept illustration (Figure 3-3). Three HGBs are proposed at varying heights on the up-dip side of the panels along the low pressure return airway (Figure 3-4).

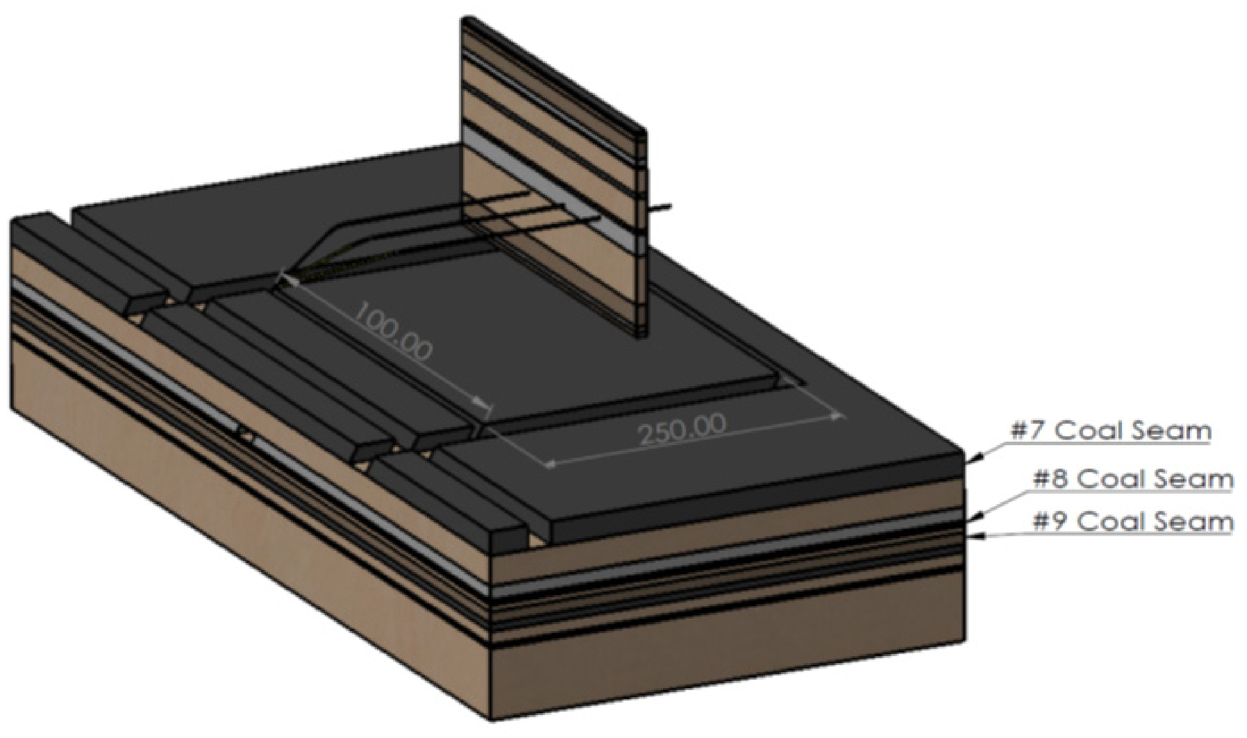


Figure 3-3: Horizontal Gob Boreholes Drilled from Mining Level

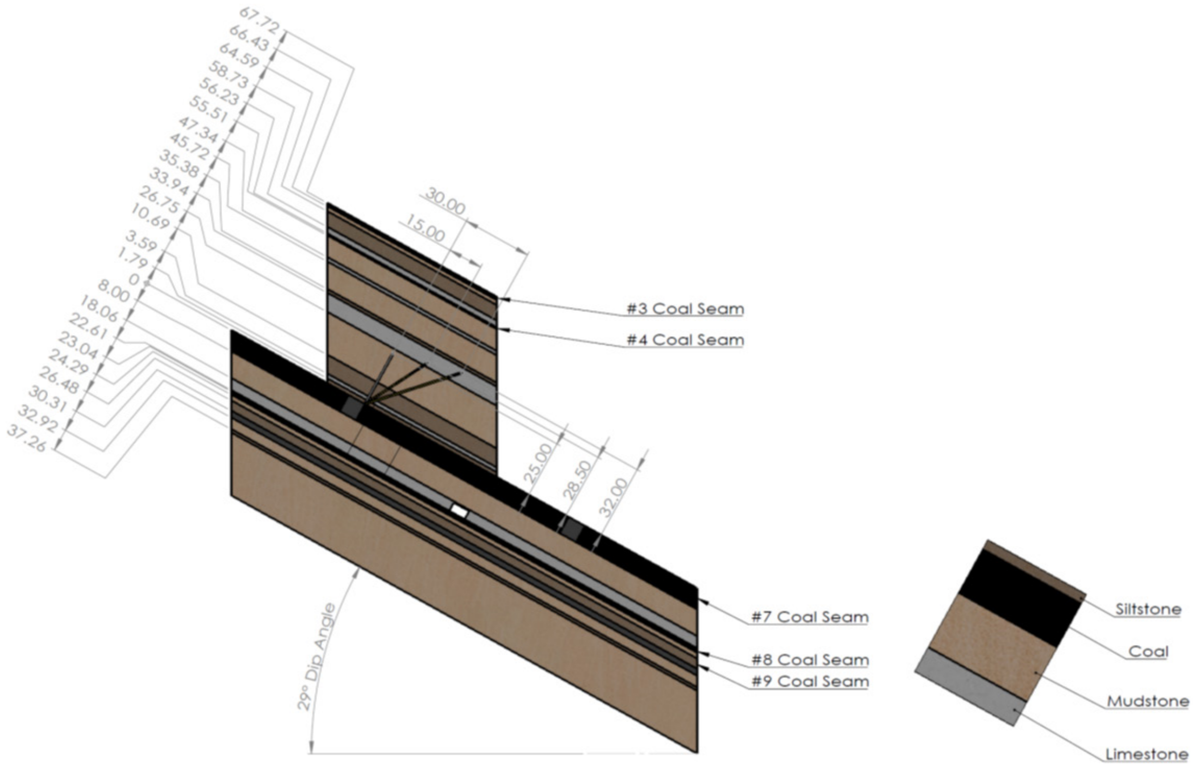


Figure 3-4: Horizontal Gob Boreholes Drilled from Mining Level (Profile View)

3.2 Estimating Gas Production from In-Seam Pre-Drainage Boreholes

A series of reservoir models designed to simulate gas production volumes from in-seam pre-drainage boreholes were constructed. The following sections discuss the construction of the gas drainage borehole models, the input parameters used to populate the reservoir simulation models, and the simulation results.

3.2.1 Simulation Models

Four, single-layer models were constructed to calculate gas production for a longwall panel located within the current mining district. One model for each seam was designed to simulate production from in-seam boreholes implemented from the rock gallery (or other lower elevation gallery) that penetrate up into the mining seam at intervals of 30 m. Two additional models (one for each seam) were developed to explore an alternative spacing case where the in-seam boreholes penetrate up into the mining seam at intervals of 10 m. All boreholes are drilled into a longwall panel with the face dipping at an angle of 29 degrees and are assumed to be 250 m in lateral length. The models were run for ten years to simulate gas production rates and cumulative production volumes from each seam within a typical longwall panel in the current mining area.

A typical longwall panel at the mine targeting either the No. 3 or No. 7 seam is estimated to have a face width of 100 m and a panel length of 250 m covering an aerial extent of 2.5 hectare (ha) (or 6 acres). Based on these dimensions, model grids were created to accommodate each of the well spacing scenarios. The model grid setup for the 30 m spacing case consisted of 25 grid-blocks in the x-direction, 50 grid-blocks in the y-direction, and one grid-block in the z-direction, while the model grid setup for the 10 m spacing case consisted of 25 grid-blocks in the x-direction, 34 grid-blocks in the y-direction, and one grid-block in the z-direction. The model layouts for the in-seam pre-drainage concepts are illustrated in Figure 3-5, Figure 3-6, and Figure 3-7, which show an example simulation model from plan, profile, and 3D view, respectively.

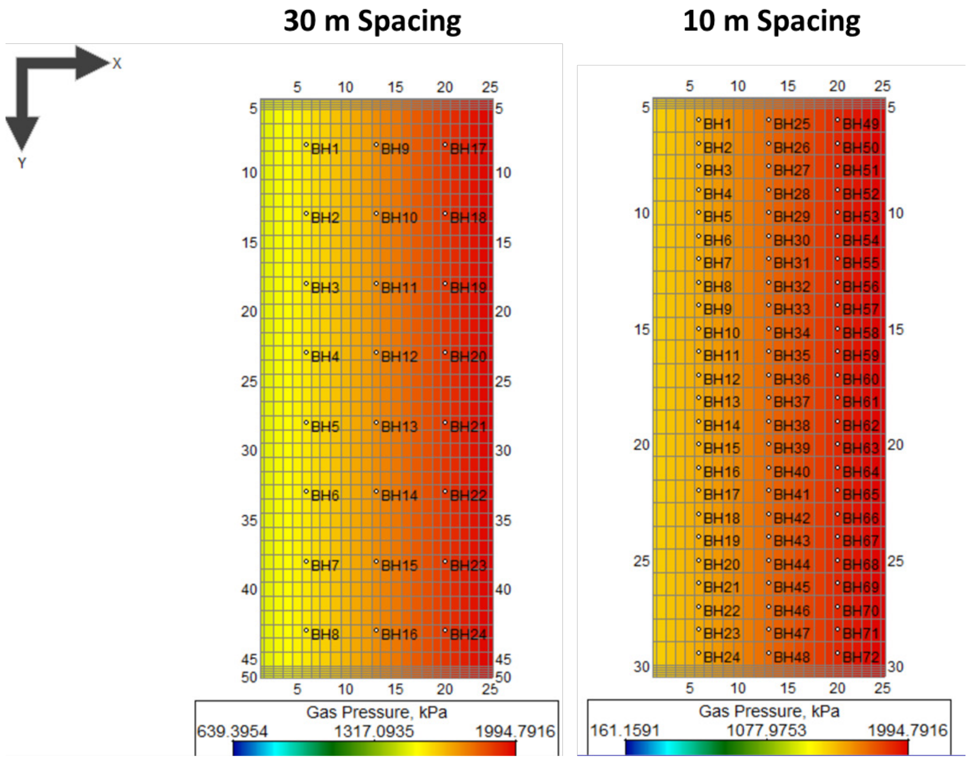


Figure 3-5: Example Model Layout for In-Seam Pre-Drainage Boreholes (Plan View)

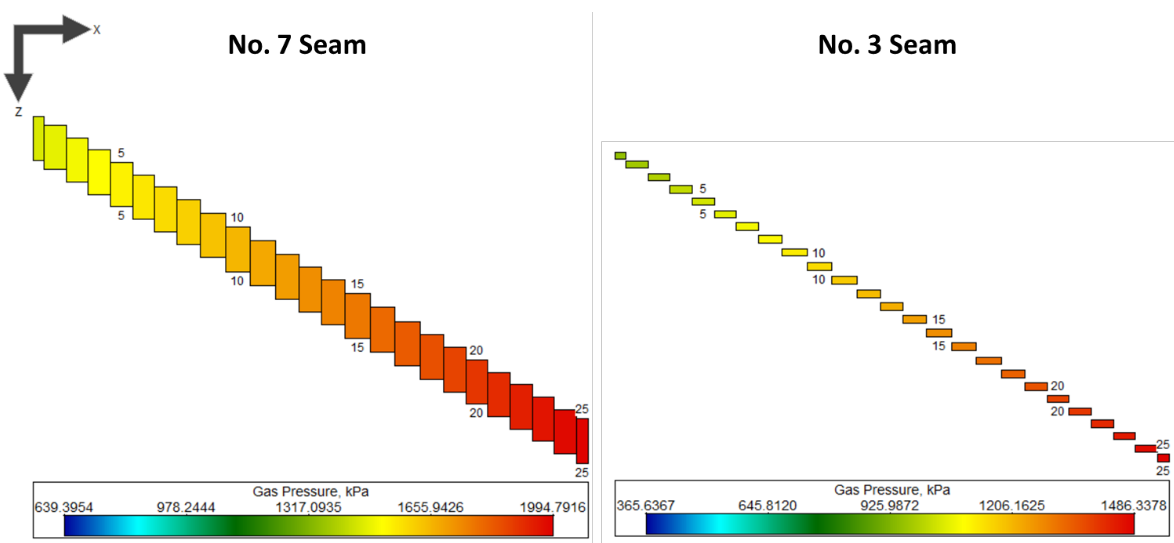


Figure 3-6: Example Model Layout for In-Seam Pre-Drainage Boreholes (Profile View)

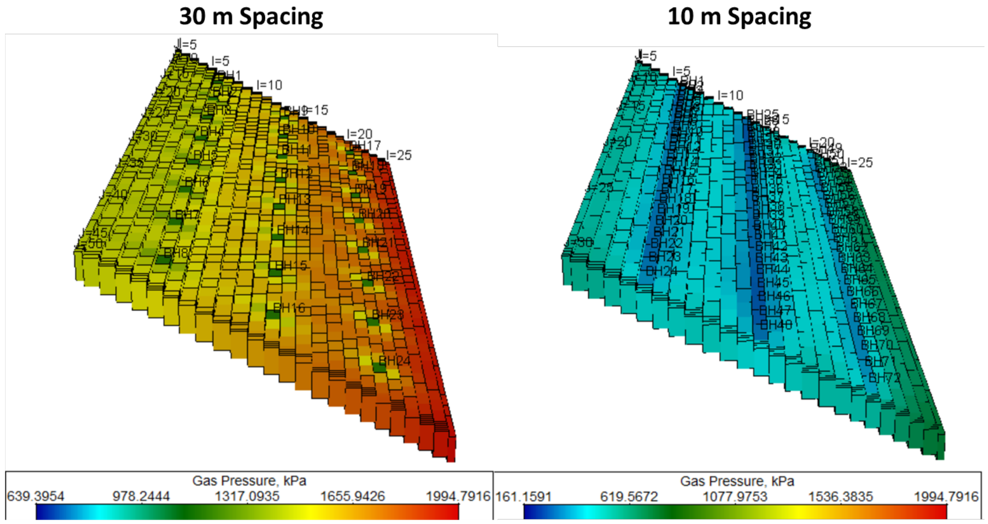


Figure 3-7: Example Model Layout for In-Seam Pre-Drainage Boreholes (3D View)

3.2.2 Model Preparation and Runs

The input data used to populate the reservoir model was obtained primarily from the mine's geologic and reservoir data. Where appropriate, supplemental geological and reservoir data from analogous projects were also used. The input parameters used in the reservoir simulation study are presented in Table 3-1, followed by a brief discussion of the most important reservoir parameters.

Reservoir Parameter	Value(s)		Notes
	Seam 3	Seam 7	
Seam Elevation (TOP), m above MSL	1496	1420	Mine data from Area 1; Core hole No. 24
Coal Depth (TOP), m	80	149	Mine data from Area 1; Core hole No. 24
Coal Thickness, m	1.3	8.0	Mine data from Area 1; Core hole No. 24
Coal Density, g/cc	1.62	1.39	Mine data
Pressure Gradient, kPa/m^3	11.94	9.51	Calculated from reservoir pressure and depth
Initial Reservoir Pressure, kPa	950	1420	Mine data; Top of each seam
Initial Water Saturation, percent	100	100	Assumption
Langmuir Volume, m^3/tonne	28.97	28.15	Mine data; Isotherm analysis
Langmuir Pressure, kPa	1126	1045	Mine data; Isotherm analysis
In Situ Gas Content, m^3/tonne	12.63	15.06	Mine data
Desorption Pressure, kPa	870	1202	Calculated based on in situ gas content and maximum storage capacity from isotherm
Sorption Times, days	10	10	Assumption
Fracture Spacing, cm	2.54	2.54	Assumption
Dip Angle of Face, degrees	29	29	Based on Area 1 mine data
Absolute Cleat Permeability, md	0.55	0.55	Mine data; midpoint of range (0.1 to 1 md)
Cleat Porosity, percent	5.55	4.32	Mine data
Relative Permeability	Curve	Curve	Assumption; See Figure 3-10
Pore Volume Compressibility, kPa^{-1}	2.76E-03	2.76E-03	Assumption
Matrix Shrinkage Compressibility, kPa^{-1}	0.00E+00	0.00E+00	None
Gas Gravity	0.6	0.6	Assumption
Water Viscosity, (mPa·s)	0.8	0.8	Assumption
Water Formation Volume Factor, reservoir barrel per stock tank barrel (RB/STB)	1.00	1.00	Calculation
Completion and Stimulation	Assumes skin factor of zero		
Borehole Operation	In-mine pipeline with surface vacuum station providing vacuum pressure of 16 kPa		
Borehole Spacing	Two cases: In-seam boreholes implemented from rock gallery (spaced 30 m apart) that penetrate up into seams at intervals of 30 m (Case 1) and 10 m (Case 2)		

Table 3-1: Reservoir Parameters for Simulation of In-Seam Pre-Drainage Boreholes

3.2.2.1 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 seams range from 0.1 milidarcy (md) to 1 md. The permeability value for both seams is assumed to be 0.55 md, which represents the midpoint of the permeability range provided.

3.2.2.2 Langmuir Volume and Pressure

Based on the laboratory measured Langmuir volumes and pressures for the No. 3 and No. 7 seams in the current mine area, the corresponding Langmuir volumes and Langmuir pressures used in the reservoir simulation models are 28.97 cubic meters per tonne (m^3/t) and 1,126 kilopascal (KPa), respectively, for the No. 3 Seam, and 28.15 m^3/t and 1,045 KPa, respectively, for the No. 7 Seam. Figure 3-8 and Figure 3-9 depict the methane isotherms utilized in the simulation for the in-seam pre-drainage boreholes for the No. 3 and No. 7 seams, respectively.

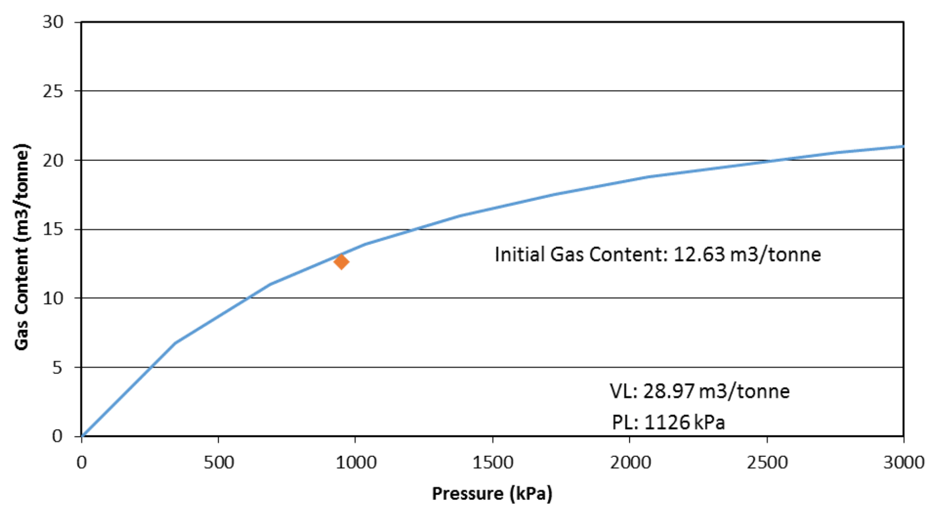


Figure 3-8: Methane Isotherm Used in Simulation of In-Seam Pre-Drainage Boreholes in the No. 3 Seam

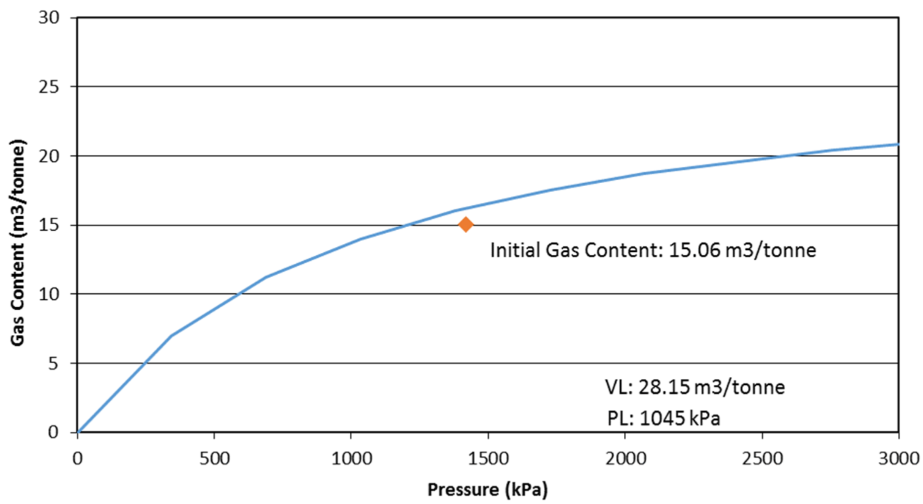


Figure 3-9: Methane Isotherm Used in Simulation of In-Seam Pre-Drainage Boreholes in the No. 7 Seam

3.2.2.3 Gas Content

Based on the results of gas desorption analyses conducted on coal samples from the No. 3 and No. 7 seams, an initial gas content value of 12.63 m^3/t was used in the simulation study for the No. 3 Seam, and 15.06 m^3/t was used in the No. 7 Seam simulations. As shown in Figure 3-8 and Figure 3-9, the coal seams are slightly undersaturated, with respect to gas, at 95 percent and 93 percent saturation for the No. 3 and No. 7 seams, respectively.

3.2.2.4 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 and pore space in the 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 multiple fluid phases (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 project area was unavailable. Therefore, the relative permeability curve used in the simulation study was obtained from the results of reservoir simulation study performed in the region. Figure 3-10 is a graph of the relative permeability curves used in the reservoir simulation of the study area.

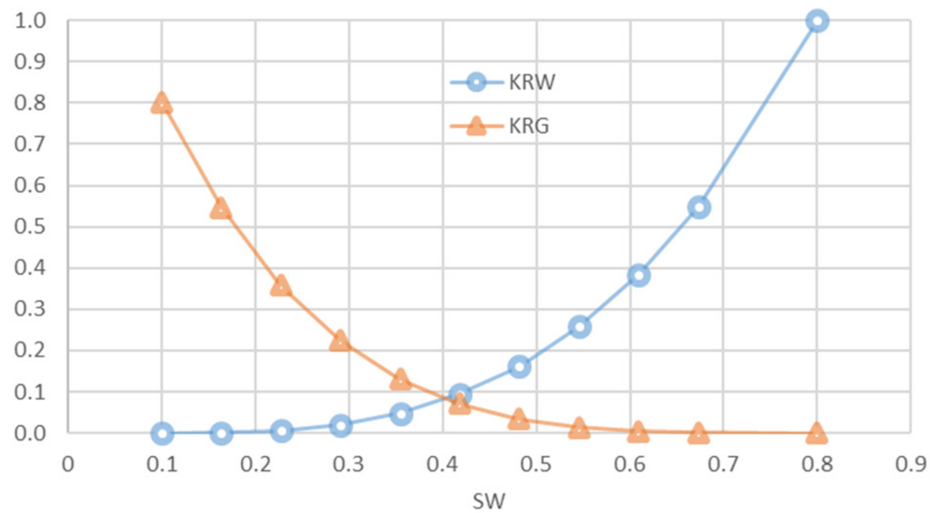


Figure 3-10: Relative Permeability Curve Used in Simulation

3.2.2.5 Coal Seam Depth and Thickness

Based on corehole No. 24 located in Area 1, the elevation of the No. 3 Seam floor is 1,496 m above sea level with a seam thickness of 1.3 m, while the elevation of the No. 7 Seam floor is 1,420 m above sea level with a seam thickness of 8 m. For modeling purposes, a depth from surface to the top of the coal reservoir of 80 m and 149 m was used for the No. 3 and No. 7 seams, respectively. All coal faces were assumed to dip by 29 degrees.

3.2.2.6 Reservoir and Desorption Pressure

An initial reservoir pressure of 1,126 kPa and 1,420 kPa was reported by the mine at the top of the No. 3 and No. 7 seams, respectively, which correspond to hydrostatic pressure gradients of 11.94 and 9.51 kPa/m. Because the coal seam is assumed to be undersaturated with respect to gas, desorption pressures of 870 and 1,202 kPa are calculated based on in situ gas contents and maximum storage capacity from the isotherms for the No. 3 and No. 7 seams, respectively.

3.2.2.7 Porosity and Initial Water Saturation

Porosity is a measure of the void space in a material. Based on the data for the No. 3 and No. 7 seams, porosity values of 5.55 percent and 4.32 percent were used in the simulations. The cleat and natural fracture system in the reservoir was assumed to be 100 percent water saturated.

3.2.2.8 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 10-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.

3.2.2.9 Fracture Spacing

A fracture spacing of 2.54 centimeters (cm) was assumed in the simulations, which is consistent with data in the region. In the model, fracture spacing is only used for calculation of diffusion coefficients for different shapes of matrix elements and it does not materially affect the simulation results.

3.2.2.10 Borehole Spacing

As discussed previously, in-seam boreholes implemented from the rock gallery (or other lower elevation gallery) that penetrate up into the mining seam at intervals of 30 m are proposed. An alternative case is also explored where in-seam boreholes penetrate up into the mining seam at intervals of 10 m. For both cases, three separate branches will be drilled with the central branch running down the center of the panel and the adjacent branches spaced at 30 m from the central branch.

3.2.2.11 Completion

In-seam boreholes with lateral lengths of 250 m are drilled and completed in the longwall panel. For modeling purposes, a skin value of zero is assumed.

3.2.2.12 Borehole Operation

An in-mine pipeline with a surface vacuum station providing a vacuum pressure of 16 kPa was assumed. In coal mine methane operations, low borehole pressure is required to achieve maximum gas content reduction. The wells were produced for a total of ten years.

3.2.3 Model Results

As noted previously, four reservoir models were created to simulate gas production for the current mine area at the Liulong Mine. The models were run for a period of ten years and the resulting gas production profiles were calculated. Simulated gas production rate and cumulative gas production for a longwall panel developed in the No. 3 Seam using 30 m borehole spacing is shown in Figure 3-11, while Figure 3-12, Figure 3-13, and Figure 3-14 show the same results for the No. 7 Seam using 30 m borehole spacing, the No. 3 Seam using 10 m borehole spacing, and the No. 7 Seam using 10 m borehole spacing, respectively.

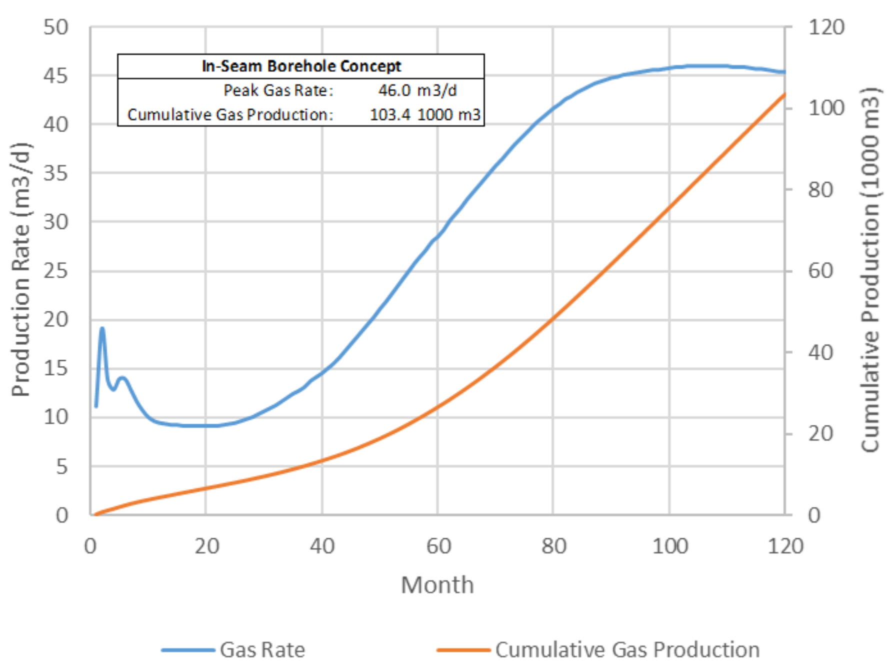


Figure 3-11: No. 3 Seam Simulation Results – Gas Rate and Cumulative Production at 30 m Spacing

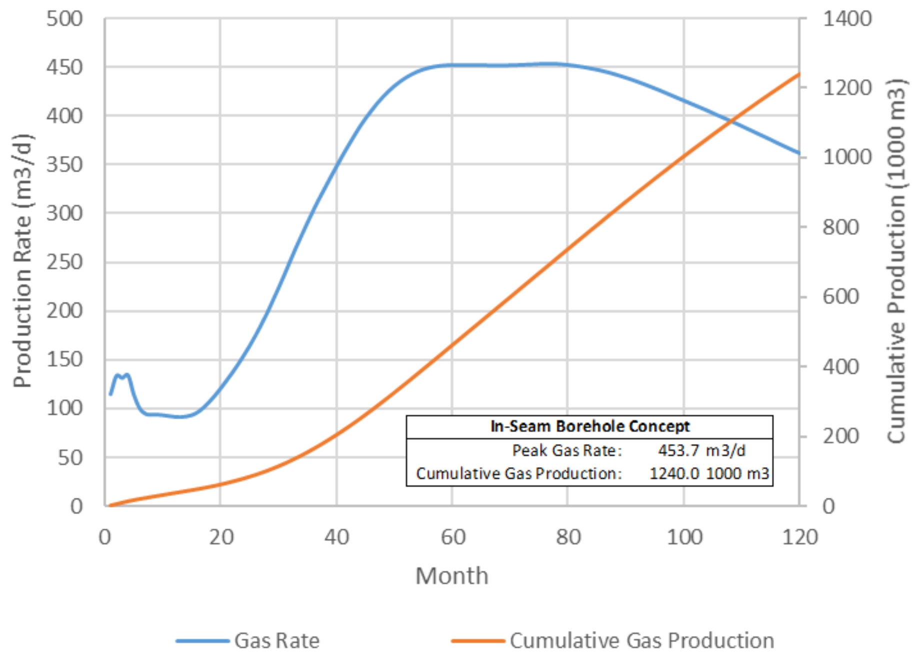


Figure 3-12: No. 7 Seam Simulation Results – Gas Rate and Cumulative Production at 30 m Spacing

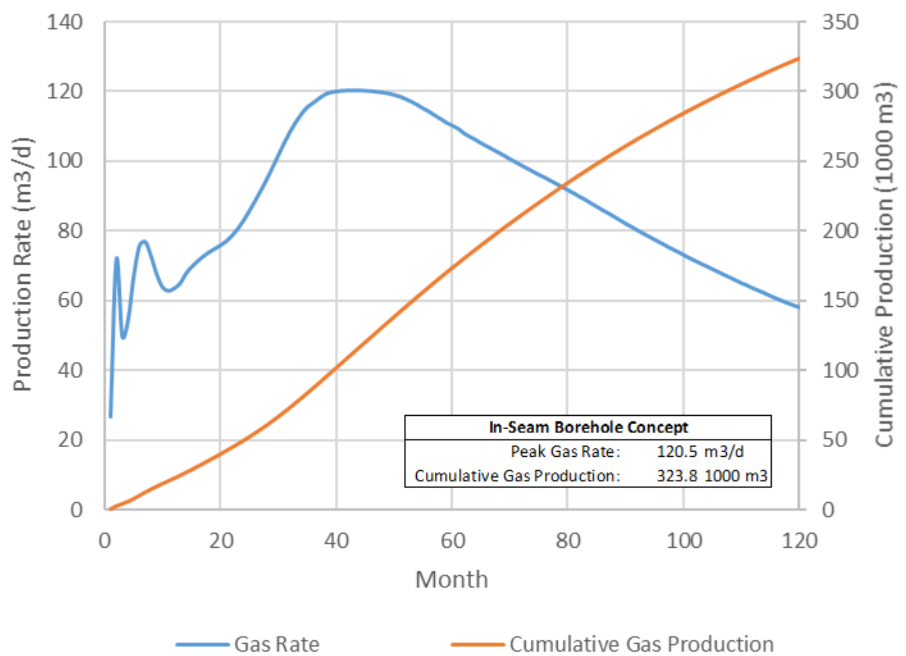


Figure 3-13: No. 3 Seam Simulation Results – Gas Rate and Cumulative Production at 10 m Spacing

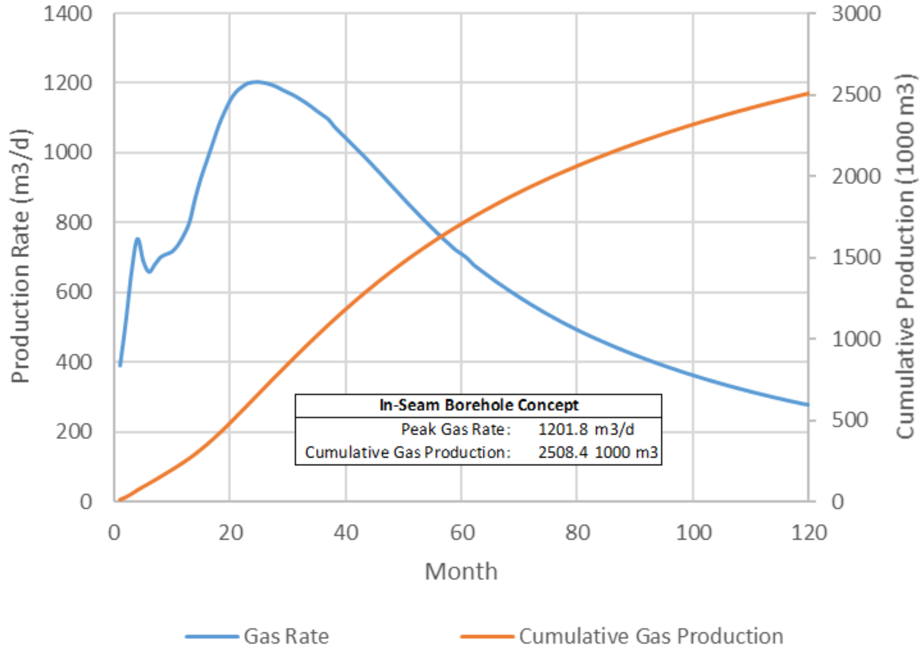


Figure 3-14: No. 7 Seam Simulation Results – Gas Rate and Cumulative Production at 10 m Spacing

Figure 3-15 shows the simulated reduction in in-situ gas content of the panel over time utilizing in-seam pre-drainage boreholes drilled into Seam No. 3 using a borehole spacing of 30 m. Likewise, Figure 3-16 through Figure 3-18 show the simulated reduction in in-situ methane for the other three models. Figure 3-19 through Figure 3-22 show the change in in-situ gas content over time in chart form for each of the four models.

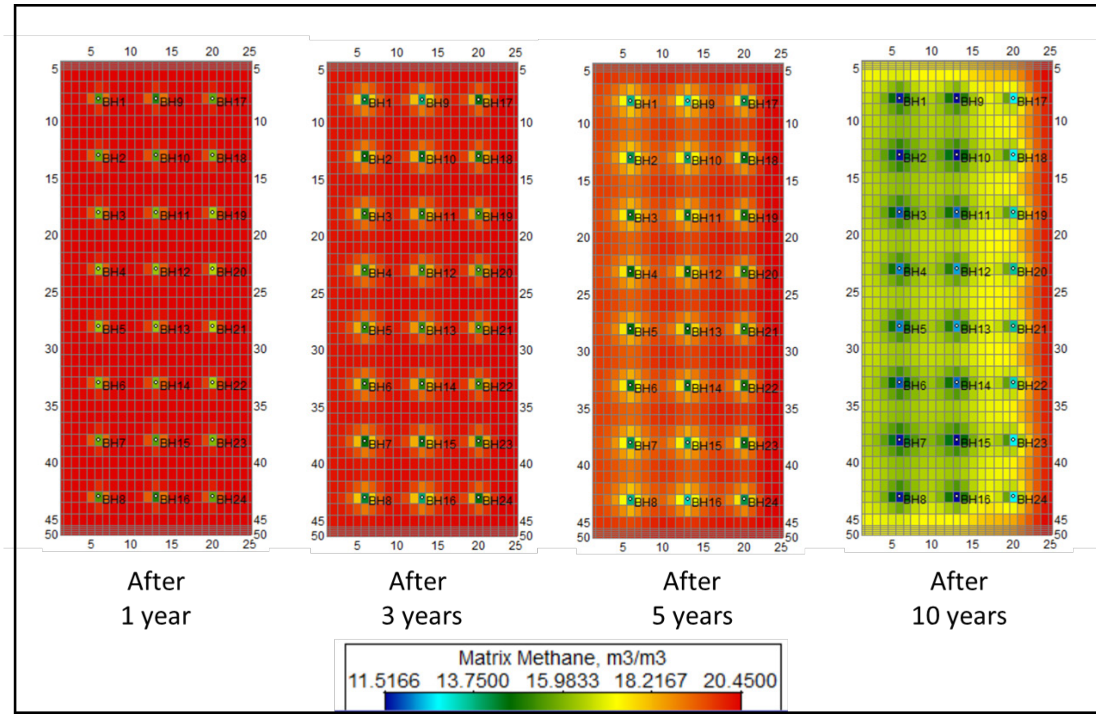


Figure 3-15: Reduction in In-Situ Gas Content Over Time Using In-Seam Pre-Drainage Boreholes – No. 3 Seam at 30 m Spacing

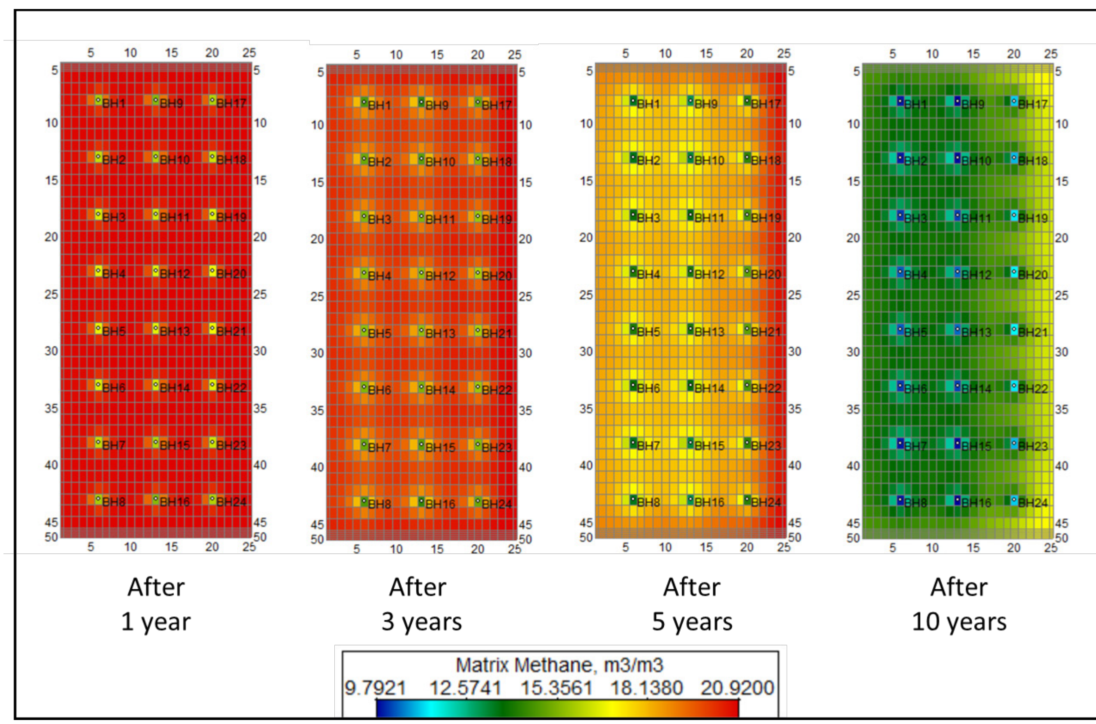


Figure 3-16: Reduction in In-Situ Gas Content Over Time Using In-Seam Pre-Drainage Boreholes – No. 7 Seam at 30 m Spacing

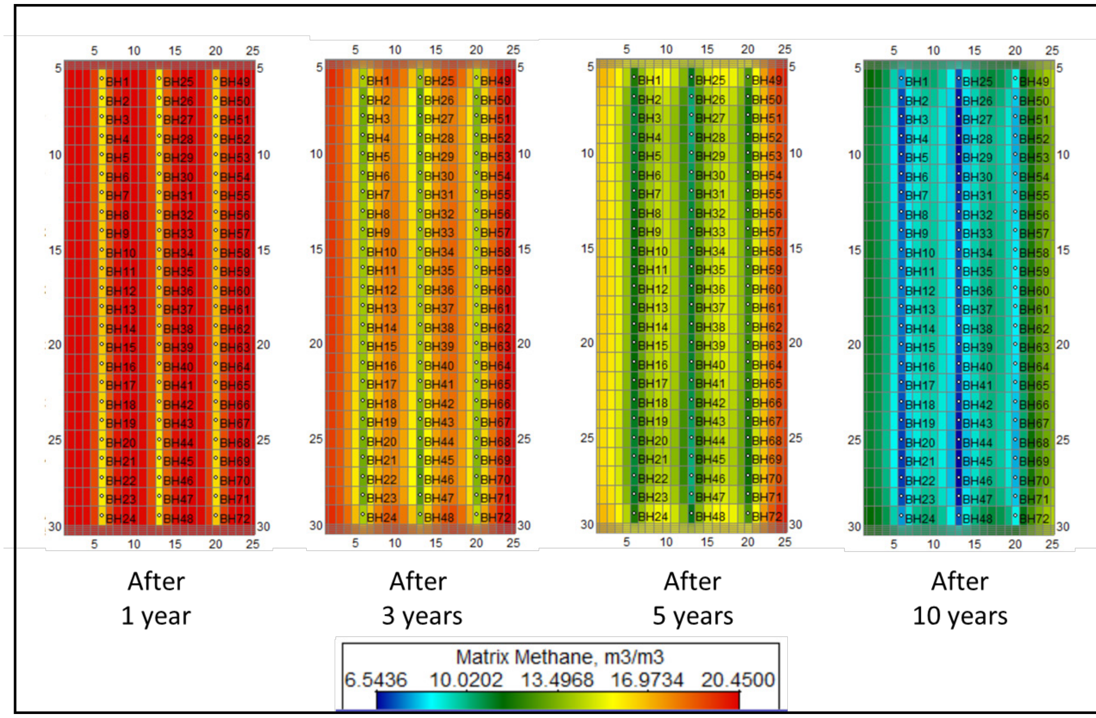


Figure 3-17: Reduction in In-Situ Gas Content Over Time Using In-Seam Pre-Drainage Boreholes – No. 3 Seam at 10 m Spacing

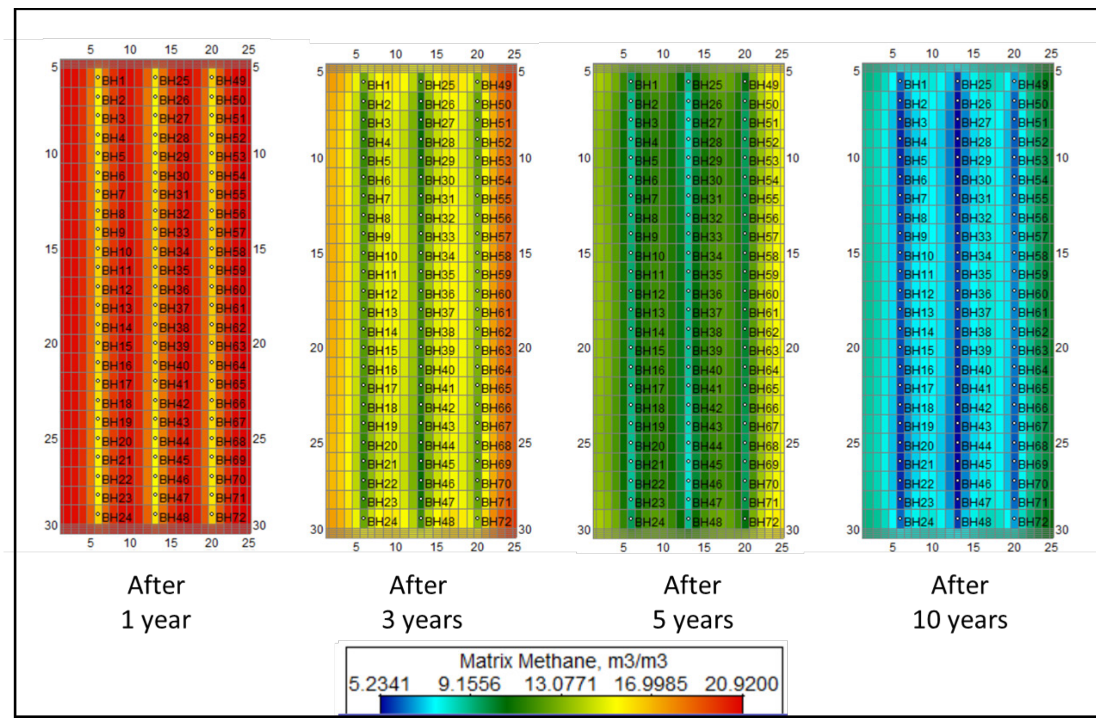


Figure 3-18: Reduction in In-Situ Gas Content Over Time Using In-Seam Pre-Drainage Boreholes – No. 7 Seam at 10 m Spacing

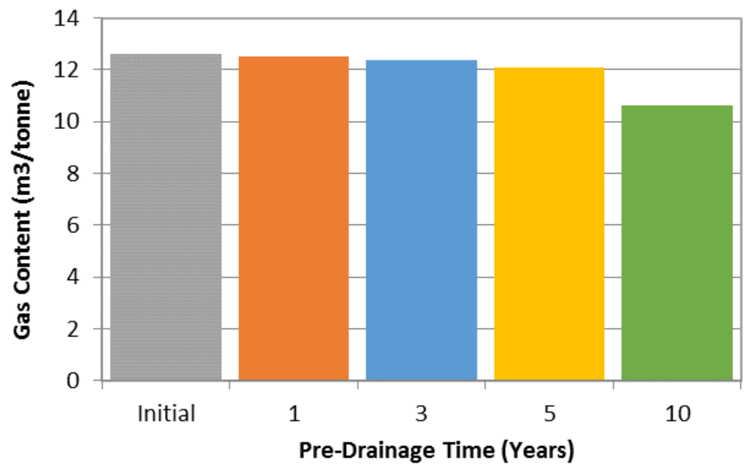


Figure 3-19: Summary of Reduction in In-Situ Gas Content Over Time Using In-Seam Pre-Drainage Boreholes – No. 3 Seam at 30 m Spacing

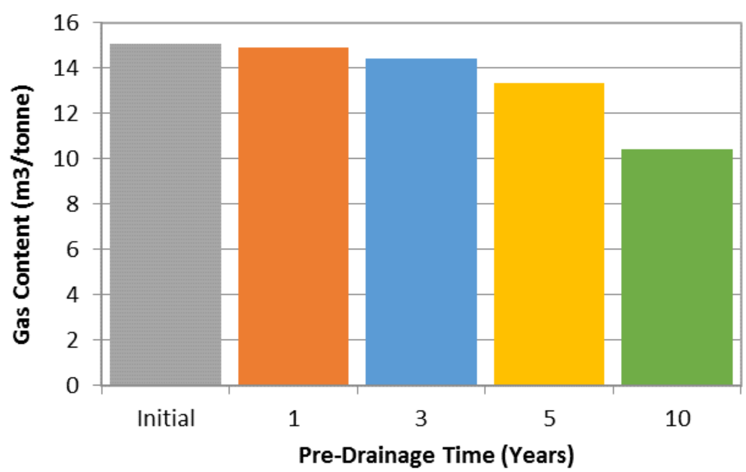


Figure 3-20: Summary of Reduction in In-Situ Gas Content Over Time Using In-Seam Pre-Drainage Boreholes – No. 7 Seam at 30 m Spacing

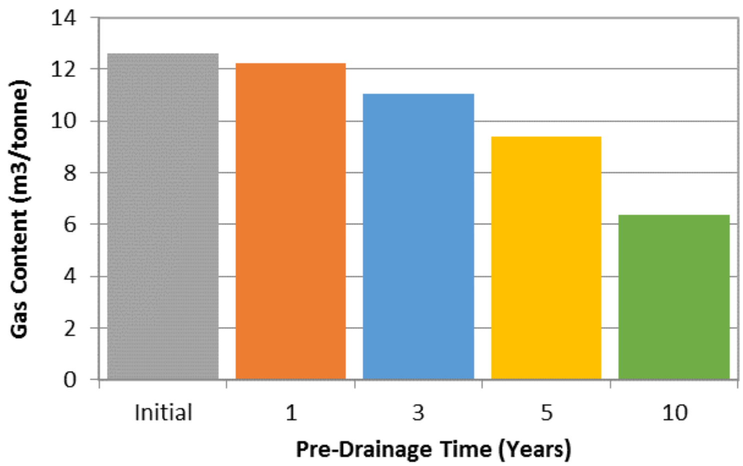


Figure 3-21: Summary of Reduction in In-Situ Gas Content Over Time Using In-Seam Pre-Drainage Boreholes – No. 3 Seam at 10 m Spacing

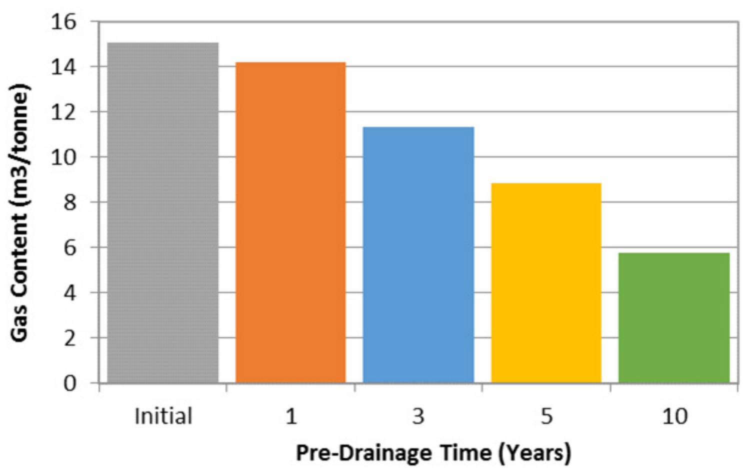


Figure 3-22: Summary of Reduction in In-Situ Gas Content Over Time Using In-Seam Pre-Drainage Boreholes – No. 7 Seam at 10 m Spacing

3.3 Estimating Gas Production from Horizontal Gob Boreholes

Estimating gas production (i.e., gob gas flow rate) from HGBs is difficult since gob gas flow rates typically fluctuate over time and vary with borehole length and configuration. HGB performance is a function of parameters such as borehole diameter, length, lining, wellhead vacuum, vertical placement above the mining seam, and lateral placement along tension zones. HGB gas flow rates are most influenced by borehole diameter, length, wellhead vacuum, and reservoir pressure contribution, while HGB effectiveness is attributed to parameters such as vertical placement above the longwall panel, lateral placement relative to tension zones along the gob, and wellhead/stand-pipe integrity (Brunner & Schumacher, 2012).

As discussed by Brunner and Schumacher (2012), gob gas flow rate can be approximated using the General Flow equation for the steady-state isothermal flow in a gas pipeline, which relates the pressure drop along a pipeline with flow rate. This approach utilizes adjustments to the friction factor to match collected data, and assumes that gob gas flow measured at the HGB collar originates from the end of the hole. The basic equation for steady-state isothermal flow in a gas pipeline, as recommended by Menon (2005), is provided below.

$$Q = 1.3303\,(10)^{-5}\left(\frac{T_b}{P_b}\right)\left[\frac{(P_1^2 - P_2^2)}{GT_f LZf}\right]^{0.5} D^{2.5}$$

Where:
Q = gas flow rate, measured at standard conditions, l/s
f = coefficient of friction, dimensionless
P_b = base (standard) pressure, kPa
T_b = base (standard) temperature, K
P_1 = upstream pressure, kPa
P_2 = downstream pressure, kPa
G = gas gravity (air = 1.0)
T_f = average gas flowing temperature, K
L = pipe length, km
Z = gas compressibility factor, dimensionless
D = pipe inside diameter, mm

Gob gas flow rates from HGBs placed above the No. 3 and No. 7 seams at Liulong Mine were estimated by applying the above equation based on the input parameter values summarized in Table 3-2. An average coefficient of friction of 0.0200, as derived from analysis by Brunner and Schumacher (2012), was used to estimate gob gas flow rates at currently achievable diameter and length configurations for varying wellhead vacuum pressures assuming a gob gas concentration of 70 percent methane in air. Mine operators typically drill HGBs between 75 mm and 150 mm in diameter. For the current analysis, gob gas flow rates for three borehole configurations – 96 mm, 121 mm, and 146 mm – were investigated. HGBs with borehole lengths of 250 m are planned for the Liulong Mine, which is well within the technical limits observed in the field, as mine operators routinely drill boreholes to lengths of up to 1,200 m. Based on the low vacuum (3.3 kPa) and high vacuum (16 kPa) drainage systems currently located at the Liulong Mine, two additional wellhead vacuum pressure cases were also investigated.

Parameter	Value
Coefficient of Friction, dimensionless	0.0200
Base (standard) Pressure, kPa	No. 3 Seam: 1179 No. 7 Seam: 1729
Base (standard) Temperature, K	293
Upstream Pressure, kPa	No. 3 Seam: 1179 No. 7 Seam: 1729
Downstream Pressure, kPa	Calculated based on wellhead vacuum pressure; 3.3 and 16 kPa cases investigated
Gas Gravity (air = 1.0)	0.6
Average Gas Flowing Temperature, K	293
Pipeline Length, km	0.25
Gas Compressibility Factor, dimensionless	Seam No. 3: 0.99 Seam No. 7: 0.98
Pipe Inside Diameter, mm	96, 121 and 146 mm cases investigated

Table 3-2: Horizontal Gob Borehole Model Inputs

Figure 3-23 and Figure 3-24 show the incremental increase in gob gas flow capacity as a function of wellhead vacuum and borehole diameter for a 250 m unlined HGB at 96 mm, 121 mm, and 146 mm drilled in the No. 3 and No. 7 seams, respectively. As illustrated in the exhibits, gob gas flow rates typically increase as both the borehole diameter and wellhead vacuum pressure increase. Assuming a HGB with a 121 mm borehole diameter placed on 16 kPa of vacuum pressure, gob gas flow rates are estimated to be between 92 to 111 liters per second (l/s), or 5.5 to 6.6 m^3/min (3.9 to 4.6 m^3/min of pure CH_4). Based on a panel length of 250 m and an average face advance rate of 2.5 meters per day (m/d), a longwall panel will take 100 days to mine through, resulting in an estimated total gob gas production for a single HGB placed above the No. 3 Seam of 956 thousand cubic meters (1000-m^3) (669 1000-m^3 of pure CH_4). If placed above the No. 7 Seam, a single HGB is estimated to produce 793 1000-m^3 of gob gas (555 1000-m^3 of pure CH_4). Strategic placement of the HGBs may allow borehole collars to remain intact and allow boreholes to remain productive after longwall mining is completed, which would further increase total gob gas production.

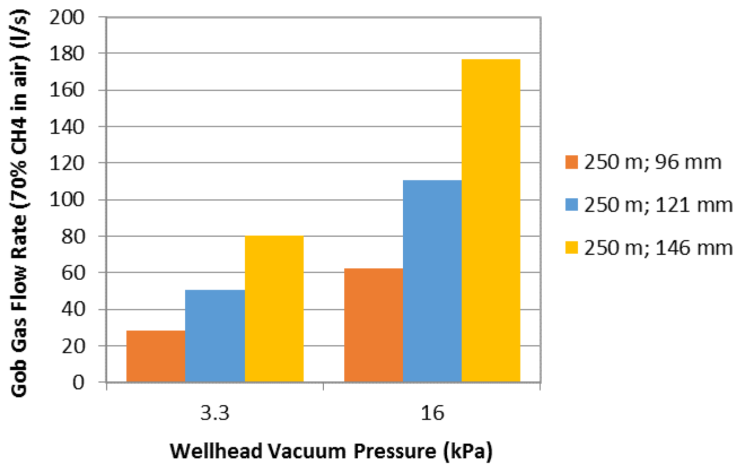


Figure 3-23: Gob Gas Flow Rate Projections for 250 m Horizontal Gob Borehole Configurations in Seam No. 3 at Varying Wellhead Vacuum (70 percent CH_4)

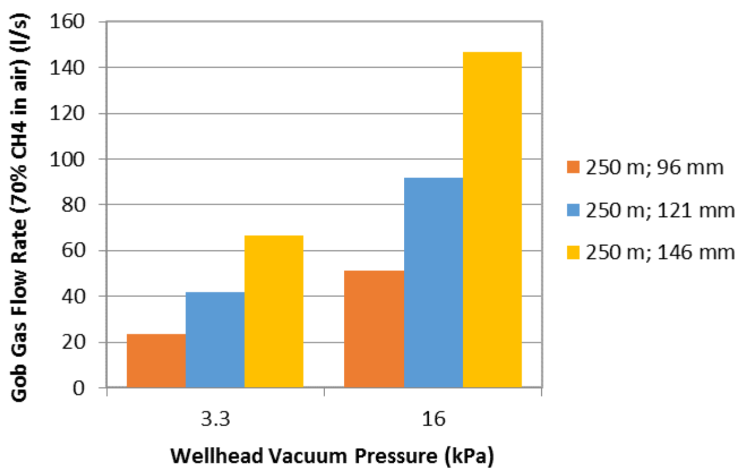


Figure 3-24: Gob Gas Flow Rate Projections for 250 m Horizontal Gob Borehole Configurations in Seam No. 7 at Varying Wellhead Vacuum (70 percent CH_4)

4 Market Information

CMM in China has evolved from a safety concern to a valued commodity and significant source of natural gas supply (USEPA, 2015). In 2011, the Chinese government's "Natural Gas Development Plan During the 12th Five-Year Plan Period" included CBM/CMM for the first time. This plan, which covered the years between 2011 and 2015, targeted the consumption of 20 Bcm of CBM/CMM by 2015 (USEPA, 2015). Furthermore, the "Twelfth Five-year Plan for CBM and CMM", which was more ambitious, called for total production to rise to 30 Bcm by 2015, with 16 Bcm coming from CBM and 14 Bcm coming from CMM. Utilization of CMM was targeted to rise to 8.4 Bcm, and construction of 13 pipelines with a total length of 2,000 km and 12 Bcm per year of total transport capacity was also called for (USEPA, 2015). The "Twelfth Five-year Plan for CBM and CMM" further targeted CMM to be primarily used for local power generation, called for an increase in the number of household users to 3.3 million, and called for CMM generating capacity to quadruple to 2,850 MW between 2010 and 2015 (USEPA, 2015).

Although CMM drainage and utilization is being heavily promoted by the Chinese government, there are still significant barriers to project development. China's natural gas market and infrastructure are underdeveloped considering that natural gas only accounts for approximately 5.6 percent of China's primary energy consumption (BP, 2017). Most Chinese cities and towns do not offer access to natural gas for the majority of their citizens. The locations of coal mines that produce CMM are mostly in remote mountainous areas with no access to natural gas distribution networks, and constructing pipelines in these remote areas is usually not feasible because of the difficult terrain.

In Guizhou Province, the primary utilization options for CMM are power generation and civil use. Guizhou is economically underdeveloped with little to no natural gas infrastructure, and in most cases, it is not feasible to construct pipeline systems to transport CMM from producing mines due to the province's terrain having vast differences in topographic highs and lows. Where the gas is being used, most mines use drained CMM to generate power for their own mining activities, reducing their energy costs with potential to sell any surplus energy back into the grid, as is the intention of BMG.

With respect to electricity, there are still significant barriers to selling surplus energy to the grid. The process of connecting to the grid is complicated and requires approval on the provincial level from the Development and Reform Commission, the Electricity Regulatory Office, the Planning Bureau, Price Bureau, Environmental Protection Bureau, Land and Resources Bureau, Power Supply Bureau, and other authorities (GZICCEP, 2011). There is also high volatility in CMM production and power generation due to the complex geology of the coal seams and the characteristic low permeability coals.

4.1 Guizhou Province Economic Conditions

Guizhou has been ranked as one of the fastest growing provinces in China since 2010. Between 2010 and 2015, the gross regional domestic product broke through RMB 1 trillion to RMB 1.05 trillion, with the average annual increase of 12.5 percent (Guizhou Province, 2016). Other economic indicators improved over the same period, such as:

- Investment in fixed assets amounted to RMB 1.07 trillion, with an average annual increase of 29.5 percent.
- The balance of deposits and loan in financial institutions reached RMB 1.9 trillion and RMB 1.5 trillion, respectively, representing an average annual increase of 21.4 percent and 21.2 percent, respectively.

- Stock market capitalization increased on average by 41.2 percent per year to RMB 2.59 trillion in 2015.
- Total retail sales of consumer goods stood at RMB 328.3 billion, which is an average annual increase of 17.2 percent.
- Government revenues amounted to RMB 150.34 billion, with an average annual increase of 23 percent.
- Per capita disposable income of residents in the cities and rural areas reached RMB 24,580 and RMB 7,387 respectively, with an average annual increase of 11.8 percent and 14.4 percent, respectively.

During the 13th Five Year Plan (2016-2020) period, Guizhou's main economic and social development goals are to increase employment opportunities in the cities and towns, increase the urbanization rate to at least 50 percent, and to meet the energy conservation and emission reduction goals outlined by the Chinese Central Government (CCII, 2016). CMM capture and use projects like the one being considered by the Liulong Coal Mine would help achieve these goals by generating employment, modernizing the local energy infrastructure, and reducing emissions from mining activities.

4.2 Liupanshui Economic Conditions

During China's 12th Five Year Plan (2011-2015) period, the gross domestic production (GDP) of Liupanshui reached RMB 120 billion, with an average annual increase of 14.9 percent; the investment in fixed assets rose to RMB 528 billion, with an average annual increase of 42.6 percent. Per capita disposable income of residents in the cities and towns experienced an annual increase of 11.5 percent. According to the Guizhou Provincial Government, the Liuzhi Special District is considered an economically strong county (Guizhou Province, 2016).

The economic and social development goals for Liupanshui, as laid out in China's 13th Five Year Plan (2016-2020), are as follows (Liupanshui City Government, 2015):

- Average annual increase of gross regional domestic product above 12 percent,
- Increase in investment in fixed assets of 20 percent,
- Increase in total retail sales of consumer goods by 12 percent,
- Increase government budget revenues by 6 percent,
- Increase of the per capital disposable income of residents in rural areas by 11 percent and 12 percent, respectively,
- Employment opportunities in cities and towns to reach 350,000, with a registered urban unemployment rate under 4.2 percent,
- A targeted urbanization rate above 55 percent,
- A 20 percent increase in the proportion of emerging industries in the GDP,
- Service industry GDP to rise to 45 percent,
- A forest coverage rate of 60 percent or above, and
- To achieve the energy conservation and emission reduction targets assigned for the province.

4.3 Energy Commodity Markets in Liupanshui

4.3.1 Power

In 2015, annual power generation for Liupanshui City was 35.5 billion kWh, with a total installed capacity of approximately 15 MW. Electricity was primarily consumed for civil use and by the commercial sector, which consumed 11.4 billion kWh in 2015. In the first quarter of 2016, total power generation reached 7.7 billion kWh, dropping 14.2 percent on a year-over-year basis, while commercial power consumption reached 2.1 billion kWh, accounting for 27.5 percent of the total.

During the 12th Five Year Plan (2011-2015) period, power sector investment totaled RMB 6.7 billion and 29 transformer stations of 110-kilovolt (kV) or above were built. By the end of 2015, 7,631 km of additional transmission lines were installed and full coverage of the double 220-kV main network frame loop was achieved. In the same year, the municipal electrical grid's reliability rose to 99.87 percent and the completion of the first phase of the Liupanshui 500-kV transformer substation significantly strengthened the connection between the regional grid and Guizhou's main grid. During the 13th Five Year Plan (2016-2020) period, Liupanshui City plans to increase investments for electrical power by RMB 670 million with a focus on renewable and unconventional energy supplies (CCII, 2016).

In the Liuzhi Special District, where the Liulong coal mine is located, total investment in power grid construction was RMB 666 million during the 12th Five Year Plan (2011-2015) period. Presently there is one 220-kV transformer substation, two main transformer substations, and six 110-kV transformer substations with installed capacity of 360 mega-volt ampere (MVA). There also are 12 main transformer substations with an installed capacity of 549 MVA, 10 35-kV transformer substations, and 20 main transformer substations with installed capacity of 105.15 MVA.

4.3.2 Natural Gas and/or Town Gas

The Liupanshui Natural Gas Corporation (LNGC) operates the local gas distribution system, which includes over 80,000 residential and 1,600 commercial customers. LNGC's network has over 700 km of gas pipeline, 200 regional regulator stations, and covers nearly 60 percent of the urban areas. The primary source of town gas is the Shuicheng Iron & Steel Group plant, with an annual coal gas production output of 574 Mcm. Although the distribution system is extensive, it is not adequate to meet existing demand. For example, gas demand in Liupanshui during the winter is around 360,000 m^3/d, while daily gas supply is only 280,000 m^3/d. Presently in Liupanshui, the demand for natural gas is approximately 60 to 70 Mcm per year, but by the end of 2020, demand is expected to exceed 500 Mcm (CCII, 2016).

LNG storage and distribution stations are currently under construction in all of the districts and counties of Liupanshui. At present, one LNG station in the Hongqiao New District has been completed and already has 43,000 gas users. The construction of the natural gas pipeline network in Panxian County has also been completed and there are upwards of 1,200 customers.

The primary challenge faced by a CMM gas pipeline sales project in Liupanshui is the high cost of gas transportation and the low cost of coke oven gas. The nominal burner tip price of natural gas for civil use is RMB 3.8 per m^3 ($16.15 per thousand cubic feet, Mcf, at current exchange rates), but this must compete with the low price of coke oven gas from Shuicheng Iron & Steel Group, which costs only RMB 0.90 per m^3 ($3.82 per Mcf). As a result, the LNGC must discount prices for civil use to RMB 1.40 per m^3 ($5.95 per Mcf) while still covering the cost of transportation. Other LNGC burner tip prices are: non-profit gas is

RMB 1.65 per m^3 ($7.00 per Mcf); commercial gas is RMB 1.75 per m^3 ($7.43 per Mcf), and the domestic rate for low income residents is RMB 0.90 m^3 ($3.82 per Mcf).

The Sino-Burma natural gas pipeline, which was scheduled for completion in 2016, connects to Liupanshui and is expected to provide some price relief. It is estimated that the price of natural gas for civil use will fall to RMB 3.2 per m^3 ($13.60 per Mcf). Furthermore, the LNGC plans to invest RMB 471 million to build a 103 km natural gas pipeline from Liuzhi to Shuicheng in order to supply 480 Mcm of natural gas per year to the citizens. The market for coke oven gas is expected to eventually disappear from the regional market.

4.3.3 Other Relevant Energy Markets

During the 13th Five Year Plan (2016-2020) period, Liupanshui plans to expend considerable effort to accelerate industrial transformation and promote the comprehensive utilization of coal resources and clean energy. Comprehensive development in wind power, hydroelectricity, and photovoltaic power generation projects will be completed while significant effort will be made to further increase CBM and CMM production, and construction of CNG/LNG projects (Liupanshui Municipal Bureau of Statistics , 2015).

In 2015, mines in Liupanshui City drained 1.18 Bcm, with 479 Mcm of this CMM utilized primarily for power generation or town gas. The relatively large scale of CMM capture and use in the area suggests that infrastructure and technical capacity are available to the Liulong Mine for BMG's efforts to improve gas recovery at the mine (Liupanshui Municipal Bureau of Statistics , 2015),

In the next five years, existing gas extraction systems are scheduled to be upgraded and transformed throughout the city. By 2020, it is estimated that CBM/CMM drainage will reach 3 Bcm. In-mine drainage is estimated to account for 2 Bcm, while surface gob wells and pre-drainage wells are estimated to account for the remaining 1 Bcm. The CBM/CMM utilization rate is expected to reach 60 percent, or 1.8 Bcm, an increase of 275 percent from 2015. CMM with concentrations below 30 percent will be used for power generation, while CMM with concentrations above 30 percent will likely be processed and upgraded into CNG/LNG to be used as fuel for civil or industrial use (CCII, 2016).

In 2015, LNG production in Liupanshui City was 28,400 tons, and CNG production was 69,900 m^3 with an estimated value of RMB 34.95 million. In 2016, a 1 Mcm LNG production facility was expected to come on line. In addition, as part of the 13th Five Year Plan (2016-2020) Liupanshui City is slated to build a facility to convert up to 1 Bcm of coke oven gas to LNG/CNG (Liupanshui Municipal Bureau of Statistics , 2015).

4.4 Environmental Markets

Since 2005, China has participated in the global carbon market through the Clean Development Mechanism (CDM) under the United Nations Framework Convention on Climate Change (UNFCCC). From 2005 through 2012, the National Development and Reform Commission (NDRC) approved 128 CMM projects under the CDM, although not all projects qualified for Certified Emission Reductions (CERs) during the eligibility period, which ran from 2008 through 2012. Since 2012, the price of CERs has dropped due to a lack of demand, and the CDM is no longer applicable to new CMM projects in China (UNECE, 2016). However, by 2013 China established seven pilot carbon markets, and is expected to launch a national emissions market in late 2017. The seven carbon emission trading pilots were set up in Shenzhen, Beijing, Guangdong, Shanghai, Tianjin, Hubei, and Chongqing, and in 2016, an eighth carbon exchange was added in Sichuan.

When introduced, the Chinese national emissions trading system (ETS) will be the largest market for carbon emissions permits in the world. Originally envisioned to include eight major industrial sectors, the national trading system is now expected to cover only three at initial launch, consisting of electricity, aluminum, and cement (Kahn, 2017). While specifics of the market have not yet been released, Chinese Certified Emissions Reduction (CCER) credits generated from CMM projects are expected to be eligible for use as offsets in the national market as they have been in some of the pilot carbon markets. However, the percentage of allocations that can be met with CCERs is currently unknown.

4.5 Legal and Regulatory Environment

As part of China's broader strategy to reduce air pollution, the government set a target of 40 Bcm of CBM/CMM production by 2020, which is more than double the country's 2015 production of 18 Bcm. To incentivize companies to invest in the CBM/CMM industry, China has offered gas producers preferential policies, including exemption from equipment import duties, refunds on value-added tax collected from gas sales, accelerated depreciation of assets, tax credits for investment in technical innovation, free-market gas pricing, and access to technology development funds (Econotimes, 2016).

Of particular interest to the proposed CMM project at Liulong are two national subsidies available to CMM projects that can potentially provide the incremental funding necessary to achieve desirable rates of return.

- Subsidy for CMM-to-power: CMM-to-power projects are eligible for a subsidy of RMB 0.25 per kWh (US$0.038/kWh). Considering that breakeven costs for a CMM-to-power project are usually US$0.04 – $0.06 per kWh, this is an attractive subsidy. The NDRC also granted coal mining companies permission to utilize any electricity generated by themselves, and stipulated that grid operators should give priority to surplus electricity generated from CBM with respect to grid connection.
- Subsidy for sales to town gas or natural gas systems: There is an RMB 0.30 per m^3 (US$1.27 per Mcf) subsidy for selling CMM as town gas or to the natural gas network. This is also an attractive subsidy, especially if the infrastructure is already in place to allow immediate gas sales, but each case must be evaluated to determine if the subsidy is adequate. For example, it may not be sufficient if a gas pipeline sales project will require gas processing, compression, and construction of a lateral pipeline.

While numerous beneficial policies exist to promote the development of the CBM/CMM industry in China, it is not clear how effective these incentives will be as the sector faces numerous hurdles to development. CBM/CMM competes on price with oil and gas from conventional sources, which have been on a downward trend since late 2014. Intervention by local governments could also potentially diminish the impact of CBM/CMM related incentives. Additionally, CBM/CMM exploration priority is usually given to existing petroleum and coal mining rights holders, which is concentrated at the national oil companies. In Guizhou, the majority of CBM mining rights have been registered by CNPC and Sinopec Group, while most of the coal mining rights belong to the local government, which has inhibited private capital penetration and constrained development of the province's CBM resources (Econotimes, 2016).

4.6 CMM Utilization Options for the Liulong Mine

With average methane concentrations ranging between 12 and 30 percent, drained gas from the Liulong Mine is considered low-concentration CMM. Implementation of improved gas drainage will increase considerably the quality of CMM produced at Liulong. As shown in Section 5, CH_4 concentrations are expected to increase to between 70 and 98 percent, depending on the drainage technology used. It is also crucial to increase the CH_4 concentration to reduce the risk of explosion. Methane is explosive in concentrations between 5 and 15 percent. If ignited, the flame can propagate through a gas drainage pipe increasing the scale and impact of an explosion. The sections below briefly explore each potential option for CMM utilization at the Liulong Mine.

4.6.1 Power Generation

On-site power generation using CMM is one of the many utilization options considered in this study. Any electricity generated by a CMM power plant would likely be used at the mine, with excess power being sold to the local electric grid. There is a strong case to use the CMM for power generation. There is significant experience throughout the Chinese coalfields with CMM power, including in Guizhou. The knowledge, expertise, and experience are widely available to support cost-effective implementation, operation, and maintenance of a CMM power plant. Industrial power prices are also attractive for CMM-to-power projects. A generally accepted breakeven cost for CMM-based power projects is RMB 0.27 to 0.40 per kWh (US$0.04-0.06 per kWh). The price paid by the Liulong Mine is RMB 0.65/kWh (US$0.098 per kWh), amounting to a savings potential of RMB 0.25 to 0.38 per kWh (US$0.037 to 0.056 per kWh). In addition, the RMB 0.25 (US$0.038/kWh) subsidy makes power generation even more attractive.

There are several other advantages for power production at the mine. Suppliers deliver turn-key solutions with the gas engine, generator, and control system combinations in prefabricated containers. These plants are modular and can be easily expanded if gas availability increases. The ability to offset high power prices at mines has been another reason CMM-to-power projects are very attractive in China. The technical challenges of wheeling excess power to the grid are easily overcome because mines are large users of electricity with access to high voltage interconnects or even electricity substations at the mine.

4.6.2 Town Gas/Natural Gas

Historically, town gas was the predominant use of CMM in China prior to the Kyoto Protocol, when power generation grew in popularity. Town gas is produced from in-mine or surface gob wells, and is often stored in large holding tanks at a mine. Town gas is medium-quality, usually ranging from 30 to 60 percent CH_4, and is distributed to local communities in the immediate vicinity of a coal mine through low pressure distribution lines. Natural gas pipelines typically require higher quality gas, normally above 90 percent CH_4. Unlike many CMM markets in China, the LNGC provides a local gas distribution network. LNGC has previously sold town gas produced from coking ovens, but is upgrading the system to use higher quality natural gas.

There are four major constraints facing BMG in selling to the LNGC grid. Although the burner-tip price of natural gas is high at RMB 3.8 per m^3 (US$16.15 per Mcf), the price of coke oven gas is low. For natural gas to compete, LNGC must discount the price of natural gas by two-thirds. Second, demand for natural gas outstrips grid supply. As the grid expands, the capacity problems should be addressed; however, this is likely to increase rates as the LNGC seeks to recover the capital costs of expansion. Third, selling CMM to the grid will necessitate upgrading the gas quality to medium or high quality CMM if future CMM production yields gas quality similar to current CH_4 concentrations. Due to the very low quality of the Liulong drained gas, this will probably require multi-stage processing and compression. Should either of the drilling methods proposed prove successful, gas quality upgrades may not be necessary. The capital cost (Capex) for a gas processing unit would cost approximately US$1 to 4 million and annual operating expenses (Opex) could be expected to be around US$250,000 to 1 million. Although inseam drainage should produce high-quality CMM, the final constraint faced by natural gas pipeline sales is the long distance to a trunkline and the lack of a pipeline from the mine to the gas grid, which makes this option impractical. Although there is an RMB 0.30 per m^3 (US$1.27 per Mcf) subsidy for selling CMM for town gas or the natural gas network, this may not be enough to offset the cost of laying a pipeline lateral to the LNGC.

4.6.3 Industrial Use

There are no industrial operations adjacent to the mine, and it would be very expensive to lay a pipeline to an industrial user considering the terrain. However, the mine does maintain a coal preparation plant and CMM could replace coal as the fuel used for coal drying. This currently occurs at one mine in the United States, the Buchanan Mine in Virginia.

4.6.4 Boiler Fuel

Coal boilers are used at many mines for heating and hot water in mine buildings and for heating mine shafts. CMM could be used at the Liulong Coal Mine to fuel boilers used for heating and hot water in the mine buildings and employee apartments. There is some demand for heating in winter; however, it is limited by the mild climate in southwestern China. Should BMG consider using CMM in boilers in place of coal, it would necessarily require upgrading the gas quality to at least medium concentration gas. Due to the cost of gas processing equipment, this is not likely to be economically feasible.

4.6.5 Compressed Natural Gas (CNG)/Liquefied Natural Gas (LNG)

There is growing interest in CNG and LNG in China as demonstrated by the USEPA feasibility study for the Songzao mine in Chongqing (U.S. Environmental Protection Agency, 2009), and BMG expressed interest in this option. Certainly, the continuing development of natural gas infrastructure in Liupanshui City, including CNG and LNG operations, provides a potential avenue for a CMM-to-CNG/LNG operation. However, CNG or LNG is not economically feasible at this time, even if future gas production is medium quality. CNG and LNG production requires significant capital costs to upgrade gas quality, compress, and liquefy the gas. For example, Capex to manage the residual gas flow at each mine could total US$3 million for CNG and US$6-7 million for an LNG plant. Opex at each mine could total US$1-2 million per year. The sale price for LNG would need to be roughly RMB 2.15 per 1000 metric tons or the equivalent of RMB 3.0 per m^3 (US$12.00 per Mcf) of pipeline quality gas.

4.6.6 Flaring

To be allowed in China, flaring must be part of an integrated approach that includes other CMM utilization options such as power generation, industrial supply, boiler fuel or CNG/LNG production. Should BMG move forward with a CMM project, a good strategy may be to incorporate a flare into the project to reduce emissions when the primary utilization technology is unavailable, for example when gas engines are down for maintenance.

4.6.7 Recommendation for CMM Utilization

After consideration of the potential options for CMM utilization at the Liulong Mine, power generation is the most viable option, considering current market conditions in Guizhou Province and the priorities of mine management. Therefore, for this pre-feasibility study, the Economic Analysis in Section 7 focuses on CMM power generation. Based on gas supply forecasts, the mine could be capable of operating as much as 9 MW of electricity capacity.

This pre-feasibility study is intended to provide an initial assessment of project viability. A Final Investment Decision (FID) should only be made after completion of a full feasibility study based on more refined data and detailed cost estimates, completion of a detailed site investigation, implementation of well tests, and possibly completion of a Front End Engineering & Design (FEED).

5 Economic Analysis

5.1 Project Development Alternatives

In order to assess the economic viability of the drainage scenarios presented throughout this report, it is necessary to first define the project scope. CMM gas production profiles were generated for a total of three project development cases, as follows:

- Case 1: In-Seam pre-drainage boreholes penetrating mining seams at intervals of 30 m
- Case 2: In-Seam pre-drainage boreholes penetrating mining seams at intervals of 10 m
- Case 3: Horizontal gob boreholes placed above mining seams

Figure 5-1 and Figure 5-2 show a conceptual mine layout and development plan for the existing mine and the Dayong reserve addition, respectively. For the existing mine, the plan shows the five remaining panels yet to be mined. Three panels in the No. 3 Seam are scheduled to be mined beginning in January, May, and September of 2017, with the remaining two panels, which target the No. 7 Seam, scheduled to be mined in January and May of 2018. For the purpose of forecasting gas production from the existing mine, it is assumed these five panels have already been defined, with drilling locations identified. For development cases 1 and 2, which utilize in-seam drainage, it is assumed that borehole development will take place before the project start date of January 2017, which means gas production from four of the five panels will commence at the beginning of the project. No gas production is assumed for Panel 1034 since the proposed project timeline does not allow for pre-drainage using in-seam boreholes. For Case 3, which employs HGBs, it is assumed production is initiated as each longwall panel begins mining operations.

For the Dayong reserve addition, the plan shows panels with mining commencing in January 2019 through January 2032. Proposed panel locations were mapped using a panel size of 250 m by 100 m. The plan as shown identifies 40 panel locations in a single seam. Since both the No. 3 and No. 7 seams will be mined in the reserves addition area, a total of 80 panels are proposed in the development schedule, which assumes the same layout for both seams. For the purpose of forecasting gas production from the reserve addition, and since the mine permit allows for simultaneous mining at two panels, it is assumed panels in both the No. 3 and No. 7 seams are mined at the same time. Based on an advance rate of 2.5 m/d, it is assumed to take a total of 130 days to mine each panel, which includes 100 days to mine each panel plus an additional 30 days per panel to account for stoppages and movement of the longwall equipment between panels. As a result, three panels per year will be developed in each seam (total of six per year), with the initiation of operations staggered in order to reduce fluctuations in gas production volumes. Panels in the No. 7 Seam have start dates of January, May, and September, while panels in the No. 3 Seam have start dates of March, July, and November.

For cases employing in-seam drainage, it is assumed all necessary mine roads and drilling locations are developed at a pace to allow gas production from one new panel to come online every two months beginning in January 2019. As for the existing mine, production for the case employing HGBs in the reserve addition is also assumed to start as each longwall panel begins mining operations. For all development cases in the existing mine and the reserve addition, production from in-seam pre-drainage boreholes is terminated prior to the initiation of mining operations at each panel, and production from HGBs is assumed to either extend six months after mining at each panel is completed, or terminate once 100 percent of each seams' gas resource has been depleted, whichever occurs first.

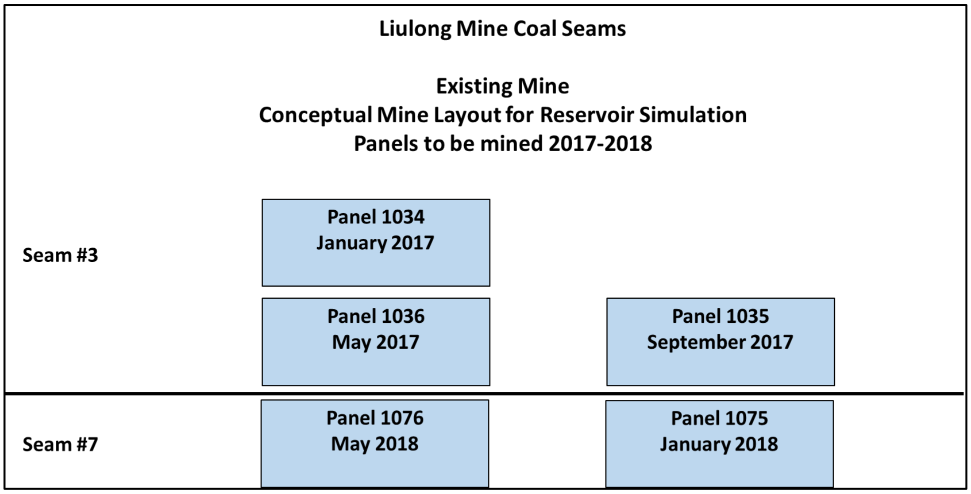


Figure 5-1: Conceptual Mine Layout and Development Schedule for the Existing Mine

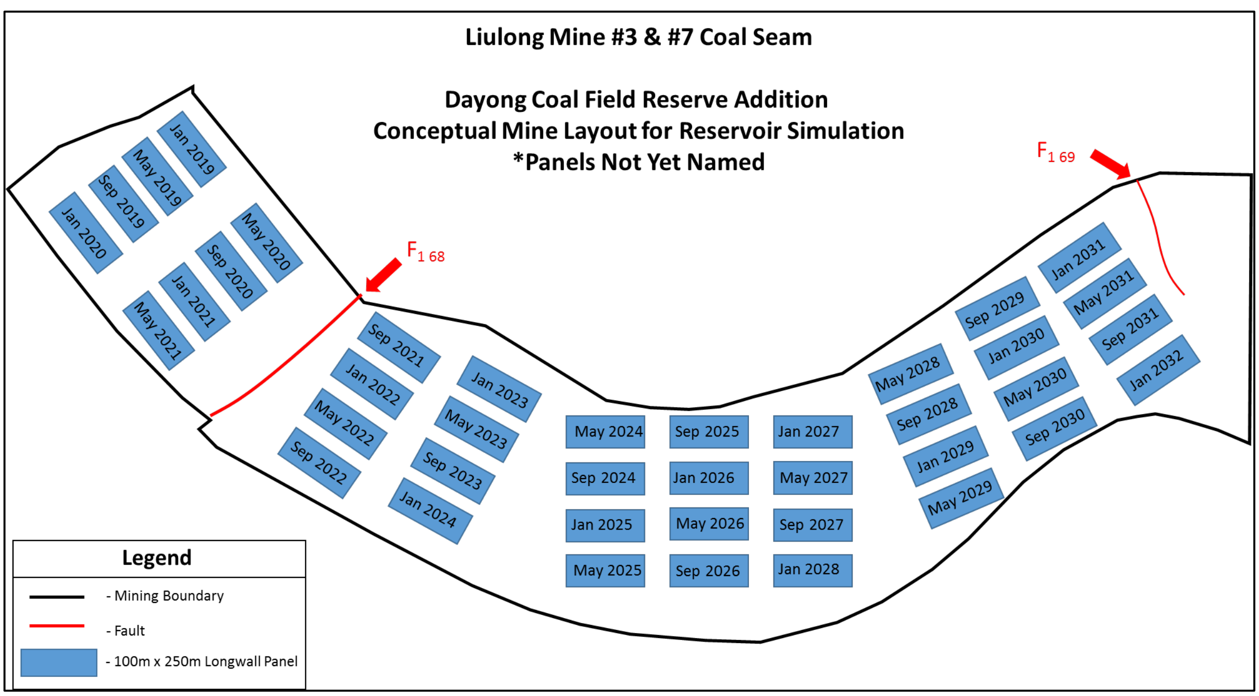


Figure 5-2: Conceptual Mine Layout and Development Schedule for the Dayong Reserves Addition

5.2 Gas Production Forecasts

Gas production forecasts were developed using the simulation results and the development scenarios discussed above. The CMM production forecasts for Cases 1, 2, and 3 are shown in Figure 5-3. As shown in the graph, HGBs are expected to produce significantly greater volumes of CMM during the life of the project.

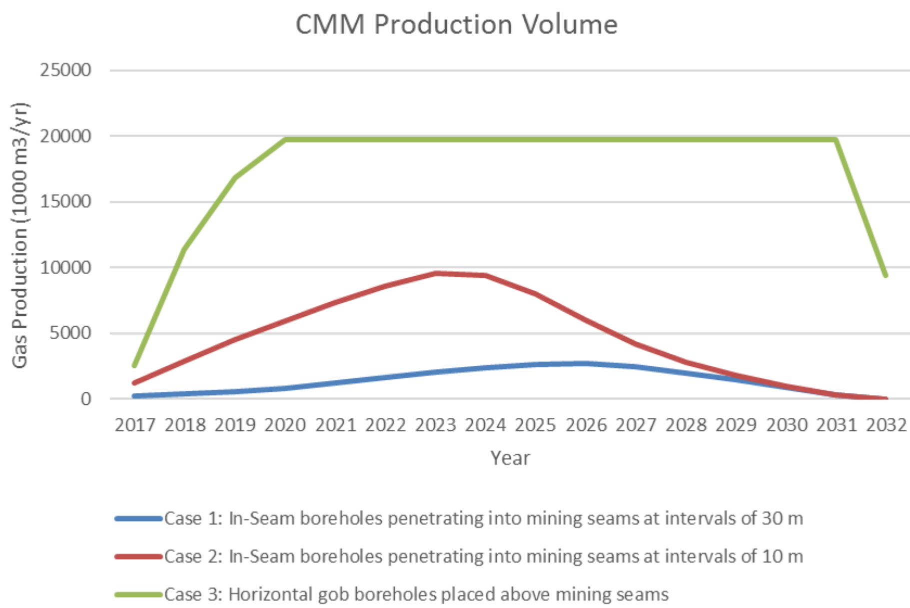


Figure 5-3: CMM Production Forecast

5.3 Project Economics

5.3.1 Economic Assessment Methodology

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

5.3.2 Economic Assumptions

Cost estimates for goods and services required for the development of the CMM project at the Liulong Mine were based on a combination of data provided by CCII, known average development costs of analogous projects in the region and the U.S., and other publicly available sources (USEPA, 2011). A more detailed analysis should be conducted if this project advances to the full-scale feasibility study level. The major cost components for the CMM project include the in-seam and horizontal gob boreholes, gathering system, surface vacuum station, compressor, and power plant.

5.3.2.1 Drainage System Input Parameters

The drainage system capital cost assumptions, operating cost assumptions, and physical and financial factors used in the economic evaluation are provided in Table 5-1. A more detailed discussion of each input parameter is provided below.

Physical & Financial Factors	Units	Value
Methane Concentration of Drained Gas	percent	98
Methane Concentration of Gob Gas	percent	70
Cost Escalation	percent	3.0
Price Escalation	percent	3.0
Capital Expenditures	**Units**	**Value**
Drainage System		
Borehole Cost	$/m	100 (in-seam); 130 (HGB)
Surface Vacuum Station	$/W	1.34
Vacuum Pump Efficiency	$W/1000m^3/d$	922
Gathering System		
Gathering Pipe Cost	$/m	75
Gathering Pipe Length	m/panel	450
Operating Expenses	**Units**	**Value**
Field Fuel Use (gas)	percent	10
O&M	$\$/1000m^3$	17.66

Table 5-1: Summary of Drainage System Input Parameters

5.3.2.1.1 Drainage System Physical and Financial Factors

Price and Cost Escalation: All prices and costs are assumed to increase by 3 percent per annum.

Methane Concentration of Gas: The drained gas is assumed to have a methane concentration of 98 percent and the gob gas is assumed to have a methane concentration of 70 percent.

5.3.2.1.2 Drainage System Capital Expenditures

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

Borehole Cost: In-seam borehole costs are estimated at $100 per m. For the 30 m borehole spacing case, total borehole costs for the application of the in-seam drainage concept is $96,600 per panel, which includes 750 m of borehole drilled in the underlying gallery plus 216 m of borehole drilled from the gallery into the target seam. For the 10 m borehole spacing case, total borehole costs for the application of the in-seam drainage concept is $139,800 per panel, which includes 750 m of borehole drilled in the underlying gallery plus 648 m of borehole drilled from the gallery into the target seam. HGB costs are estimated at $130 per m. With three 250 m boreholes per panel, total borehole cost for the application of the HGB drainage concept is $97,500 per panel.

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 pump station, a pump cost of $1.34 per Watt (W) and a pump efficiency of 922 watts per thousand cubic meters per day ($W/1000m^3/d$) 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., $/W x $W/1000m^3/d \times 1000m^3/d$).

Gathering System Cost: The gathering system consists of the piping and associated valves and meters necessary to get the gas from within the mine to the power plant located on the surface. The gathering system cost is a function of the piping length and cost per meter. For the proposed project, we assume a piping cost of $75/m and roughly 450 m of gathering lines per panel.

5.3.2.1.3 Drainage System Operating Expenses

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

Normal Operating and Maintenance Cost: The normal operating and maintenance cost associated with the vacuum pumps and compressors is assumed to be $17.66/1000m^3.

5.3.2.2 Power Plant Input Parameters

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 assumptions used to assess the economic viability of the power project are presented in Table 5-2. A more detailed discussion of each input parameter is provided below.

Physical & Financial Factors	**Units**	**Value**
Generator Efficiency	percent	40
Run Time	percent	65
Electricity Price	$/kWh	0.10
CMM Subsidy	$/kWh	0.04
Capital Expenditures	**Units**	**Value**
Power Plant	$/kW	760
Operating Expenses	**Units**	**Value**
Power Plant O&M	$/kWh	0.03
Carbon Emission Reductions	**Units**	**Value**
Global Warming Potential of CH_4	tCO_2e	25
CO_2 from Combustion of 1 ton CH_4	tCO_2	2.75

Table 5-2: Summary of Power Plant Input Parameters

5.3.2.2.1 Power Plant Physical and Financial Factors

Generator Efficiency and Run Time: Typical electrical power efficiency is between 30 percent and 44 percent and run time generally ranges between 7,500 to 8,300 hours annually (USEPA, 2011). For the proposed power project an electrical efficiency of 40 percent and an annual run time of 65 percent, or 5,694 hours, were assumed. The efficiency value is based on information provided by CCII and the run time value is consistent with the typical operation of Shengli engines in the field.

Electricity Price and CMM Subsidy: The effective electricity sales price received for the power produced is $0.14/kWh, which includes a base electricity price of $0.10 and a CMM subsidy of $0.04/kWh.

5.3.2.2.2 Power Plant Capital Expenditures

Power Plant Cost Factor: The power plant cost factor, which includes capital costs for gas pretreatment, power generation, and electrical interconnection equipment, is assumed to be $760/kW.

5.3.2.2.3 Power Plant Operating Expenses

Power Plant Operating and Maintenance Cost: The operating and maintenance costs for the power plant are assumed to be $0.03/kWh.

5.3.2.2.4 Carbon Emission Reductions

Global Warming Potential of CH_4: A global warming potential of 25 is used. This value is from the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC, 2013) .

CO_2 from Combustion of CH_4: Combustion of methane generates 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 18.25 tCO_2e per ton of CH_4 destroyed.

5.3.3 Economic Results

The economic results for the power project are summarized in Table 5-3. Cases 2 and 3 both have a positive NPV-10. However, Case 3, which has a NPV-10 of over $30 million and an IRR of 43 percent, is preferable to Case 2, which has a NPV-10 of just under $1.3 million and an IRR of 12 percent.

Case	Description	Max Power Plant Capacity	NPV-10 US$000	IRR	Payback Year	Net CO_2e Reductions (Million metric tons)
1	In-seam boreholes penetrating mining seams at intervals of 30 m	2 MW	-5,722	-3%	-	0.32 Mt
2	In-seam boreholes penetrating mining seams at intervals of 10 m	6 MW	+1,278	+12%	8	1.1 Mt
3	Horizontal gob boreholes placed above mining seams	9 MW	+30,054	+43%	3	2.9 Mt

Table 5-3: Summary of Economic Results

6 Conclusions, Recommendations and Next Steps

This pre-feasibility study proposes three methane drainage approaches for the Liulong Coal Mine in Guizhou Province. The study further provides a high-level estimate of gas production using these methods and an economic analysis of using the CMM to generate power. After consideration of possible options for CMM utilization at the Liulong Mine, power generation was selected as the best option for the mine given market conditions and mine management priorities. As the analysis shows, drainage using horizontal gob boreholes will be the most effective option for the Liulong Mine in terms of gas drainage and economics. In addition, net emission reductions associated with the destruction of drained methane are estimated to total 2.9 $MtCO_2e$ over the life of the project using the optimal development scenario.

It is recommended that BMG pursue the development of a small 1-MW power project using CMM from the existing system of cross-panel boreholes. The power plant could grow as gas availability increases with improved drainage. Based on the results of this pre-feasibility study, for BMG to move toward project development the following next steps are recommended:

- Develop a clear mine layout for the Dayong coalfield with exact panel dimensions and coal production forecasts.
- Take additional core samples in the Dayong coalfield and conduct gas desorption analyses to obtain accurate measure of gas content, permeability and porosity of the coals. This will inform a more thorough gas production forecast.
- Confirm the ability of the Liulong Mine to sell excess electricity to the power grid and establish a confirmed price for an interconnect to the grid.
- Conduct pilot tests for both types of in-mine degasification technologies proposed in this study to develop more accurate forecasts for CH_4 concentration and volumetric throughput.
- Investigate and analyze 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.
- Begin investigation of financing options to confirm available sources of project finance so that BMG can determine the appropriate sources and mix of financing, including the mix of debt and equity.

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