Pre-Feasibility Study for Coal Mine Methane Capture and Utilization at the Mahui and Pingshang Mines

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Pre-Feasibility Study for Coal Mine Methane Capture and Utilization at the Mahui and Pingshang Mines

Shanxi Province

People's Republic of China

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Prepared by:
Advanced Resources International, Inc.

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Acronyms/Abbreviations

ARI	Advanced Resources International, Inc.
Bcf	Billion Cubic Feet
cc	Cubic centimeter
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CMOP	US EPA Coalbed Methane Outreach Program
CMM	Coal Mine Methane
CH_4	Methane
CO_2	Carbon Dioxide
EU ETS	European Union Emissions Trading Scheme
ft	Feet
GMI	Global Methane Initiative
Ha	Hectare
Hg	Mercury
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	Short tons
Tonnes	Metric tonnes
USEPA	US Environmental Protection Agency
VAM	Ventilation air methane
VL	Langmuir volume (scf/ton

Metric/Imperial Unit Conversions

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

Table of Figures and Tables

Executive Summary

With funding from the United States Environmental Protection Agency (USEPA), under the auspices of the Global Methane Initiative (GMI), this pre-feasibility study forecasts coal mine methane (CMM) production and evaluates the economic feasibility of CMM utilization options for the Pingshang and Mahui coal mines of the Yangquan Coal Group Jindong Coal Management Company in Shanxi Province, China.

The Pingshang mine (Xiyang County Pingshang Coal Co. Ltd.) and the Mahui mine (Shanxi Xiyang Fenghui Coal Co. Ltd.) are located in eastern Shanxi province in Xiyang County 75 km south of the city of Yangquan and about 400 kilometers southwest of Beijing. Xiyang County is located in the northeastern corner of the methane-rich Qinshui coalfield, one of China's best known and most productive coalbed methane basins.

Although operated by two different companies, the Pingshang and Mahui mines are affiliated as their respective owners are subsidiaries of the same parent company, the Yangquan Coal Group Jindong Coal Management Co. The mines are located in close proximity to each other, although they do not share a boundary and are geographically distinct. The two mines are also affiliated with another subsidiary of Yangquan Jindong, the Shanxi Xiyang Fenghui project development company, which is responsible for CMM utilization at Yangquan Jindong mines.

Gas management at both mines consists of mine ventilation and methane drainage. Each mine's methane drainage system relies on a system of sealed drainage galleries developed in seams above the mined seam with negative pressure applied to the galleries to draw mine gas into the drainage networks. A share of the drained CMM produced at the mines is captured for utilization while the remainder is vented. The Mahui mine currently hosts a 9.8 MW combined heat and power plant and a 14.4 MW power plant is operating at the Pingshang mine.

Yangquan Jindong is planning to expand the existing power plants and is also interested in other markets for the drained gas with a target date of 2015 to commence project expansion at each mine. At the same time, mining is moving further below surface at each mine. The company, therefore, will benefit from an analysis that projects gas production to properly plan for future expansion and to justify the investment required. To assist Yangquan Jindong, a gas production forecast for each mine was prepared based on available geologic data, current and future mine plans and historic gas production data. Potential market options for CMM utilization were also evaluated for both mines. This pre-feasibility study aims to assist Yangquan Jindong with moving closer to project implementation in 2015.

Mahui Mine

The Mahui Coal Mine is located in Mahui Village, Dazhai Town, Xiyang County. It is 12 km south of Xiyang. The mine has total coal reserves of 84.96 million tonnes (42 million tonnes being mineable), with no known or planned reserve additions. The planned production rate is 1.2 Mta; however, actual annual coal production ranges between 1.2 to 1.6 million metric tonnes per annum (Mta). The expected remaining mine life is 30 years.

Figure ES-1 below shows the residual gas forecast for high, best (i.e., base) and low cases for the Mahui mine. Residual gas is the gas production available for incremental use assuming demand from existing power plants will continue.

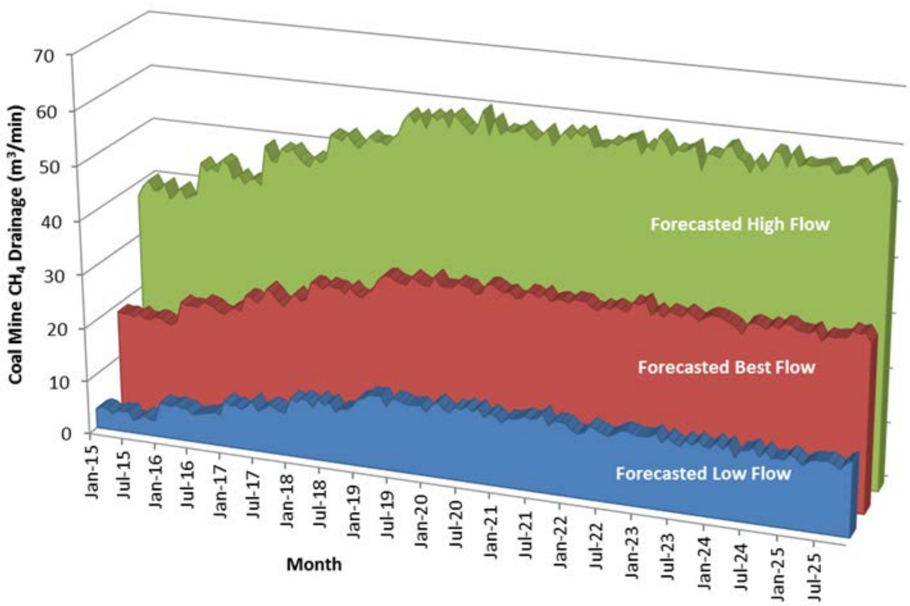

Figure ES-1: Mahui Mine Forecasted Coal Mine Methane Drainage Available for Use (m3/min)

Pingshang Mine

The Pingshang coal mine is located approximately 8.5 km north-northwest of the Mahui Coal Mine in Xinangou Village, Leping Town in Xiyang County. The Pingshang mine was consolidated from two coal mines, the Pingshang and Xinangou mines, both of which started coal production in 1983. In 2006, approval was received to consolidate the two mines into one larger mine with total coal production capacity of 300,000 tonnes per annum (tpa). In the same year, Yangquan Jindong entered into a joint operating agreement with Pingshang Coal Mining Co. Ltd., making Pingshang a subsidiary company of Yangquan Jindong. It was then decided to upgrade the mine to reach production capacity of 900,000 tpa.

The Pingshang mine has total coal reserves of 60 million tonnes (26 million tonnes being mineable), which is undergoing expansion through a reserve addition of 20 million tons. Although the planned coal production rate is 900,000 tpa, the mine's actual coal production is 1.2 Mta and Yangquan Jindong plans to expand future coal production to 1.2-1.5 Mta. The estimated remaining life of the mine is 20+ years.

Similar to the Mahui mine, residual gas production available for incremental use was calculated, assuming that demand from existing power plants will continue. Figure ES-2 shows the gas forecast for the low, base (i.e., "best") and high cases. For the Pingshang mine, a residual gas deficit in forecasted in the base case for the first year, and for the first three years in the low case.

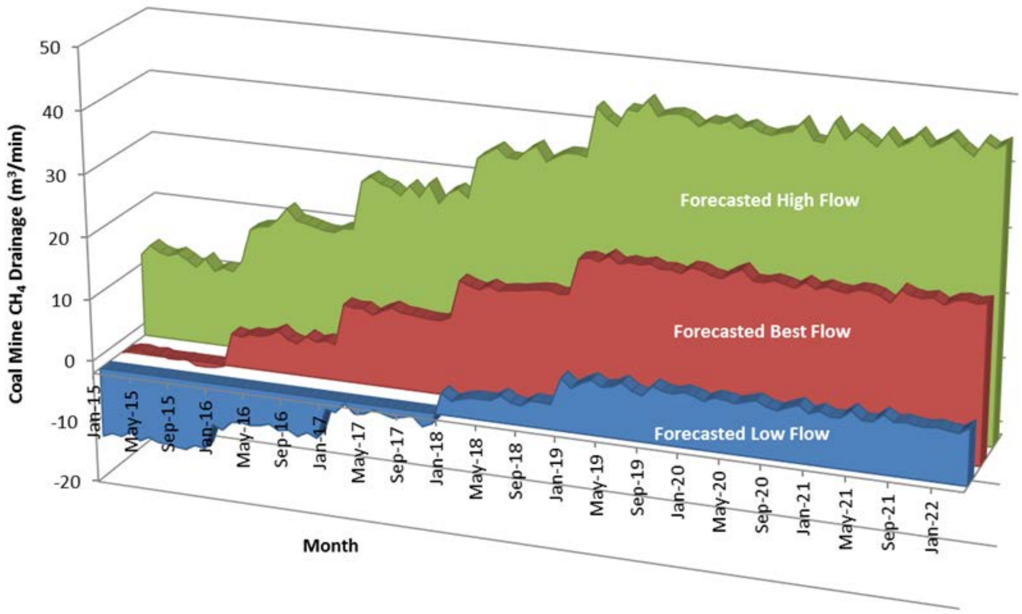

Figure ES-2: Pingshang Mine Forecasted Coal Mine Methane Drainage Available for Use (m^3/min)

CMM Utilization

Xiyang County is located 75 km due south of Yangquan, a major and well-known metropolitan area within Shanxi Province. However, Xiyang is relatively isolated from Yangquan by surrounding rugged mountain terrain. Therefore, any market for the CMM will most likely be limited to Xiyang County.

The use of residual CMM produced by both mines in on-site power plants or boilers for hot water and steam would be a likely market given Yangquan Jindong's existing experience with power generation. Another option is use in industrial applications at nearby manufacturing facilities.

While not economically feasible at this time, the following market options were also considered:

- *Natural gas distribution as town gas* – CMM quality at both mines ranges from 40-50 percent at the surface which is sufficient for town gas distribution. However, a town gas project would require installing 12 km and 8 km low pressure transmission lines to Xiyang from Mahui and Pingshang, respectively, and then the construction of gas distribution mains in Xiyang.
- *Natural gas pipeline sales* – There are no major natural gas trunklines in close proximity to the mines. Furthermore, the capital cost (Capex) for a gas processing unit would be approximately US$4 million and annual operating expenses (Opex) could be expected to total around US$1 million.
- *Compressed Natural Gas (CNG)/Liquefied Natural Gas (LNG)* – Although this may be an attractive option in the future for mines in Xiyang County, conversion of drained gas from the Mahui and Pingshang mines is not economically feasible at this time. 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. Moreover, a market must exist to accept CNG and LNG. This infrastructure does not exist yet in Xiyang.

- *Flaring* - The mine is not interested in flaring methane, as it is difficult to receive authorization to flare CMM in China because the energy value of CMM is highly valued. There is no economic incentive to flare at this time.

In assessing market opportunities, the credibility and position of Yangquan Jindong as the CMM project host was also considered. Yanguan Jindong's success with the existing projects provides confidence that it has the technical and financial capacity to deliver a CMM project.

Mahui Mine Project Economics

Using a discount rate of 10 percent, the baseline (i.e., best or base) case for use of residual gas production at the Mahui mine generates an estimated cash flow stream with a net present value (NPV-10) of US$16.9 million and an internal rate of return over 90 percent. Combining both the existing 9.8 MW power project and 8.8 MW for the new power project, the NPV-10 is $42.7 million.

With the addition of another 8.8 MW of electricity generation capacity at Mahui mine above and beyond the existing plant of 9.8 MW, 100 percent of the drained methane is destroyed resulting in net emission reductions of 183,000 tCO2e/yr over the 11-year project life. Additionally, the incremental electricity generated will offset electricity consumption from the North China Power Grid, which would decrease project-related emissions by an estimated 55,000 tCO2e/yr, for a total emission reduction of 238,000 tCO2e/yr over the 11-year project life.

Pingshang Mine Project Economics

The maximum power production case at Pingshang mine generates an estimated cash flow stream with an NPV-10 of US$17.3 million. The results of the economic analysis indicate an incremental increase in NPV-10 of US$4.6 million for the maximum power production case, as compared to the baseline case, at Pingshang mine. The fertilizer production project at Pingshang reduces NPV-10 by US$9.6 million when compared to the baseline case, which indicates that the loss of revenue from decreased electricity sales outweighs any fuel cost savings associated with switching from coal to gas.

With the addition of another 6.2 MW of electricity generation capacity at Pingshang mine, 100 percent of the drained methane is destroyed resulting in net emission reductions of 78,000 tCO2e/yr over the 8-year project life. Additionally, the incremental electricity generated will offset electricity consumption from the North China Power Grid, which would decrease project-related emissions by an estimated 23,000 tCO2e/yr, for a total emission reduction of 101,000 tCO2e/yr over the 8-year project life.

With the utilization of drained gas in the fertilizer plant and on-site power generation plant at Pingshang mine, 100 percent of the drained methane is destroyed resulting in net emission reductions of 78,000 tCO2e/yr over the 8-year project life. Additionally, the use of drained gas by the fertilizer plant will offset emissions from coal by 62,000 tCO2e/yr. However, since drained gas previously utilized to generate on-site electricity is diverted to the fertilizer plant, electricity purchased from the North China Power Grid will increase, which will offset any emission reductions gained by switching to gas from coal at the fertilizer plant. As a result, total emission reductions over the 8-year project life are estimated at 78,000 tCO2e/yr.

Next Steps

Although Mahui and Pingshang mines already host CMM utilization projects, the support of USEPA and the GMI fill an important market need by providing the crucial early-stage analysis necessary for any further project development. Yangquan Jindong faces a challenge common with many mines today in China. Low prices for carbon credits, uncertainty over a successor agreement to the Kyoto Protocol and lower coal prices have diverted resources away from planning CMM projects. This pre-feasibility study presents a rigorous analysis based on high level data that shows expansion of existing projects to be feasible and economically attractive. This provides a foundation for a more thorough full feasibility study potentially leading to project investment and implementation.

The following next steps are suggested to prepare for an expansion of existing operations, including production of a more detailed project feasibility study:

1. Take cores in the future mining districts 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.
2. Review the mine maps to specify the exact height of overburden over the coal seams throughout the mine to support more accurate modeling.
3. Evaluate the potential for participation in Chinese carbon markets, including obtaining reputable carbon price projections for these markets.
4. Consider other mine degasification options including use of boreholes to enhance drainage of gob gas into the drainage galleries, use of cross-measure boreholes, longhole in-mine boreholes. Surface gob vent boreholes may also be considered.

1 Introduction

Under the auspices of the Global Methane Initiative (GMI), the U.S. Environmental Protection Agency (USEPA) works with coal mines in the U.S. and internationally 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.

An integral element of USEPA's international outreach in support of the GMI is the development of CMM pre-feasibility studies. These studies provide the cost-effective first step to project development and implementation by identifying and evaluating potential opportunities through a high-level review of gas availability, end-use options, and emission reduction potential. In recent years, USEPA has sponsored feasibility and pre-feasibility work in China, India, Kazakhstan, Mongolia, Poland, Russia, Turkey, and Ukraine. These studies can be found at http://www.epa.gov/coalbed/resources/international.html.

Advanced Resources International, Inc. (ARI) prepared this study for the Yangquan Coal Group Jindong Coal Management Company Mahui and Pingshang coal mines in Shanxi Province, China. The Pingshang mine (Xiyang County Pingshang Coal Co. Ltd) and the Mahui mine (Shanxi Xiyang Fenghui Coal Co. Ltd) are located in eastern Shanxi province in Xiyang County 75 km south of the city of Yangquan and about 400 km southwest of Beijing. Xiyang County is located in the northeastern corner of the methane-rich Qinshui coalfield, one of China's best known and most productive coalbed methane basins.

Although operated by two different companies, the Pingshang and Mahui mines are affiliated as their respective owners are subsidiaries of the same parent company, the Yangquan Coal Group Jindong Coal Management Co.

Although CMM utilization projects currently exist at both mines, Yangquan Jindong wishes to better understand future gas availability to plan for expansions of existing projects and to diversify end use options to spread risk. The objective of this pre-feasibility study is to develop CMM production forecasts and assess potential utilization options at the two mines. The study also includes a high-level financial analysis of the prospective CMM utilization options and estimates greenhouse gas emission reductions.

This pre-feasibility study is intended to provide an initial assessment of project viability. A final investment decision (FID) should be made only after completion of a more rigorous study of project feasibility utilizing more refined data and detailed cost estimates, completion of a detailed site investigation, and more accurate gas production forecasts.

2 Background

2.1 Coal Mine Methane Potential in China

Any sustained effort to reduce global CMM emissions must include China. Chinese coal mines produce 3.68 billion metric tonnes of coal per year, almost four times the production of the United States, the next largest producer.[1] Today, China accounts for almost 50 percent of global production[2], and China's energy use is predicted to steadily increase over the next twenty years, impacting all energy sectors. Recently, China's National Development & Reform Commission (NDRC) approved construction of 15 new, very large coal mines with combined capacity of 100 million tonnes, and by 2015, China aims to increase total coal production capacity by 860 million tonnes over 2010 production.[3]

China also leads the world in CMM emissions. Figure 2-1 below shows China's projected CMM emissions through 2030 in relation to other major emitting countries. Total emissions for China are around 23 billion cubic meters (Bm^3). According to the China Coal Information Institute (CCII), CMM drainage volume increased from 2.2 Bm^3 in 2005 to 12.6 Bm^3 in 2013. In the first six months of 2014, gas drainage was 6.56 Bm^3, a 7.7 percent increase over 2013. Shanxi province leads all other provinces in total gas drainage with 2.71 Bm^3 in 2013 or 22 percent of China's total. China's CMM emissions are anticipated to continue increasing with growth in coal production far outpacing every other country. China will account for 56 percent of global CMM emissions by 2030, presenting significant opportunities for methane capture and use.[4]

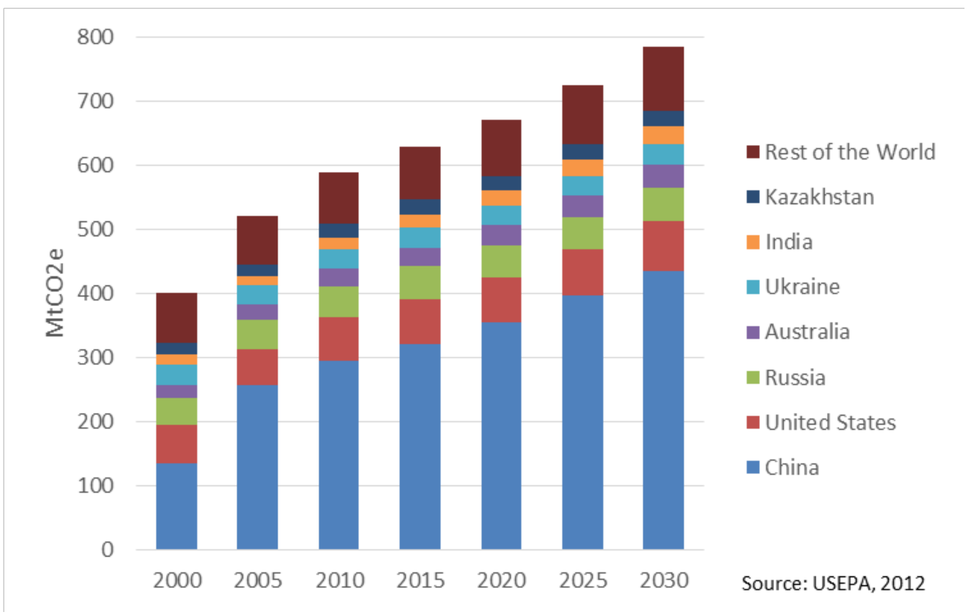

Figure 2-1: Global CMM Emissions

The large quantity of methane liberated from coal mines has, in turn, led to the implementation of many methane recovery and use projects. Today, China hosts a wide variety of CMM projects, including town gas and power production, flaring, boiler fuel, industrial uses, and VAM oxidation. Shanxi province in particular is the host of many Chinese CMM projects accounting for 43 percent of China's CMM drainage

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[1] Huang Shengchu (2014). *Coal Sector Updates in China.* Presented to the Coal Subcommittee of the Global Methane Initiative, Geneva, Switzerland. October 2014. http://www.unece.org/fileadmin/DAM/energy/se/pp/coal/cmm/9cmm_gmi_ws/3_CHINA.pdf.

[2] World Coal Association (2012) *Coal Statistics (2012e)* http://www.worldcoal.org/resources/coal-statistics/

[3] Reuters (2014). http://uk.reuters.com/article/2014/01/07/china-coal-idUKL3N0K90H720140107

[4] United States Environmental Protection Agency (USEPA, 2012). Global Anthropogenic Non-CO2 Greenhouse Gas Emissions: 1990 - 2030 December 2012. Washington, DC. EPA 430-R-12-006

utilization with 0.96 Bm^3 used in 2013.[5] This is due to its extensive and well-capitalized mining industry, large CMM resource base, and support from the provincial government. Other important drivers are high industrial power prices and prospective internal Chinese carbon markets. Despite the success in China generally and in Shanxi province specifically, there is still great demand for technical assistance with respect to mine gas assessment, management, and utilization. Coal mines in China are still venting 8.3 Bm^3 of drained gas.[6]

2.2 Selection of the Mahui and Pingshang Mines for the Pre-Feasibility Study

The Mahui and Pingshang coal mines in east central Shanxi Province are excellent subjects for a pre-feasibility study for several reasons:

- They are sizeable coal mines with each mine producing over one million tonnes of coal per year.
- The coals being mined have relatively high gas contents.
- Surrounding rock strata and coal seams also hold methane influencing the volume of gas flow into the mine.
- Both mines already employ methane drainage, thus there is a ready source of gas for utilization.
- There are CMM utilization projects at both mines, providing confidence that the mine operator and the associated project developer have the technical and operational capacity to deliver future expansions of the existing projects, and to also expand into other utilization options.
- Existing projects have not relied on carbon markets for revenues, instead using conventional energy markets to support the projects; therefore, the absence of regional, national and international markets may not have an adverse impact on the ability of Yangquan Jindong to implement the projects.
- The mine operator has expressed a clear need for technical assistance to forecast future gas availability to meet its anticipated development date of 2015, including anticipated increases in gas production due to deepening mining conditions.

An initial data request was provided to the mines in October 2013 with subsequent data requests in December 2013 and April 2014. The project team visited the coal mines and the mines' affiliated project development company, Shanxi Xiyang Fenghui Industry Co., Ltd., in November 2013. This provided the opportunity to gather data, tour surface facilities at the mines, meet with staff of both mines, and observe operations including gas and electricity production and transport. During the visit and in subsequent communications, management at Yangquan Jindong, both mines and Shanxi Xiyang Fenghui Industry Co. Ltd. demonstrated a strong commitment to maximizing gas capture and use at the two mines now and in the future. The company's senior management, including the Yangquan Jindong Group Chief Executive Officer, participated in meetings.

2.3 Corporate Affiliation

The Mahui and Pingshang mines are affiliated but owned by two different subsidiaries of the same parent company. The Mahui mine is operated by Shanxi Xiyang Fenghui Coal Co. Ltd. and Pingshang mine is operated by Xiyang County Pingshang Coal Co. Ltd. The parent company of Shanxi Xiyang and Xiyang Pingshang is the Yangquan Jindong Coal Management Company. The Mahui mine was constructed in 1983 by the local county and privatized in 2000. In 2009, Fenghui bought the mine. The project development affiliate of both mines and subsidiary of Yangquan Jindong is the Shanxi Xiyang

[5] Huang (2014)
[6] Huang (2014)

Fenghui Industry Company. The diagram in Figure 2-2 highlights the corporate structure of Yangquan Jindong and shows the relationships between the companies.

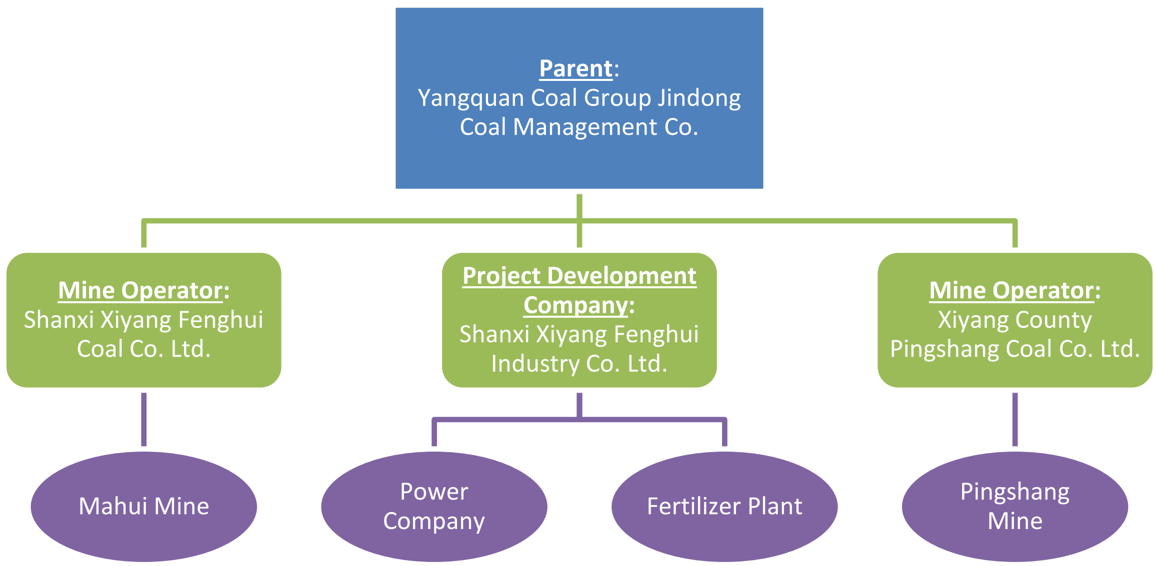

Figure 2-2: Corporate Structure

2.4 Location

The two mines are located in Shanxi Province, roughly 415 km to the southwest of Beijing in what is known as the Northern China region. The mines are situated along the eastern border of the province in Jinzhong prefecture, one of 11 prefecture-level divisions within Shanxi Province. Specifically, Mahui and Pingshang mines are located within Xiyang County, which is 75 km south of Yangquan city, the major metropolitan area of east central Shanxi (see Figure 2-3).

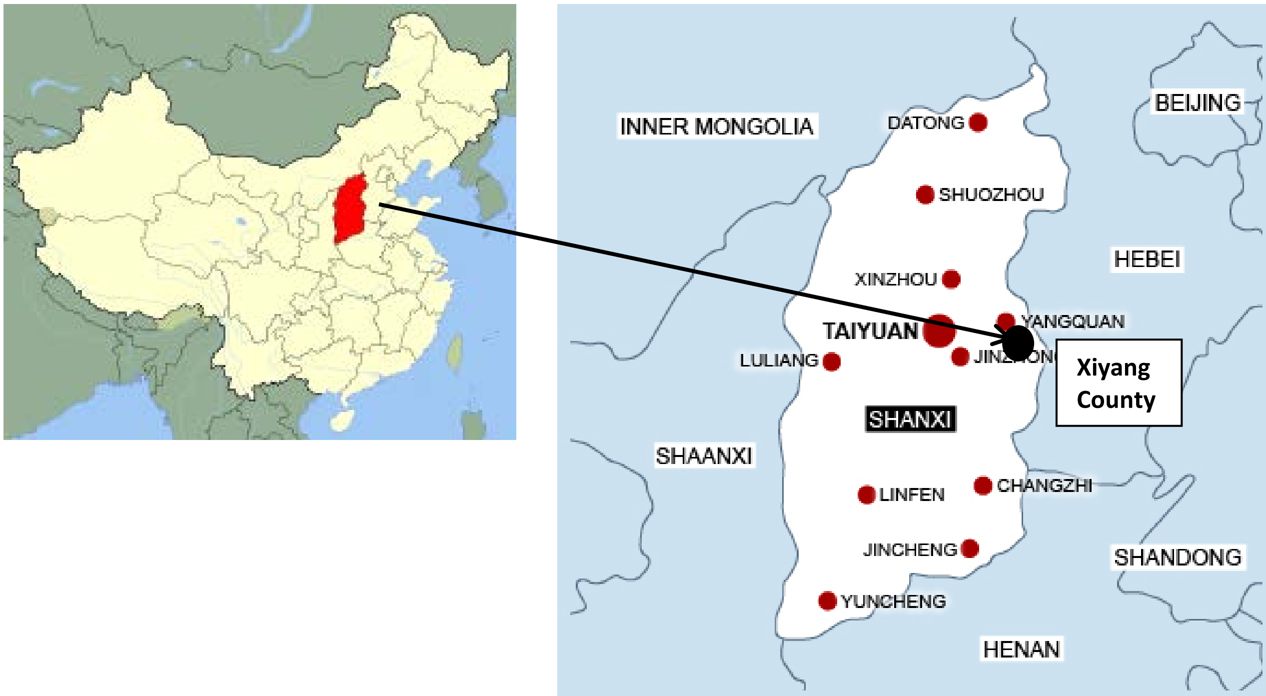

Figure 2-3: Shanxi Province and Location of the Mahui and Pingshang Coal Mines

2.5 Topography and Climate

The primary consideration for the Mahui and Pingshang mines is the mountainous terrain in eastern Shanxi province. The mines are located in the northeastern edge of Qinshui coalfield, along the western ridge of the Taihang Mountains. The Taihang have an average elevation of 1,500 to 2,000 meters (4,900 to 6,600 ft). The terrain consists primarily of mountains interspersed with valleys. Although small villages are located in the valleys, the mine galleries are located under mountains at varying elevations.

The valleys are typically cut by surface streams and rivers. Commercial, industrial, and residential areas and farming are located in the valleys, including the Mahui and Pingshang mine offices and buildings. However, some aspects of the mining operations necessarily are located in the higher elevations including ventilation fans, gas drainage pump stations, and electricity substations.

The Mahui mine is at a slightly higher elevation than Pingshang. The highest point of the Mahui mining area is in the western area of the mine plan, at elevation of 1,129 m (3,704 ft). The altitude drops to the east, with the lowest point in the eastern part of the permitted mine plan situated at 993 m (3257 ft).

For the Pingshang mining area, the terrain is higher in the west and central regions of the mine concession, with the highest point in the southwest section of the mine property at 996 m (3,267 ft) above sea level. The surface elevation drops to 862 m (2,827 ft) at the lowest point in the northeast.

The elevation at the main portals for both mines is approximately 960 m above sea level (3,150 ft).

Shanxi Province has a dry, monsoon-influenced humid continental climate, with cold and very dry winters, and warm, humid summers. Spring is extremely dry and prone to dust storms. Monthly average temperatures range from -3.4°C (26°F) in January to 24°C (75°F) in July. The average annual temperature is 9.4°C (49°F). Construction and operation of CMM projects in mountainous areas of Shanxi province can be influenced by weather. Delays or the complete cessation of construction activity can occur in winter months (effectively November through March) due to extreme cold temperatures that may occasionally bring ice and snow.

2.6 Regional Geology

Both the Mahui and Pingshang mines are located in the northeastern corner of the Qinshui Basin, which is one of China's major coal basins. The Qinshui basin, one of the Mesozoic basins that evolved from the late Paleozoic Northern China's Craton Basin, is surrounded by the Taihang Mountains, Huo Mountain, Wutai Mountain, and Zhongtiao Mountain. The Mahui and Pingshang coal mines exploit coal seams that occur within the Carboniferous Taiyuan Formation and the overlying Permian Shanxi Formation.

Ordovician carbonates form the basement for the coal deposits in the area. The Ordovician unit contains limestone and dolomite rock and averages 578 m in thickness. Unconformably overlying the Ordovician is the Carboniferous Benxi Formation, which is made up of siltstones, organic-rich shale, and thin discontinuous coals. No mineable coals occur in the Benxi formation.

Overlying the Benxi Formation is the Carboniferous Taiyuan Formation, one of two principal coal-bearing units, which is comprised of a siltstone, mudstone, and coal sequence that averages 120 m in thickness. Importantly for this analysis, the Taiyuan Formation contains coal seams No. 15, No. 8, and No. 9. Seam No. 15, the seam currently being mined in the Mahui and Pingshang mines, lies on top of a thick (over 7 m) clay and siltstone formation, which is immediately overlain by limestone followed by sandstone and clay. The mines are also authorized to produce coal from the No. 8 and No. 9 seams, but thus far have only produced run-of-mine coal from the No. 8 seam where gas drainage galleries are driven above the No. 15 seam. The planned expansions at both mines will occur in the No. 15 seam, with drainage galleries in the No. 8 seam.

Overlying the Taiyuan Formation is the Shanxi Formation. The Shanxi has an average thickness of 56 m and contains less desirable coals than the Carboniferous Taiyuan Formation. Overlying the Shanxi Formation is the Permian Lower Shihexi Formation, which is a regressive sequence that contains much more coarse-grained sandstone than the underlying coal bearing formations. Over the lower Shihexi formation is the Permian Upper Shihexi Formation, which is an assemblage of poorly sorted sandstone, siltstone, and mudstone. Lastly, overlying the Permian upper Shizexi Formation is the Permian Shiqianfeng Formation.

The Mahui and Pingshang mines are located on the southern edge of the Pingxi mining field, which is on the eastern edge of the northern section of Qinshui Depression and the west wing uplift of Taihang Mountain. The basic form is a monocline structure whose axis strikes NNE to NW. This monocline developed lower level folds. The dip is generally around 10°, but locally can be up to 20 °. The axial direction of faults and folds are mostly north east with some being north west. Collapse columns are generally developed.

Overall, the structural configuration of the mining area is broadly consistent with regional structure (i.e., a monoclinic structure with a gentle dip of 5-8 °). Faults are well developed. Wide and gentle folds can be seen in the southeast.

3 CMM Project Evaluation at Mahui Mine

3.1 Summary of Mahui Mine Characteristics

The Mahui Coal Mine is located in the central eastern part of Shanxi Province, in Mahui Village, Dazhai Town, Xiyang County. It is 12 km south of Xiyang with coordinates 37°31'47.0"N, 113°40'16.0"E, and has an aerial extent of 13.95 km^2. The topography is mountainous. The mine is located 75 km or about 1 hour drive south of the city of Yangquan (see Figure 3-1).

Figure 3-1: Location of the Mahui Mine

Construction on the Mahui mine began in 1978 with production starting in 1981. The mine has total coal reserves of 84.96 million tonnes (42 million tonnes being mineable), with no known or planned reserve additions. The planned production rate is 1.2 Mta; however, actual annual coal production ranges between 1.2 to 1.6 Mta. The expected remaining mine life is 30 years. Table 3-1 shows the historical coal and gas production at the mine since 2010, the earliest data provided by the mine.

Mine	Year	Gas Production (Mm3/yr)	Coal Production (kt/yr)	Relative Gas Emissions (m3/t)	Absolute Gas Emissions (m3/min)
Mahui	2013	46	1200	38	88
	2012	30	1200	25	57
	2011	15	900	17	29
	2010	14	800	18	27

Table 3-1: Coal Historical Production and Gas Production at the Mahui Mine

Two coal seams in the Mahui mine have been approved for mining by the government, seam No. 8 and seam No. 15, but only the No. 15 is currently being mined. Yangquan Jindong uses retreat longwall mining in the No. 15 seam. Coal is produced from the No. 8 seam but only as part of mine development to drive drainage galleries and associated roadways in the gas drainage system. The coal characteristics of the No. 8 and No. 15 are shown in Table 3-2. Seam 15 is located in the lower part of the Taiyuan formation and has a thickness of 4.2 to 5.3 m and an average thickness of 5.0 m. The seam has permeability of 0.068 m^2/Mpa^2 d, and the roof is sandy mudstone and the floor is mudstone. The mining level is 640 m above sea level, which makes the depth of mining in the range of 293 to 489 m below surface. Currently the Mahui mine operates one longwall in the No. 15 seam with a face width of 200 m.

	Ash (ad) Content (percent)		Volatile (Vdaf) Content (percent)		Sulfur (St. d) Content (percent)		Calorific (Qb, d) (MJ/kg)
Seam	Raw avg	Float avg	Raw avg	Float avg	Raw avg	Float avg	avg
15	17.00	7.04	9.26	6.96	1.49	0.74	33.69
8	27.16	10.16	11.06	7.55	0.75	0.55	32.86

Table 3-2: Characteristics of Seams No. 8 and 15 at the Mahui Mine

The geology of the mine is not considered to be complex, according to mine management. This is positive as structurally complex areas often have low permeability due to the annealing of coal cleats under tectonic stress over geologic time. However, CMM is far less sensitive to geologic structure than virgin coalbed methane or other unconventional natural gas reservoirs because even low inherent permeability is greatly increased by the intense fracturing that takes place during mining and gob collapse.0

3.2 Mahui Mine Gas Resources

Xiyang Fenghui reports that in situ gas content (also referred to as the inherent gas content) at the Mahui coal mine is 7.48 m^3/t. Seam No. 15 has a gas in place estimate of 318 million m^3. Although No. 15 is the only seam being mined by longwall method, seams 8 and 9, which overlie seam 15, are both attractive gas reservoirs with gas in place estimates of 97 million m^3 and 175 million m^3, respectively. There is also sandstone overlying No. 15 which has a gas in place estimate of 955 million m^3. Thus the

Mahui mine has a total gas reserve estimate of 2925 Mm^3 and recoverable gas is believed to be 877 Mm^3.

Methane liberated during coal extraction at the Mahui mine is managed through mine ventilation and methane drainage. The mine ventilation system contains three inlet returns and one outlet return. The methane drainage system at the Mahui mine employs drainage galleries developed in the No. 8 and No. 9 seams, which are located approximately 40 meters above the No. 15 seam. Drainage galleries, which are also sometimes referred to as the superjacent method, are driven and sealed in the No. 8 and 9 seams allowing gob gas to migrate into the galleries. The galleries are sealed and gas is drawn into the gathering network using vacuum pumps. While superjacent galleries sometimes include drainage boreholes drilled from the galleries into the gob area in order to augment gas drainage, such boreholes are not necessary at the Mahui mine. The galleries have been effective at drawing gas with just a vacuum pump. The mine gas is transported through two drainage systems, one high pressure and one low pressure, to the surface. Drainage pump stations are located on the surface along with dewatering equipment.

The methane concentration at the longwall face varies from 45 percent to 70 percent CH_4, while the average concentration in the drainage system at the surface is 45 percent CH_4. The dilution is due to air ingress into the collection system, not loss of methane during transport. However, mine gas with a relatively consistent CH_4 content of 45 percent can be used in many applications. The reported drainage recovery efficiency is 53 percent.

Figure 3-2: Passive vent and vacuum pump at the Mahui mine

3.3 Mahui Mine Gas Production Forecast

3.3.1 Mahui Mine Forecast Approach

As noted previously, the methane drainage systems at both mines utilize drainage galleries developed in coal seams above the #15 seam (Figure 3-3). The galleries are sealed and connected to the methane extraction system via a pipeline that is under suction (i.e., vacuum or negative pressure). As the longwall passes and the roof collapses, gob gas is collected in the drainage galleries and transported to the surface for utilization.

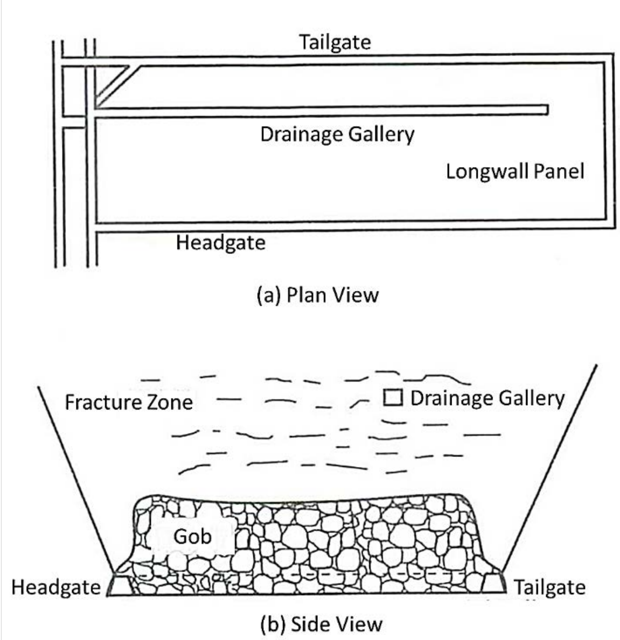

Figure 3-3: Schematic Diagram of Existing Drainage System

Gas production from Mahui mine was estimated based on the mining plan provided by the mine operator (Figure 3-4). The mine plan for the Mahui mine project consists of 8 panels with one set of panels being 2000 m by 200 m and the other set being 1000 m by 200 m. For purposes of modeling, however, the project area for the gas drainage project has been divided into 12 longwall panels, each having a length of 1000 m, a width of 200 m, and an average height of 5 m. The mine plan shows longwall panels scheduled to be mined at Mahui through 2026. For forecasting purposes a face advance rate of 3 meters per day (m/d) is assumed, which results in a total project duration of approximately 132 months for the Mahui mine.

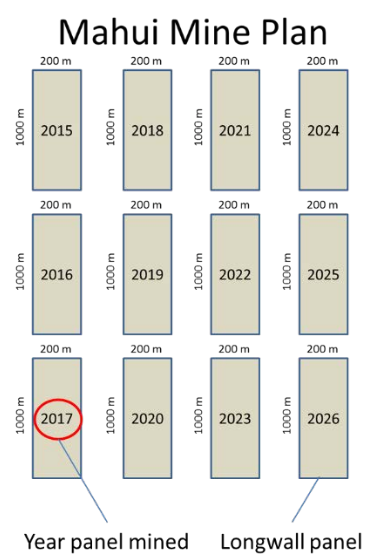

Figure 3-4: Mine Plan for Mahui Mine

Since gas liberation is largely a function of the gas content of the coal seams and the rate of coal production, historical production data can be a useful indicator of future gas drainage potential. Table 3-3 shows annual coal and gas production data as provided by mine management (also presented earlier in the overview of the Mahui mine). Gas emissions per tonne of coal mined range from 17 to 38 m^3/t from Mahui mine. Over the four year period for which data are available, gas emissions have a direct relationship to the quantity of coal produced at the Mahui mine.

Mine	Year	Gas Production (Mm3/yr)	Coal Production (kt/yr)	Relative Gas Emissions (m3/t)	Absolute Gas Emissions (m3/min)
Mahui	2013	46	1200	38	88
	2012	30	1200	25	57
	2011	15	900	17	29
	2010	14	800	18	27

Table 3-3: Historical Production and Emissions Data for Mahui Mine

In order to forecast future gas production at the Mahui mine, a model was developed to simulate gas drainage volumes based on mine-specific data and assumptions. Monte Carlo simulation (10,000 trials) was conducted in order to develop a probability density function to predict gas drainage volume for a given quantity of coal mined. Based on planned mine capacity increases, coal production forecasts were generated for the project area. Monthly gas production was then forecast by sampling the probability density function (1000 trials for each month) and multiplying the results by forecasted monthly coal production. The monthly gas volumes were then aggregated into annual quantities to be used in the economic analysis.

3.3.2 Mahui Mine Forecast Assumptions

Probability distributions were estimated for each of the key input parameters used in the gas drainage simulation model. Table 3-4 presents the range of distributions used in the simulation model. The model is based on work conducted by the Shenyang Institute of Coal Science Research in association with the preliminary design of the gas drainage project at the Mahui mine.[7] The probability distributions for the input parameters were based on actual data provided by the mines, recommended ranges provided by the Institute, and values derived through matching of historical data via trial simulations.

[7] Shenyang Research Institute of Coal Research (2000). Shanxi Coal Industry Co., Ltd. Xiyang Fenghuiyuan Mergers and Acquisitions Integration of Mine Gas Drainage Project Preliminary Design. February 2000.

Parameter	Units	Distribution	Minimum	Mahui Mine Most Likely	Maximum
Rock gas emission coefficient	ratio	Triangular	1.15	1.30	1.30
Coal face gas emission coefficient	ratio	Triangular	1.00	1.25	1.50
Seam gas content	m3/t	Triangular	7.48	7.48	13.92
Adjacent layer gas emission coefficient	ratio	Triangular	1.50	150	2.10
Coal production	Mt/yr	Uniform	0.800		1.200
Gob gas emission coefficient	ratio	Triangular	1.20	1.20	1.45
Adjacent layers drainage rate	%	Triangular	70%	90%	90%
Gob drainage rate	%	Triangular	20%	62%	62%

Table 3-4: Gas Drainage Simulation Model Input Distributions for Mahui Mine

3.3.3 Mahui Mine Forecast Results

The probability density function for the Mahui mine is presented in Figure 3-5. A lognormal probability distribution function was fit to the simulation results in order to facilitate random sampling during the generation of the monthly gas forecast. This function is used to estimate the likelihood of a volume of gas being drained for a specific quantity of coal produced.

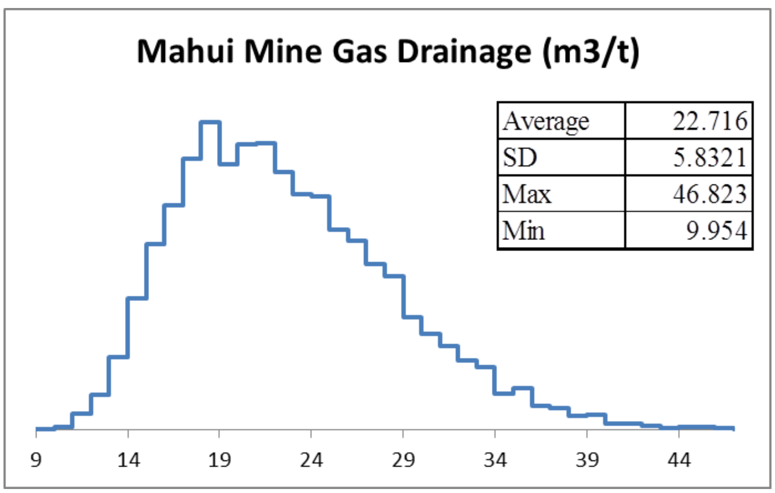

Figure 3-5: Histogram Summarizing Results of Mahui Mine Gas Drainage Simulation

The coal production forecast used in the calculation of gas drainage is presented is Figure 3-6. Coal production was assumed to remain flat at 1.2 Mt/yr through the end of 2014. Future planned capacity of 1.6 Mt/yr was provided by the mine and a five year ramp-up period was assumed beginning in 2015.

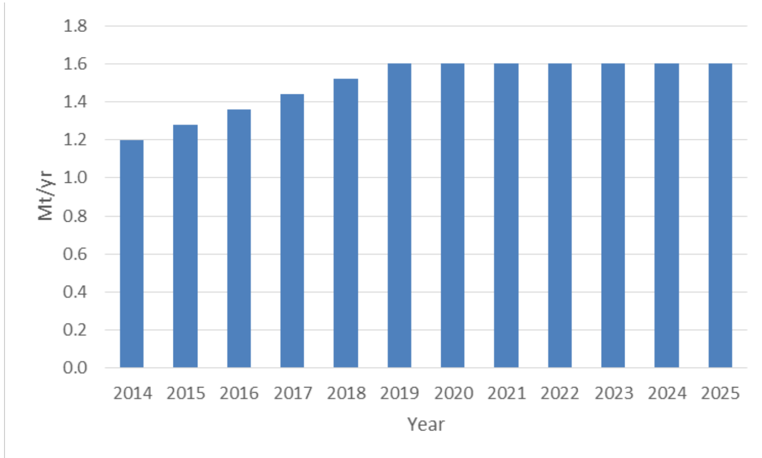

Figure 3-6: Coal Production Forecast for Mahui Mine

A gas forecast was developed for the Mahui mine based on the coal production forecast and the low, best, and high values (i.e., 10th, 50th, and 90th percentile, respectively) from random sampling of the probability distribution function for relative gas emissions at Mahui. Figure 3-7 shows the forecasted gas drainage from Mahui, and Figure 3-8 shows drained gas available after current (baseline) gas utilization is accounted for. The gas drainage volumes shown in Figure 3-8 are the residual volumes available for use after the fuel needs of the existing power plant have been met. Current gas consumption is based on an 80 percent utilization factor for existing engines and is estimated at 35 m^3/min at Mahui mine.

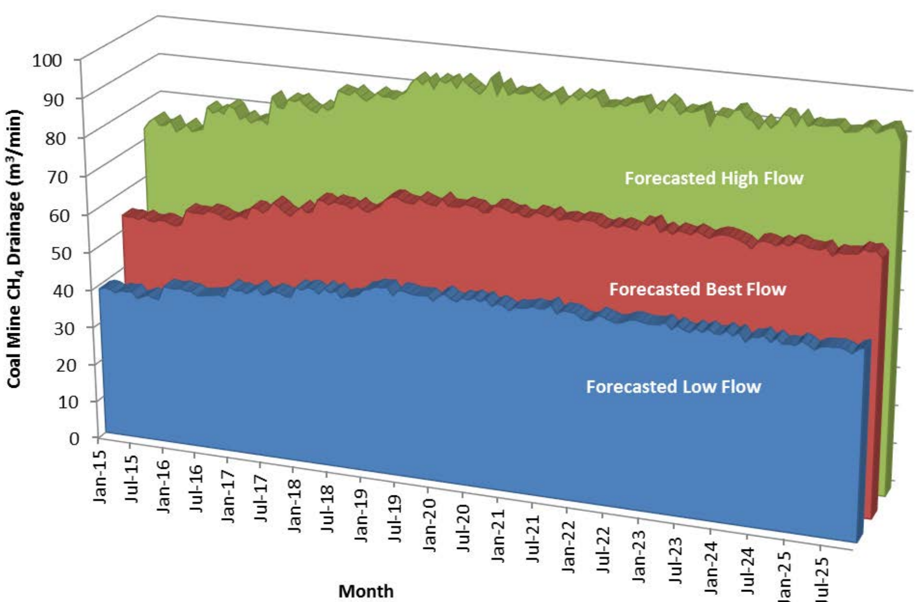

Figure 3-7: Mahui Mine Forecast Coal Mine Methane Drainage (m3/min)

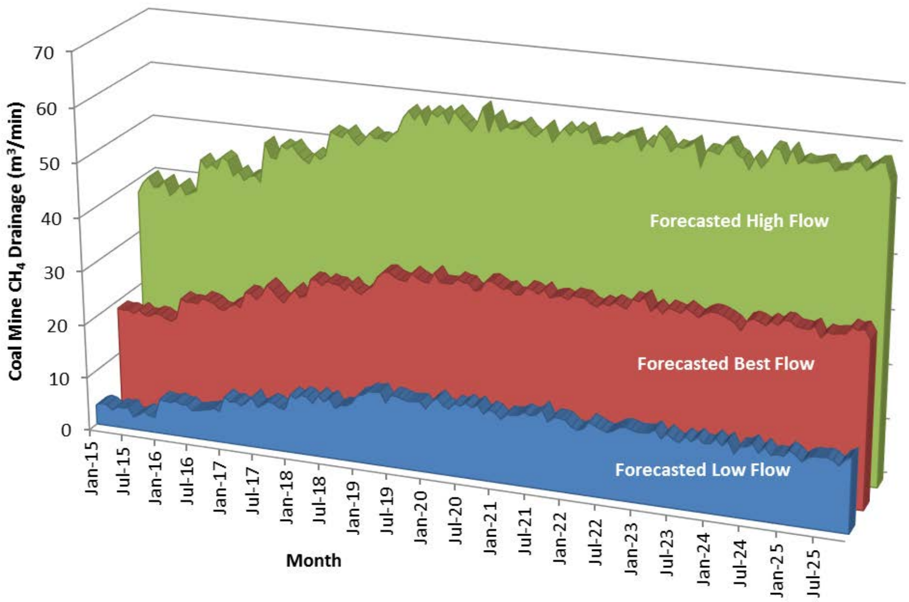

Figure 3-8: Mahui Mine Forecasted Coal Mine Methane Drainage Available For Use

3.4 Mahui Mine Preliminary Cost-Benefit Analysis

3.4.1 Technical Assessment of Utilization Options at Mahui Mine

Currently all methane produced from the Mahui mine is either utilized by the onsite power plant or vented to the atmosphere. Yangquan Jindong would like to expand the existing power plant based on the expectation that CMM production will increase in future years. Other markets for the additional CMM were considered as noted in Section 5; however, power generation in internal combustion engines remains the most favorable utilization scheme given the experience of Yangquan Jindong and Xiyang Fenghui.

3.4.2 Mahui Mine Project Development Cases

Incremental project economics are evaluated where cash flows from alternative gas utilization cases are compared to cash flows resulting from business as usual (i.e., the baseline case). The assessment is based on the best gas production forecasts (i.e., 50 percentile) for each mine, and all economics are compared on a pre-tax basis. The cases evaluated are shown in Table 3-5.

Case	Description
Baseline	Business as usual; drained gas used as fuel for existing 9.8 MW of on-site electricity generation capacity; excess drained gas vented to the atmosphere
Maximum Power Production	New electricity generation capacity added to utilize 100 percent of available drained gas

Table 3-5: Summary of Mahui Mine Project Development Cases

3.4.3 Economic Assumptions and Input Parameters for Mahui Mine

The assumptions and input parameters used in the economic evaluation are summarized in the tables below. Table 3-6 presents the general physical and financial factors used in the modeling and Table 3-7 highlights input parameters related to power generation at Mahui mine.

The baseline case is designed to represent current operations at the Mahui mine. It is assumed that gas will be utilized in the existing engines, which are assumed to have an electricity generation efficiency of 35 percent and a run time of 80 percent. The baseline case assumes 9.8 MW of electrical generation capacity is available at the Mahui mine – this is the existing plant. The capital expenditure for the existing generation capacity is assumed to represent a sunk cost and is therefore not factored into the project economics. Existing agreements between the mines and the power development affiliate, Xiyang Fenghui, are also represented in the baseline case where Mahui mine provides gas free of charge to the power company. The calorific value of the drained gas from Mahui mine is assumed to have a heating value of 459 Btu/cf (4,084 kcal/m^3) corresponding to a methane concentration of 45 percent.

The maximum power production case assumes new electricity generation capacity is added until 100 percent of available drained gas is utilized. New generation capacity is assumed to cost \$401 per kW, which includes costs for installation and other ancillary equipment.[8]

Parameter	Value
Price Escalation	3%
Cost Escalation	3%
Calorific Value of Gas	459 Btu/cf

Table 3-6: General Physical & Financial Factors Used in Economic Modeling of Mahui Mine

[8] This cost represents the installed cost in China for Chinese-made gas engines and is significantly less than the cost of purchasing and installing gensets from western manufacturers which can range from \$700-\$1200 per kW.

Parameters	Value
<u>Physical & Financial Factors</u>	
Baseline Electricity Generation Capacity	9.8 MW
Power Sales Price	$0.0817/kWh
Generator Efficiency	35%
Run Time	80%
<u>CAPEX</u>	
Generator Cost Factor	$401/kW
Generator Relocation Fee	$100/kW
<u>OPEX</u>	
Power Plant O&M	$0.03/kWh
Fuel Cost	$0/yr

Table 3-7: Input Parameters Used to Model Economics of Mahui Mine Power Generation

3.4.4 Mahui Mine Baseline Case Results

Table 3-8 shows the cash flow profile and economic results of the baseline case for the Mahui mine. Using a discount rate of 10 percent, the baseline case at Mahui generates an estimated cash flow stream with a net present value (NPV-10) of US$25.8 million.

Mine: Mahui
Forecast: Best
Case: Baseline

Year	Electricity Generation Capacity Utilized MW	Electricity Generation MWh	Electricity Sales Price $/kWh	Revenue $,000	Fuel Cost $,000	O&M Cost $,000	Operating Income $,000	Capital Cost $,000	Cash Flow $,000	Cumulative Cash Flow $,000
2014	0.0	0	0.082	0	0	0	0		0	0
2015	9.8	68,678	0.084	5,779	0	2,271	3,509		3,509	3,509
2016	9.8	68,678	0.087	5,953	0	2,339	3,614		3,614	7,122
2017	9.8	68,678	0.089	6,131	0	2,409	3,722		3,722	10,845
2018	9.8	68,678	0.092	6,315	0	2,481	3,834		3,834	14,678
2019	9.8	68,678	0.095	6,505	0	2,556	3,949		3,949	18,627
2020	9.8	68,678	0.098	6,700	0	2,633	4,067		4,067	22,695
2021	9.8	68,678	0.100	6,901	0	2,712	4,189		4,189	26,884
2022	9.8	68,678	0.103	7,108	0	2,793	4,315		4,315	31,199
2023	9.8	68,678	0.107	7,321	0	2,877	4,445		4,445	35,644
2024	9.8	68,678	0.110	7,541	0	2,963	4,578		4,578	40,222
2025	9.8	68,678	0.113	7,767	0	3,052	4,715		4,715	44,937
TOTAL		755,462		74,022	0	29,085	44,937	0	44,937	

Discount Factor: 10%
NPV ($,000): 25,805
IRR: -

Table 3-8: Cash Flow and Economic Results of Base Case for Mahui Mine

3.4.5 Mahui Mine Maximum Power Production Case Results

Table 3-9 shows the cash flow profile and economic results of the maximum power production case for Mahui mine. The maximum power production case at Mahui generates an estimated cash flow stream with an NPV-10 of US$42.7 million.

Mine: Mahui
Forecast: Best
Case: Max Power

Year	Electricity Generation Capacity Utilized MW	Electricity Generation MWh	Electricity Sales Price $/kWh	Revenue $,000	Fuel Cost $,000	O&M Cost $,000	Operating Income $,000	Capital Cost $,000	Cash Flow $,000	Cumulative Cash Flow $,000
2014	0.0	0	0.082	0	0	0	0	2,023	(2,023)	(2,023)
2015	14.8	104,016	0.084	8,753	0	3,439	5,314	409	4,905	2,882
2016	15.8	110,945	0.087	9,616	0	3,779	5,838	396	5,442	8,323
2017	16.8	117,466	0.089	10,487	0	4,121	6,366	393	5,974	14,297
2018	17.7	123,742	0.092	11,379	0	4,471	6,908	389	6,519	20,816
2019	18.5	129,780	0.095	12,292	0	4,830	7,462	32	7,430	28,246
2020	18.6	130,263	0.098	12,708	0	4,993	7,715	0	7,715	35,960
2021	18.5	129,970	0.100	13,060	0	5,132	7,928	0	7,928	43,889
2022	18.5	129,848	0.103	13,439	0	5,281	8,158	0	8,158	52,047
2023	18.6	130,095	0.107	13,868	0	5,449	8,419	0	8,419	60,466
2024	18.5	129,528	0.110	14,222	0	5,588	8,634	0	8,634	69,100
2025	18.5	129,664	0.113	14,664	0	5,762	8,902	0	8,902	78,002
TOTAL		1,365,319		134,489	0	52,844	81,645	3,642	78,002	

Discount Factor: 10%
NPV ($,000): 42,736
IRR: 253%

Table 3-9: Cash Flow and Economic Results of Maximum Power Production Case for Mahui Mine

3.4.6 Mahui Mine Incremental Economic Results

Table 3-10 presents the incremental economics for the Mahui maximum power production case, in other words the maximum power production case less the baseline case (existing project). The results of the economic analysis indicate an incremental increase in NPV-10 of US$16.9 million for the maximum power production case as compared to the baseline case at Mahui mine. Total incremental generating capacity would be 8.8 MW for a total nameplate capacity of 18.6 MW at Mahui by 2020.

Mine: Mahui
Forecast: Best
Case: Incremental (Max Power - Baseline)

Year	Electricity Generation Capacity Utilized MW	Electricity Generation MWh	Electricity Sales Price $/kWh	Revenue $,000	Fuel Cost $,000	O&M Cost $,000	Operating Income $,000	Capital Cost $,000	Cash Flow $,000	Cumulative Cash Flow $,000
2014	0.0	0	0.000	0	0	0	0	2,023	(2,023)	(2,023)
2015	5.0	35,338	0.000	2,974	0	1,168	1,805	409	1,397	(627)
2016	6.0	42,267	0.000	3,664	0	1,440	2,224	396	1,828	1,201
2017	7.0	48,788	0.000	4,356	0	1,711	2,644	393	2,251	3,453
2018	7.9	55,064	0.000	5,063	0	1,990	3,074	389	2,685	6,137
2019	8.7	61,101	0.000	5,787	0	2,274	3,513	32	3,481	9,618
2020	8.8	61,585	0.000	6,008	0	2,361	3,647	0	3,647	13,266
2021	8.7	61,292	0.000	6,159	0	2,420	3,739	0	3,739	17,005
2022	8.7	61,170	0.000	6,331	0	2,488	3,843	0	3,843	20,848
2023	8.8	61,417	0.000	6,547	0	2,573	3,975	0	3,975	24,822
2024	8.7	60,849	0.000	6,681	0	2,625	4,056	0	4,056	28,878
2025	8.7	60,986	0.000	6,897	0	2,710	4,187	0	4,187	33,066
TOTAL		609,856		60,467	0	23,759	36,708	3,642	33,066	

Discount Factor: 10%
NPV ($,000): 16,931
IRR: 92%

Table 3-10: Cash Flow and Incremental Economic Results for Mahui Mine (Max Power minus Baseline)

With the addition of another 8.8 MW of electricity generation capacity at Mahui mine, 100 percent of the drained methane is destroyed resulting in net emission reductions of 183,000 tCO2e/yr over the 11-year project life or 2,013,000 tCO2e over the life of the project. Additionally, the incremental electricity generated will offset electricity consumption from the North China Power Grid, which would decrease project-related emissions by an estimated 55,000 tCO2e/yr, for a total emission reduction of 238,000 tCO2e/yr over the 11-year project life. Thus the project would yield a total 3,113,000 tCO2e in emission reductions over the project life. Table 3-11 illustrates the impact on project economics resulting from the potential monetization of carbon emission reductions under various carbon price regimes.

Carbon Price ($/tCO2e)	NPV-10 ($,000)	IRR (percent)
0	16,931	92%
1	18,410	99%
5	24,324	129%
10	31,717	165%
15	39,110	202%

Table 3-11: Summary of Incremental Economic Results for Mahui Mine Maximum Power Production Case with Carbon Price Sensitivities

4 CMM Project Evaluation at Pingshang Mine

4.1 Summary of Pingshang Mine Characteristics

The Pingshang coal mine is located approximately 8.5 km north-northwest of the Mahui Coal Mine in Xinangou Village, Leping Town in Xiyang County. The geographic coordinates are $37^0$36'19.0"N, $113^0$38'10.0"E (see Figure 4-1) and the mine property has an aerial extent of 7.41 km^2. As with the Mahui mine, the topography is mountainous.

Figure 4-1: Location of the Pingshang Mine

The Pingshang mine was consolidated from two coal mines, the Pingshang and Xinangou mines, both of which started coal production in 1983. In 2006, approval was received to consolidate the two mines into one larger mine with total coal production capacity of 300,000 tpa. In the same year, Yangquan Mining (Group) Limited entered into a joint operating agreement with Pingshang Coal Mining Co. Ltd., making Pingshang a subsidiary company of Yangquan Jindong. It was then decided to upgrade the mine to reach production capacity of 900 tpa.

The Pingshang mine has total coal reserves of 60 million tonnes (26 million tonnes being mineable). Yangquan Jindong has plans for a reserve addition of 20 million tons to the existing 60 million tonnes of reserves. The reserve addition will justify production beyond 2022.

The planned coal production rate is 900,000 tpa, but the mine's actual coal production is 1.2 Mta. Additionally, the mine plans to expand future coal production to 1.2-1.5 Mta. The estimated remaining mine life is currently 20+ years with the reserve addition. Table 4-1 presents historical coal and gas production from the Pingshang mine since 2010, the earliest data provided by the mine.

Mine	Year	Gas Production (Mm3/yr)	Coal Production (kt/yr)	Relative Gas Emissions (m3/t)	Absolute Gas Emissions (m3/min)
Pingshang	2013	27	880	31	51
	2012	24	820	29	46
	2011	22	800	28	42
	2010	19	780	24	36

Table 4-1: Historical Coal Production and Gas Production at the Pingshang Mine

There are 3 coal seams in the Pingshang mine that have been mined at some point, seam No. 15, seam No. 8, and seam No. 9. Similar to the Mahui mine, longwall mining is only occurring in seam No. 15 at present. The coal characteristics of all three seams are shown in Table 4-2. Seam 8 is located in the upper Taiyuan formation and consists of the No. 81 and No. 84 coal seam groups. No. 81 has an average thickness of 0.74 m with a roof and floor of dark grey siltstone, silty mudstone and shale. No. 84 has an average thickness of 1.33 m with a roof of carbonaceous mudstone, sandy mudstone, and siltstone, and a floor of fine sandstone, siltstone, silty mudstone or shale. Seam No. 9 is also situated in the upper Taiyuan formation, has an average thickness of 1.18 m, and has a roof and floor consisting of sandy mudstone or shale. Seam No. 15 is located in the lower part of the Taiyuan formation and has an average thickness of 6.09 m with and a permeability of 0.068 m^2/Mpa^2 d and a roof and floor consisting of mudstone to sandy mudstone. The longwall face of Seam No. 15 is 165 m with a thickness of 5.5 m and an advance rate of 3 m/d. Mining is at 320m below the surface.

Seam	Ash (ad) Content (percent)		Volatile (Vdaf) Content (percent)		Sulfur (St. d) Content (percent)		Calorific (Qb, d) (MJ/kg)
	Raw avg	Float avg	Raw avg	Float avg	Raw avg	Float avg	avg
15	20.29	7.96	10.13	7.00	1.07	0.68	34.5
9	17.53	8.72	8.54	7.21	1.76	0.88	35.57
8 (No. 81)	22.81	9.81	9.89	7.56	3.94	0.72	34.81
8 (No. 84)	24.09	9.57	11.86	7.56	0.45	0.53	33.57

Table 4-2: Characteristics of Seams No. 8, No. 9 and No. 15 at the Pingshang mine

4.2 Pingshang Mine Gas Resources

The in situ gas content of the coal in the No. 15 seam at the Pingshang mine is 7.85 m^3/t, slightly higher than the Mahui mine's 7.48 m^3/t. The mine has a total gas reserve estimate of 1,032 million m^3.

Pingshang mine uses drainage and ventilation to manage methane produced in the mine. The mine ventilation system contains three inlets and one outlet return. The drainage system is very similar to that used at Mahui; sealed galleries are driven into the No. 9 seam 68 meters above the No. 15 seam with a vacuum pump used to pull the gob gas to the surface. Gas is then transported by high and low pressure systems, with high pressure systems venting to the atmosphere and a low pressure system supplying gas to the power plant. A new high-volume low pressure pump station, which has a pump capacity of 800 m^3/min, was installed in 2012, although the pump is not close to full utilization. The estimated low pressure throughput is 150 m^3/min.

Methane concentration at Pingshang averages 41 percent at the surface, and the drainage recovery efficiency at Pingshang is reported to be 59 percent.

Figure 4-2: Vacuum pump at the Pingshang Mine

4.3 Pingshang Mine Gas Production Forecast

4.3.1 Pingshang Mine Forecast Approach

As noted previously, the methane drainage systems at both mines utilize drainage galleries developed in coal seams above the #15 seam (see Figure 3-3). The galleries are sealed and connected to the methane extraction system via a pipeline that is under suction (i.e., vacuum or negative pressure). As the longwall passes and the roof collapses, gob gas is collected in the drainage galleries and transported to the surface for utilization.

Gas production from Pingshang mine was estimated based on the mining plan provided by the mine operator (Figure 4-3). The gas drainage project at the Pingshang mine consists of a total of eight longwall panels, each having a length of 1000 m, a width of 165 m, and an average height of 5.5 m. The mine plan shows longwall panels scheduled to be mined at Pingshang through 2022. With a reserve addition, the number of panels will increase at Pingshang to extend production beyond 2022. However, for this analysis, it is assumed that 2022 is the final year of production for the study area. The results can be extrapolated to future years beyond 2022 if the mining conditions and gas contents in the reserve addition are similar to the study area. For forecasting purposes a face advance rate of 3 m/d is assumed, which results in a total project duration of approximately 88 months for the Pingshang mine.

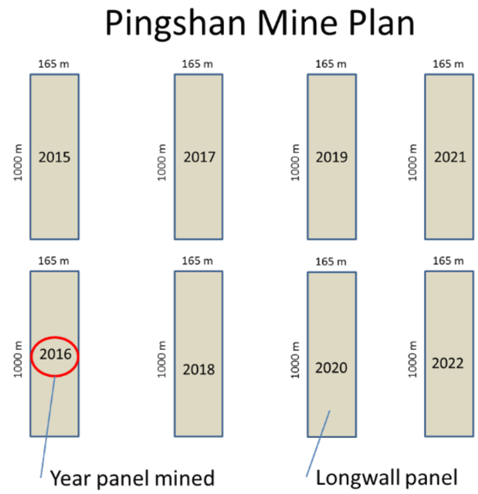

Figure 4-3: Mine Plan for Pingshang Mine

Since gas liberation is largely a function of the gas content of the coal seams and the rate of coal production, historical production data can be a useful indicator of future gas drainage potential. Table 4-3 shows annual coal and gas production data as provided by mine management (also presented earlier in the overview of the Pingshang mine). Gas emissions per tonne of coal mined range between 24 and 31 m^3/t from Pingshang mine. Over the four year period for which data are available, gas emissions have a direct relationship to the quantity of coal produced at the Pingshang mine.

Mine	Year	Gas Production (Mm3/yr)	Coal Production (kt/yr)	Relative Gas Emissions (m3/t)	Absolute Gas Emissions (m3/min)
Pingshang	2013	27	880	31	51
	2012	24	820	29	46
	2011	22	800	28	42
	2010	19	780	24	36

Table 4-3: Historical Production and Emissions Data for Pingshang Mine

As with the Mahui mine, in order to forecast future gas production at the Pingshang mine, a model was developed to simulate gas drainage volumes based on mine-specific data and assumptions. Monte Carlo simulation (10,000 trials) was conducted in order to develop a probability density function to predict gas drainage volume for a given quantity of coal mined. Based on planned mine capacity increases, coal production forecasts were generated for the project area. Monthly gas production was then forecast by sampling the probability density function (1000 trials for each month) and multiplying the results by forecasted monthly coal production. The monthly gas volumes were then aggregated into annual quantities to be used in the economic analysis.

4.3.2 Pingshang Mine Forecast Assumptions

Probability distributions were estimated for each of the key input parameters used in the gas drainage simulation model. Table 4-4 presents the range of distributions used in the simulation model. The model is based on work conducted by the Shanxi Chen State Construction Engineering Survey and Design Co., Ltd. in association with the preliminary design of the gas drainage project at the Pingshang mine.[9] The probability distributions for the input parameters were based on actual data provided by the mines, recommended ranges provided by the Shanxi Chen, and values derived through matching of historical data via trial simulations.

Parameter	Units	Distribution	Pingshang Mine Minimum	Most Likely	Maximum
Rock gas emission coefficient	ratio	Triangular	1.15	1.15	1.30
Coal face gas emission coefficient	ratio	Triangular	0.85	1.15	1.44
Seam gas content	m3/t	Triangular	4.20	7.85	12.15
Adjacent layer gas emission coefficient	ratio	Triangular	1.50	2.10	2.10
Coal production	Mt/yr	Uniform	0.780		0.880
Gob gas emission coefficient	ratio	Triangular	1.25	1.30	1.45
Adjacent layers drainage rate	%	Triangular	70%	90%	90%
Gob drainage rate	%	Triangular	20%	34%	38%

Table 4-4: Gas Drainage Simulation Model Input Distributions for Pingshang Mine

4.3.3 Pingshang Mine Forecast Results

The probability density function for the Pingshang mine is presented in Figure 4-4. A lognormal probability distribution function was fit to the simulation results in order to facilitate random sampling during the generation of the monthly gas forecast. This function is used to estimate the likelihood of a volume of gas being drained for a specific quantity of coal produced.

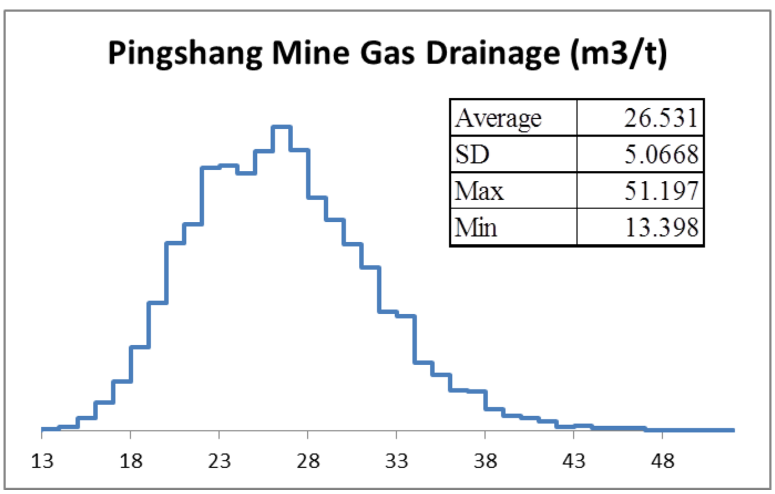

Figure 4-4: Histogram Summarizing Results of Pingshang Mine Gas Drainage Simulation

The coal production forecast used in the calculation of gas drainage is presented in Figure 4-5. Coal production was assumed to remain flat at 0.88 Mt/yr through the end of 2014. Future planned capacity of 1.5 Mt/yr was provided by the mine and a five year ramp-up period was assumed beginning in 2015.

[9] Shanxi Chen State Construction Engineering Survey and Design Co., Ltd (2008). Xiyang County Coal LLC aerodromes upgraded the 15th mechanized coal seam gas drainage preliminary design. July 2008.

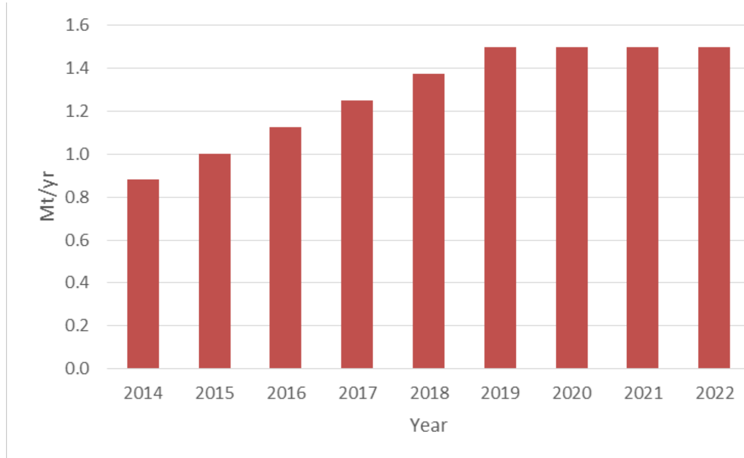

Figure 4-5: Coal Production Forecast for Pingshang Mine

A gas forecast was developed for Pingshang mine based on the coal production forecasted and the low, best, and high values (i.e., 10th, 50th, and 90th percentile, respectively) from random sampling of the probability distribution function for relative gas emissions at Pingshang. Figure 4-6 shows the forecasted gas drainage from Pingshang mine, and Figure 4-7 shows drained gas available after current (baseline) gas utilization is taken into account. Current gas consumption is based on an 80 percent utilization factor for existing engines and is estimated at 52 m^3/min at Pingshang mine.

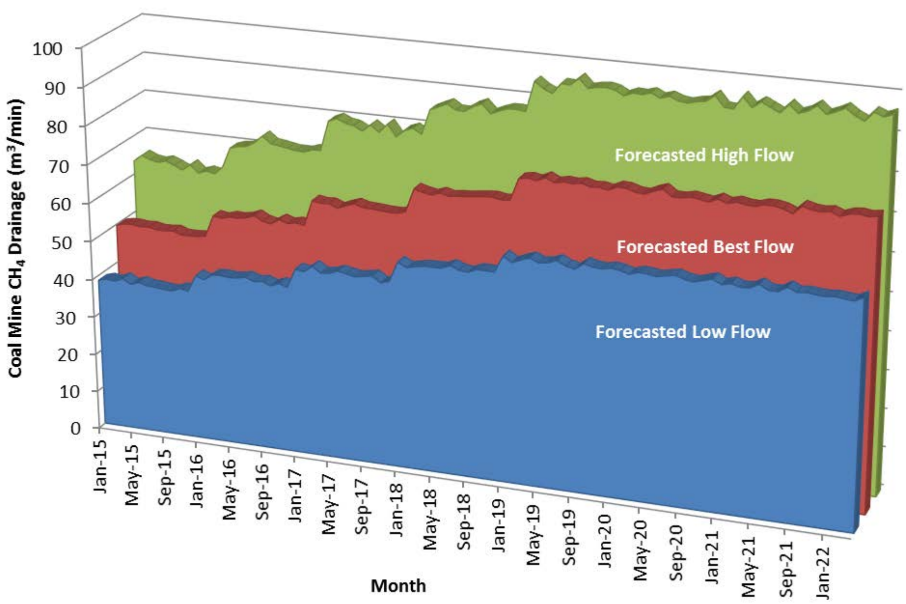

Figure 4-6: Pingshang Mine Forecasted Coal Mine Methane Drainage (m3/min)

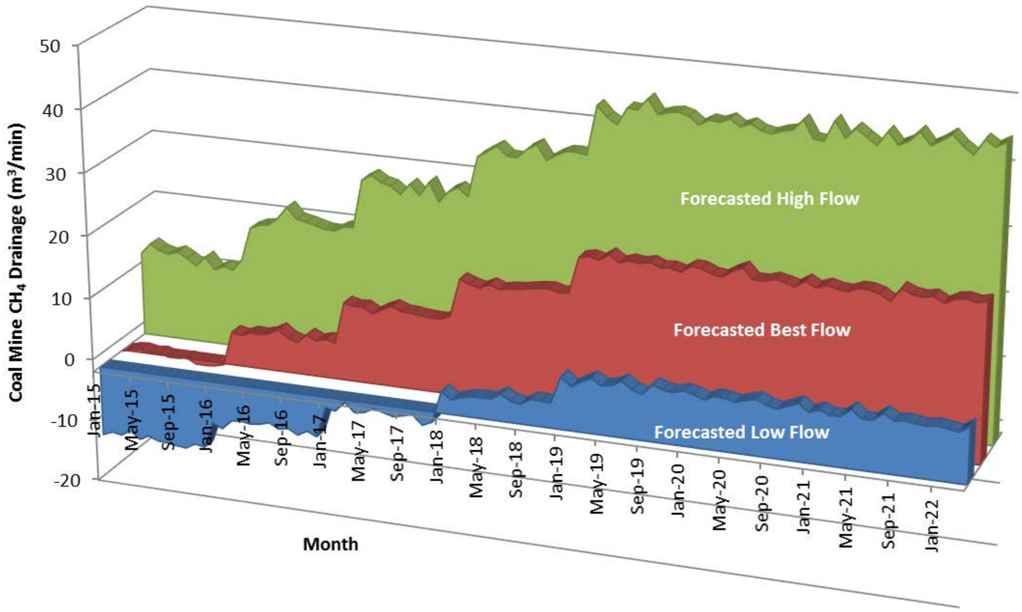

Figure 4-7: Pingshang Mine Forecasted Coal Mine Methane Drainage Available for Use (m3/min)

4.4 Pingshang Mine Preliminary Cost-Benefit Analysis

4.4.1 Technical Assessment of Utilization Options at Pingshang Mine

Currently all methane produced from the Pingshang mine is either utilized by the onsite power plant or vented to the atmosphere. There are plans to increase power generation capacity at Pingshang by adding four to six 500 kW gensets (2-3 MW). The mine is also considering supplying a nearby fertilizer plant with methane to replace coal that is currently used in a burner at the plant. The mine currently supplies the fertilizer plant with 20,000 tonnes of coal per year, which will be substituted by an estimated 12 million m^3/yr of CMM. Currently, in order to make fertilizer, the plant crushes and then mixes shells and lime before heating, which results in the final product, fertilizer. Using coal as the heat source, the plant must gasify the coal. If CMM replaces coal as the energy source at the fertilizer plant, the availability of a methane stream would allow the plant to eliminate the gasification step. Figure 4-8 is a picture of the fertilizer plant near Pingshang mine.

Figure 4-8: Fertilizer Plant Near the Pingshang Mine

4.4.2 Pingshang Mine Project Development Cases

Incremental project economics are evaluated where cash flows from alternative gas utilization cases are compared to cash flows resulting from business as usual (i.e., the baseline case). The assessment is based on the best gas production forecasts (i.e., 50 percentile) for each mine, and all economics are compared on a pre-tax basis. The cases evaluated are shown in Table 4-5.

Case	Description
Baseline	Business as usual; drained gas used as fuel for existing 14.4 MW of on-site electricity generation capacity; excess drained gas vented to the atmosphere; fertilizer plant fueled by coal
Maximum Power Production	New electricity generation capacity added to utilize 100 percent of available drained gas; fertilizer plant fueled by coal
Fertilizer Production	Fertilizer plant converted to natural gas and receives priority over on-site power station with regard to gas supply; surplus gas used to generate electricity

Table 4-5: Summary of Pingshang Mine Project Development Cases

4.4.3 Economic Assumptions and Input Parameters for Pingshang Mine

The assumptions and input parameters used in the economic evaluation are summarized in the tables below. Table 4-6 presents the general physical and financial factors used in the modeling, Table 4-7 highlights input parameters related to power generation at Pingshang mine, and Table 4-8 shows inputs for the fertilizer production case.

The baseline case is designed to represent current operations at the Pingshang mine. It assumes that gas will be utilized in the existing engines, which are assumed to have an electricity generation efficiency of 35 percent and a run time of 80 percent. The baseline case assumes 14.4 MW of electrical generation capacity is available at the Pingshang mine. The capital expenditure for the existing generation capacity is assumed to represent a sunk cost and is therefore not factored into the project economics. Existing agreements between the mines and the power development affiliate are also represented in the baseline case where Pingshang mine receives US$963,000 (RMB6 million) per year for gas, regardless of the quantity supplied. Additionally, the Pingshang baseline case assumes the fertilizer plant is fueled by 20,000 tpa of coal. The calorific value of the drained gas from Pingshang mine is assumed to have a heating value of 418 Btu/cf (3,719 kcal/m^3) corresponding to a methane concentration of 41 percent.

The maximum power production case assumes new electricity generation capacity is added until 100 percent of available drained gas is utilized. New generation capacity is assumed to cost $401 per kW, which includes costs for installation and other ancillary equipment. Under this case, the fertilizer plant associated with the Pingshang mine remains to be fueled by coal, as it is in the baseline case.

The fertilizer production case assumes the fertilizer plant is converted to natural gas and receives priority over the power station with regard to gas supply. Under this case, the fertilizer plant receives approximately 12 Mm^3 of gas each year with any surplus gas utilized to generate electricity. Incremental capital costs associated with this case include expenditures for conversion of the burner and the construction of a pipeline to the fertilizer plant.

Parameter	Value
Price Escalation	3%
Cost Escalation	3%
Calorific Value of Gas	418 Btu/cf

Table 4-6: General Physical & Financial Factors Used in Economic Modeling of Pingshang Mine

Parameters	Value
Physical & Financial Factors	
Baseline Electricity Generation Capacity	14.4 MW
Power Sales Price	$0.0817/kWh
Generator Efficiency	35%
Run Time	80%
CAPEX	
Generator Cost Factor	$401/kW
Generator Relocation Fee	$100/kW
OPEX	
Power Plant O&M	$0.03/kWh
Fuel Cost	$963,000/yr

Table 4-7: Input Parameters Used to Model Economics of Pingshang Mine Power Generation

Parameters	Value
Physical & Financial Factors	
Coal Consumption	20,000 t/yr
Coal-Gas Equivalence Factor	1.5 kg coal/m3 CH_4
CAPEX	
Burner Conversion Cost	$236,000
Pipeline Cost	$230,000
OPEX	
Fuel Cost – Coal	$88/t

Table 4-8: Input Parameters Used to Model Economics of Fertilizer Production

4.4.4 Pingshang Mine Baseline Case Results

Table 4-9 shows the cash flow profile and economic results of the baseline case for Pingshang mine. Using a discount rate of 10 percent, the baseline case at Pingshang generates an estimated cash flow stream with a NPV-10 of US$12.7 million.

Mine: Pingshang
Forecast: Best
Case: Baseline

Year	Electricity Generation Capacity Utilized MW	Electricity Generation MWh	Electricity Sales Price $/kWh	Revenue $,000	Fuel Cost $,000	O&M Cost $,000	Operating Income $,000	Capital Cost $,000	Cash Flow $,000	Cumulative Cash Flow $,000
2014	0.0	0	0.082	0	0	0	0		0	0
2015	13.8	96,793	0.084	8,145	2,811	3,201	2,134		2,134	2,134
2016	14.4	100,915	0.087	8,747	2,895	3,437	2,415		2,415	4,549
2017	14.4	100,915	0.089	9,009	2,982	3,540	2,488		2,488	7,037
2018	14.4	100,915	0.092	9,280	3,071	3,646	2,562		2,562	9,599
2019	14.4	100,915	0.095	9,558	3,163	3,756	2,639		2,639	12,238
2020	14.4	100,915	0.098	9,845	3,258	3,868	2,718		2,718	14,957
2021	14.4	100,915	0.100	10,140	3,356	3,984	2,800		2,800	17,757
2022	6.9	48,430	0.103	5,012	1,966	1,969	1,077		1,077	18,834
2023										
2024										
2025										
TOTAL		750,713		69,737	23,502	27,402	18,834	0	18,834	

Discount Factor: 10%
NPV ($,000): 12,668
IRR: -

Table 4-9: Cash Flow and Economic Results of Base Case for Pingshang Mine

4.4.5 Pingshang Mine Maximum Power Production Case Results

Table 4-10 shows the cash flow profile and economic results of the maximum power production case for the Pingshang mine. The maximum power production case at Pingshang mine generates an estimated cash flow stream with an NPV-10 of US$17.3 million. An incremental 6.2 MW of power is added to the existing power plant at Pingshang mine.

Mine: Pingshang
Forecast: Best
Case: Max Power (100% of surplus gas to additional power generation)

Year	Electricity Generation Capacity Utilized MW	Electricity Generation MWh	Electricity Sales Price $/kWh	Revenue $,000	Fuel Cost $,000	O&M Cost $,000	Operating Income $,000	Capital Cost $,000	Cash Flow $,000	Cumulative Cash Flow $,000
2014	0.0	0	0.082	0	0	0	0	0	0	0
2015	13.8	96,793	0.084	8,145	2,811	3,201	2,134	431	1,704	1,704
2016	15.4	108,215	0.087	9,380	2,895	3,686	2,799	755	2,045	3,748
2017	17.2	120,638	0.089	10,770	2,982	4,232	3,557	741	2,815	6,563
2018	18.9	132,488	0.092	12,183	3,071	4,787	4,325	781	3,544	10,108
2019	20.6	144,602	0.095	13,696	3,163	5,381	5,151	0	5,151	15,259
2020	20.6	144,404	0.098	14,087	3,258	5,535	5,294	0	5,294	20,552
2021	20.6	144,396	0.100	14,509	3,356	5,701	5,452	0	5,452	26,005
2022	6.9	48,430	0.103	5,012	1,966	1,969	1,077	0	1,077	27,082
2023										
2024										
2025										
TOTAL		939,965		87,783	23,502	34,492	29,789	2,707	27,082	

Discount Factor: 10%
NPV ($,000): 17,261
IRR: -

Table 4-10: Cash Flow and Economic Results of Maximum Power Production Case for Pingshang Mine

4.4.6 Pingshang Mine Fertilizer Production Case Results

Table 4-11 shows the cash flow profile and economic results of the fertilizer production case for the Pingshang mine. The fertilizer production case associated with Pingshang mine generates an estimated cash flow stream with an NPV-10 of US$3.0 million. In this case, the use of CMM at the fertilizer plant substantially decreases the gas available for power generation, reducing the electrical output of the power plant.

Mine: Pingshang
Forecast: Best
Case: Fertilizer (max gas to fertilizer plant; surplus gas to additional power generation)

Year	Electricity Generation Capacity Utilized MW	Electricity Generation MWh	Electricity Sales Price $/kWh	Revenue $,000	Fuel Cost $,000	O&M Cost $,000	Operating Income $,000	Capital Cost $,000	Cash Flow $,000	Cumulative Cash Flow $,000
2014	0.0	0	0.082	0	0	0	0	465	(465)	(465)
2015	3.0	21,364	0.084	1,798	992	706	99		99	(366)
2016	3.7	26,047	0.087	2,258	1,022	887	349		349	(17)
2017	4.4	31,141	0.089	2,780	1,052	1,092	635		635	618
2018	5.1	35,999	0.092	3,310	1,084	1,301	926		926	1,544
2019	5.8	40,966	0.095	3,880	1,116	1,525	1,239		1,239	2,783
2020	5.8	40,884	0.098	3,989	1,150	1,567	1,271		1,271	4,054
2021	5.8	40,881	0.100	4,108	1,184	1,614	1,309		1,309	5,364
2022	2.0	13,749	0.103	1,423	1,220	559	(356)		(356)	5,007
2023										
2024										
2025										
TOTAL		251,032		23,545	8,821	9,252	5,473	465	5,007	

Discount Factor: 10%
NPV ($,000): 3,016
IRR: 82%

Table 4-11: Cash Flow and Economic Results of Fertilizer Production Case for Pingshang Mine

4.4.7 Pingshang Mine Incremental Economic Results

Table 4-12 and Table 4-14 present the incremental economics for the Pingshang maximum power production case and the Pingshang fertilizer case, respectively. The results of the economic analysis indicate an incremental increase in NPV-10 of US$4.6 million for the maximum power production case, as compared to the baseline case, at Pingshang mine. The fertilizer production project at Pingshang reduces NPV-10 by US$9.6 million when compared to the baseline case, which indicates that the loss of revenue from decreased electricity sales outweighs any fuel cost savings associated with switching from coal to gas.

Mine: Pingshang
Forecast: Best
Case: Incremental (Max Power - Baseline)

Year	Electricity Generation Capacity Utilized MW	Electricity Generation MWh	Electricity Sales Price $/kWh	Revenue $,000	Fuel Cost $,000	O&M Cost $,000	Operating Income $,000	Capital Cost $,000	Cash Flow $,000	Cumulative Cash Flow $,000
2014	0.0	0	0.000	0	0	0	0	0	0	0
2015	0.0	0	0.000	0	0	0	0	431	(431)	(431)
2016	1.0	7,300	0.000	633	0	249	384	755	(371)	(801)
2017	2.8	19,723	0.000	1,761	0	692	1,069	741	328	(474)
2018	4.5	31,573	0.000	2,903	0	1,141	1,763	781	982	508
2019	6.2	43,686	0.000	4,138	0	1,626	2,512	0	2,512	3,020
2020	6.2	43,488	0.000	4,243	0	1,667	2,576	0	2,576	5,596
2021	6.2	43,481	0.000	4,369	0	1,717	2,652	0	2,652	8,248
2022	0.0	0	0.000	0	0	0	0	0	0	8,248
2023	0.0	0	0.000	0	0	0	0	0	0	0
2024	0.0	0	0.000	0	0	0	0	0	0	0
2025	0.0	0	0.000	0	0	0	0	0	0	0
TOTAL		189,252		18,046	0	7,091	10,955	2,707	8,248	

Discount Factor: 10%
NPV ($,000): 4,594
IRR: 87%

Table 4-12: Cash Flow and Incremental Economic Results for Pingshang Mine (Max Power minus Baseline)

With the addition of another 6.2 MW of electricity generation capacity at Pingshang mine, 100 percent of the drained methane is destroyed resulting in net emission reductions of 78,000 tCO2e/yr over the 8-year project life or 624,000 tCO2e over the project life. Additionally, the incremental electricity generated will offset electricity consumption from the North China Power Grid, which would decrease project-related emissions by an estimated 23,000 tCO2e/yr, for a total emission reduction of 101,000 tCO2e/yr over the 8-year project life or a total of 808,000 tCO2e over the project life. Table 4-13 illustrates the impact on project economics resulting from the potential monetization of carbon emission reductions under various carbon price regimes.

Carbon Price ($/tCO2e)	NPV-10 ($,000)	IRR (percent)
0	4,594	87%
1	5,093	94%
5	7,089	124%
10	9,584	160%
15	12,079	197%

Table 4-13: Summary of Incremental Economic Results for Pingshang Mine Maximum Power Production Case with Carbon Price Sensitivities

Mine: Pingshang
Forecast: Best
Case: Incremental (Fertilizer - Baseline)

Year	Electricity Generation Capacity Utilized MW	Electricity Generation MWh	Electricity Sales Price $/kWh	Revenue $,000	Fuel Cost $,000	O&M Cost $,000	Operating Income $,000	Capital Cost $,000	Cash Flow $,000	Cumulative Cash Flow $,000
2014	0.0	0	0.000	0	0	0	0	465	(465)	(465)
2015	(10.8)	(75,429)	0.000	(6,347)	(1,819)	(2,494)	(2,035)	0	(2,035)	(2,500)
2016	(10.7)	(74,868)	0.000	(6,489)	(1,873)	(2,550)	(2,066)	0	(2,066)	(4,566)
2017	(10.0)	(69,774)	0.000	(6,229)	(1,929)	(2,448)	(1,852)	0	(1,852)	(6,419)
2018	(9.3)	(64,916)	0.000	(5,969)	(1,987)	(2,346)	(1,637)	0	(1,637)	(8,055)
2019	(8.6)	(59,949)	0.000	(5,678)	(2,047)	(2,231)	(1,400)	0	(1,400)	(9,455)
2020	(8.6)	(60,031)	0.000	(5,856)	(2,108)	(2,301)	(1,447)	0	(1,447)	(10,902)
2021	(8.6)	(60,034)	0.000	(6,032)	(2,172)	(2,370)	(1,491)	0	(1,491)	(12,393)
2022	(4.9)	(34,681)	0.000	(3,589)	(746)	(1,410)	(1,433)	0	(1,433)	(13,826)
2023	0.0	0	0.000	0	0	0	0	0	0	0
2024	0.0	0	0.000	0	0	0	0	0	0	0
2025	0.0	0	0.000	0	0	0	0	0	0	0
TOTAL		(499,682)		(46,192)	(14,681)	(18,150)	(13,361)	465	(13,826)	

Discount Factor: 10%
NPV ($,000): -9,652
IRR: -

Table 4-14: Cash Flow and Incremental Economic Results for Pingshang Mine (Fertilizer minus Baseline)

With the utilization of drained gas in the fertilizer plant and on-site power generation plant at Pingshang mine, 100 percent of the drained methane is destroyed resulting in net emission reductions of 78,000 tCO2e/yr over the 8-year project life. Additionally, the use of drained gas by the fertilizer plant will offset emissions from coal by 62,000 tCO2e/yr. However, since drained gas previously utilized to generate on-site electricity is diverted to the fertilizer plant, electricity purchased from the North China Power Grid will increase, which will offset any emission reductions gained by switching to gas from coal at the fertilizer plant. As a result, total emission reductions over the 8-year project life are estimated at 78,000 tCO2e/yr or 624,000 tCO2e over the life of the project. Table 4-15 illustrates the impact on project economics resulting from the potential monetization of carbon emission reductions under various carbon price regimes.

Carbon Price ($/tCO2e)	NPV-10 ($,000)	IRR (percent)
0	-9,652	-
1	-9,271	-
5	-7,745	-
10	-5,837	-
15	-3,930	-

Table 4-15: Summary of Incremental Economic Results for Pingshang Mine Fertilizer Production Case with Carbon Price Sensitivities

5 Market Information

Xiyang County is located 75 km south of Yangquan city, a major metropolitan area within Shanxi Province, and the largest city in the east central area. Although reasonably close to Yangquan by distance, Xiyang remains somewhat isolated by the surrounding mountain ranges. Therefore, any market for the CMM will most likely be limited to Xiyang County.

5.1 Energy Markets for CMM

The status of China's energy markets at a national, regional, and local level were reviewed to determine demand for the incremental CMM volumes produced at the Mahui and Pingshang mines. With average methane contents ranging between 40 percent and 50 percent, the drained gas from the mines is considered medium-concentration CMM. Potential utilization options for medium-quality gas are power generation using internal combustion engines, industrial boilers, household use, vehicle fuel (e.g., CNG or LNG), or flaring. Following is an assessment of each potential market:

Power Generation

There is a strong case to use the incremental gas production for power generation at both mines for several reasons:

Yangquan Jindong has experience with power generation at both mines. Its success with the existing projects provides confidence that it has the technical and financial capacity to deliver a power project. The experience of developing, building and operating power projects provided an important learning experience, and future efforts should be able to capitalize on that experience to reduce overhead associated with design and build of the projects.

Generating electricity on site is attractive, because the input CMM gas stream can be used as is, with minimal processing and transportation. Additional generating sets can be installed relatively cheaply and infrastructure for the power plant and distribution system is already in place.

A generally accepted breakeven cost for CMM-based power projects is 0.04-0.06 $/kWh. The price for the North China Grid paid for power generated by the two mines is $0.082 per kWh, thus the power price is very favorable.

Coal mines are major power consumers with substations and transmission lines near large mining operations and accessible to CMM-based power projects. Capacity is available on the North China Grid for the incremental power generation at Mahui and Pingshang.

Town 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. The gas is medium-quality (usually 30 -60 percent CH_4), and distributed to local communities in the immediate vicinity of a coal mine through low pressure distribution lines.

CMM quality at both mines ranges from 40-50 percent at the surface, which is sufficient for town gas distribution. However, a town gas project would require installing 12 km and 8 km low-pressure transmission lines to Xiyang from Mahui and Pingshang respectively, and then the construction of gas distribution mains in Xiyang. This would be an expensive undertaking and would require the construction of a wide local distribution network and the conversion of heaters, stoves and other household and commercial equipment to gas from coal. Therefore, the economics for town gas are not as favorable as they are for power generation.

Natural Gas Pipeline Sales

Natural gas pipelines sales were considered but ruled out because gas pipeline sales are not possible. There are no major natural gas trunklines in close proximity to the mines. There are pipelines in other parts of Shanxi Province, but the cost to build a pipeline lateral to a natural gas pipeline in mountainous terrain, along with the cost of upgrading 45 percent CH_4 mine gas to pipeline quality, is cost-prohibitive. The capital cost (Capex) for a gas processing unit would cost approximately US$4 million and annual operating expenses (Opex) could be expected to be around US$1 million.

Industrial Use

Industrial use can be an excellent market for CMM produced by the two mines. There are several industrial/manufacturing operations in the area. Rather than distributing CMM to multiple users as would be required with town gas, one or a limited number of industrial users will require limited infrastructure investment. In addition they can present a strong, credit-worthy counterparty in a transaction.

A fertilizer plant located adjacent to the Pingshang mine uses coal to fire an industrial burner. However, the coal must be gasified prior to combustion. Therefore, the facility is interested in changing from a coal-based burner to CMM-fired burner. The proximity of the plant and interest in switching to natural gas could make the fertilizer plant an opportune off-taker of CMM.

Boiler Fuel

Use of the CMM from Mahui and Pingshang mines in boilers is technically feasible, and there is a demand for hot water to heat mine buildings and to heat ventilation shafts. However, power generation is considered a higher priority after consultations with management at both mines.

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. Although this may be an attractive option in the future for mines in Xiyang County, conversion of drained gas from the Mahui and Pingshang mines is not economically feasible at this time. Similar to natural gas pipeline injection, significant capital costs are required to first upgrade gas quality to almost pure methane, but additional costs are incurred for compression, and, for LNG, liquefaction. 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. Moreover, a market must exist to accept CNG and LNG – usually automobiles, heavy trucks, boats, trains or other transport vehicles must be converted and infrastructure must be created to transfer CNG and LNG from the seller to the buyer. This infrastructure does not yet exist in Xiyang.

Flaring

The mine is not interested in flaring methane, and it is very difficult to receive authorization to flare CMM in China because the energy value of CMM is highly valued.

5.2 Environmental Markets

Through 2012, many Chinese CMM projects relied on the value of Certified Emission Reductions (CERs) in the European Union Emissions Trading Scheme (EU ETS) to help finance projects and create a revenue stream for those projects. The lack of a post-2012 agreement to succeed the Kyoto Protocol and oversupply of emission allowances in the EU ETS resulted in a dramatic fall in CER prices starting in 2011 and today CERs are less than Euro 1.00. Even though carbon markets have been available, to date the Mahui and Pingshang mine projects have relied solely on power sales to generate revenues. They have not participated in the CER markets. Power sales and even sale of CMM for industrial use are still expected to generate revenue, and power sales in particular could be profitable for future expansions of the power plants. Still carbon markets could improve profitability and provide another source of project finance by serving as another revenue source.

While CERs are not an option in the near term, internal Chinese carbon markets could be attractive markets. In August 2014, China announced that it plans to roll out a national market for carbon permit trading in 2016.[10] If it is implemented, it could be the world's biggest emissions trading scheme. As a precursor to the national system, China has launched seven regional pilot markets in a bid to gain experience ahead of a nationwide scheme. As yet, CMM project offsets cannot be traded in the regional markets, but that may change under a national system. Allowance prices in the China regional markets are reported to be equivalent to EU ETS prices, around €6. [11]

For this pre-feasibility study, project returns were calculated with and without carbon revenues. Given price uncertainty for carbon offsets in China, the impact of carbon pricing on total project revenue is calculated over a range of carbon prices.

5.3 Government Policy

The Chinese Government is encouraging recovery and use of CMM through the *Guideline on Further Accelerating the CBM/CMM Exploitation and Utilizatio*n issued by the State Council of the People's Republic of China in September 2013. The Guideline includes the following objectives:

- Increase government funds support
- Increase indirect financial incentives
- Encourage private investment in CBM/CMM
- Market pricing mechanism
- Encourage power plants to use CBM/CMM as fuel

According to a recent GMI publication*, Legal and Regulatory Status of CMM Ownership in Key Countries: Considerations for Decision Makers,* CBM and CMM are a significant component of natural gas

[10] Reuters (2014). *China's national carbon market to start in 2016 -official* .
http://uk.reuters.com/article/2014/08/31/china-carbontrading-idUKL3N0R107420140831
[11] Carbon Brief (2014). Analysis: *China's big carbon market experiment*.
http://www.carbonbrief.org/blog/2014/09/analysing-china-carbon-market/

development in the government's Twelfth Five-year Plan. [12] The Plan calls for more CMM utilization, with increased local fuel for residential users (town gas) being a very high priority. Use in power generation is also a high priority. The Plan seeks to quadruple CMM-based generation to 2850 MW as overall CMM utilization rises by about 5.5 billion cubic meters. The plan calls for total CMM output of 30 billion cubic meters by 2015.

6 Conclusions and Recommendations

The Yangquan Jindong company and its subsidiary, Xiyang Fenghui, requested technical assistance to project gob gas production from drainage galleries in future mining areas. The objective is to assure Xiyang Fenghui that future supplies are sufficient to continue operation of existing CMM use while expanding the existing projects and expanding into other end uses, such as use in a neighboring fertilizer plant. Yangquan Jindong plans to initiate development activity in 2015.

Analysis shows that there should be adequate CMM to expand existing projects at both mines. With respect to incremental CMM development, the results of the gas production forecast and the economic analysis of end-use options indicate attractive NPV's and IRR's for the maximum power production case at both mines (current plant plus expanded operation to consume 100 percent of available CMM). The increase is due to the incremental addition of up to 8.8 MW of power at Mahui and up to 6.2 MW of power at Pingshang. The economics of power production are attractive due to the lower cost of Chinese-made gas gensets with an installed cost of ~$400 per kW compared with the cost of $700 – 1,200 per kW installed for gensets manufactured by well-established international companies. Relatively high power prices of $0.082 per kWh in China also underpin attractive project economics for power. In contrast, the fertilizer production project at Pingshang indicates that a loss of revenue from decreased electricity sales outweighs any fuel cost savings associated with switching from coal to gas.

The expanded projects would result in significant greenhouse gas emission reductions in addition to producing much more electricity than is the case with the existing plants. The 8.8 MW expansion of the Mahui mine power plant could generate up to 238,000 tCO2e/yr emission reductions over the 11-year project life, and the 6.2 MW expansion of the Pingshang mine power plant could result in 101,000 tCO2e/yr emission reductions over the 8-year project life and 78,000 tCO2e/yr if sales to the fertilizer plant are chosen.

The financial analysis shows that the most profitable projects use the CMM for power generation only at the Mahui and Pingshang mines. Sales to the fertilizer plant from Pingshang will draw CMM away from the existing power plant. While generating revenue, the fertilizer plant sale will reduce the output of the power plant by a considerable margin.

This pre-feasibility study provides a high- level assessment and analysis of the CMM production potential of the two mines and end-use options available. Yangquan Jindong has indicated that it is planning to initiate CMM project expansion plans in 2015. Given this tight time frame, the following next steps are suggested to produce a more detailed project feasibility study:

- Take cores in the future mining districts 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.

[12] US Environmental Protection Agency (2014) *Legal and Regulatory Status of CMM Ownership in Key Countries: Considerations for Decision Makers*. July 2014. http://epa.gov/coalbed/docs/CMM-Ownership-Policy-White-Paper-July2014.pdf

- Review the mine maps and cross-sections to specify the exact height of overburden over the coal seams throughout the mine to support more accurate modeling.
- Further refine cost estimates and revenue sources for the financial analysis.
- Evaluate the potential for participation in Chinese carbon markets, including obtaining reputable carbon price projections for these markets.
- Consider other mine degasification options including surface gob vent boreholes.