U.S. EPA Coalbed Methane OUTREACH PROGRAM

Feasibility Study for Coal Mine Methane Drainage and Utilization

Liuzhuang Coal Mine, Huainan Coal Field Anhui Province, China

U.S. Environmental Protection Agency
February 2010

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Acronyms and Abbreviations

Unit Abbreviations

ø	diameter
‰	parts per thousand
%	parts per hundred
°C	degrees Celsius
°F	degrees Fahrenheit
$	United States Dollar
Bbl	barrel
Bcf	billion (10^9) standard cubic feet
Bcfd	billion (10^9) standard cubic feet per day
Bm^3	billion (10^9) cubic meters
Btu	British thermal unit
D (d)	day
daf	dry, ash-free basis
$\delta_{13}C$	delta carbon-13 isotope relative to belemnite standard
ft	feet
in	inch
km	kilometer
km^2	square kilometer
m	meter
m^3	cubic meter
m^3/min	cubic meters per minute
m^3/t	cubic meters per ton of coal
Mcf	thousand (10^3) standard cubic feet
Mcfd	thousand (10^3) standard cubic feet per day
Mcm	thousand (10^3) cubic meters
Mcmd	thousand (10^3) cubic meters per day
mD	millidarcy (10^{-3} D)
mm	millimeter (10^{-3} m)
MMcf	million (10^6) standard cubic feet
MMcfd	million (10^6) standard cubic feet per day
MPa	Megapascal
Mtoe	million tonnes of oil equivalent
MW	Megawatt
psi	pounds per square inch
R_o	Vitrinite reflectance
SCE	standard coal equivalent
scf	standard cubic feet
Tcf	trillion cubic feet

Acronyms and Other Abbreviations

AAGI	Asian American Gas Inc.
ARI	Advanced Resources International, Inc.
CBM	Coalbed Methane
CDM	Clean Development Mechanism
CH_4	Methane
CMM	Coal Mine Methane
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
CO_2eq	CO_2 Equivalent
Fm	Formation
FOB	Freight on board
GDG	Green Dragon Gas Ltd.
HCMG	Huainan Coal Mining Group
HDPE	High Density Polyethylene
IC	Internal Combustion
ID	Inner Diameter
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
JCOAL	Japan Coal Energy Center
JWR	Jim Walters Resources
LNG	Liquified Natural Gas
LPG	Liquified Petroleum Gas
MLD	Multi-lateral Drilling
$MTCO_2e$	Million tonnes CO_2 equivalent
NDRC	National Development and Reform Commission
NPV	Net Present Value
Ni-Pt	Nickel-Platinum
PSC	Production Sharing Contract
RMB	Renminbi
SDIC	State Development Investment Corporation
SDIC-Xinji	State Development Investment Corporation, Xinji Energy Company Ltd.
Shengli	Shengli Power Company Ltd.
UK	United Kingdom
US	United States
US$	United States Dollars
USBM	United States Bureau of Mines
USDOE	United States Department of Energy
USEPA	United States Environmental Protection Agency
VAM	Ventilation Air Methane
VAT	Value-Added Tax
YCG	Yangquan Coal Group

Acknowledgments

The ARI Team gratefully acknowledges the support of SDIC Xinji Energy Corporation Ltd. for providing valued access to information, personnel, and the Liuzhuang mine site during the course of this study. We also acknowledge the project sponsor, the Coalbed Methane Outreach Program of the US Environmental Protection Agency.

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Executive Summary

This feasibility study was sponsored by the U.S. Environmental Protection Agency (USEPA) under the auspices of the Methane to Markets Partnership, of which both the U.S. and China are founding partners. It also supports the goals of the U.S.-China Strategic Economic Dialogue. The study assesses the technical, economic, and greenhouse gas reduction potential for improving the performance of coal mine methane (CMM) drainage and utilization at the Liuzhuang coal mine in Anhui Province, located in east-central China.

Current Practices at Liuzhuang Mine.

Situated in the western portion of the strategically important Huainan Coal Field, the Liuzhuang mine is operated by state-owned SDIC Xinji Energy Co. Ltd. Liuzhuang is a modern longwall mine that was commissioned in 2006 and has a 60-year planned life. The mine currently produces about 3 million metric tonnes per year (t/year) of bituminous-grade coal, which is mainly used for power generation. Coal production is scheduled to increase to 7.85 million t/year once a second planned longwall operation is installed, tentatively by late 2010.

To enhance safety and productivity, the Liuzhuang mine currently drains about 24.7 cubic meters per minute (m^3/min) of coal mine methane (adjusted to 100% CH_4 throughout this report based on Chinese convention). The CMM is drained primarily using short (100-m long), non-steered, cross-panel boreholes that are driven horizontally into the coal seams. Other boreholes are slanted upwards into the fractured rock (gob) zones to drain CMM that is released from overlying coal seams and sandstones as the mining face advances. Gas content data obtained from coring at Huainan indicates that CMM originally stored within the coal seam reservoirs is high-concentration methane (~95% CH_4 by volume). However, air contamination during the CMM drainage process at Liuzhuang mine reduces the actual concentration of methane in the drained gas stream to only about 7 to 10%, a low level which is difficult to utilize.

In addition to CMM drained via the boreholes and gas collection system, very dilute methane is flushed from Liuzhuang mine using a 2.8-m diameter, UK-manufactured ventilation fan. The actual methane concentration in the ventilation air is extremely low (averaging about 0.02%), which is favorable for mine safety purposes but significantly below the economic limit for VAM mitigation. Altogether, CMM emissions from Liuzhuang mine currently total approximately 30.9 m^3/min (1.6 MMcfd or 0.41 $MtCO_2$eq/year), comprising 24.7 m^3/min of 7-10% purity methane from the borehole drainage system plus an additional 6.2 m^3/min of very low concentration VAM (0.02%).

At present, none of the relatively low-quality CMM drained is being utilized at Liuzhuang mine. SDIC initially evaluated the potential installation of eight Shengli-manufactured low-concentration internal combustion (IC) engines to generate power using the drained CMM (4.0 MW total comprising 8 units x 0.5 MW). However, SDIC has also expressed interest in the concept presented in this study, which is to improve borehole drilling at the mine, increase methane concentration to as high as 40%, and utilize the CMM with larger, more efficient IC engines. If implemented, the power generated by the project most likely would be used internally by the mine.

Huainan Coal Field.

The 3,000-km^2 Huainan Coal Field, within which Liuzhuang is one of about two dozen major mines, is one of China's largest coal and CMM producing regions. Coal output from the district in 2007 totaled approximately 100 million t, equivalent to about 5% of China's total output. Huainan coal mines drained a total 190 million m^3 of CMM during 2007 (18.4 MMcfd). Whereas CMM drainage volumes have increased in the Huainan region during the past decade, the average methane concentration of drained gas has declined steadily. Not surprisingly, the overall utilization rate (defined as utilized CMM / drained CMM) has also declined over this period to about 40% at present, reflecting the difficulty of utilizing low-concentration CMM.

Consequently, approximately 60% of drained methane in the Huainan region is currently vented to the atmosphere. Additional methane is released during mining but not captured by mine drainage systems, mainly from the mine ventilation systems (ventilation air methane). Together, the total emissions related to coal mining in Huainan have increased to an estimated 1.9 billion m^3/year. Overall, including non-drained methane, only about 5% of the total CMM liberated by mining in Huainan is currently being utilized (95 million m^3/year). CBM/CMM resource estimates conducted by Chinese researchers indicate there are approximately 425 billion cubic meters or Bm^3 (15 trillion cubic feet or Tcf) to a depth of 1500 m in this coal field. Much of this methane resource is likely to be vented to the atmosphere as mining expands to deeper levels in coming decades. Clearly, the Huainan Coal Field offers significant opportunities for improving the effectiveness of CMM drainage and utilization.

CMM drainage at Huainan is particularly challenging because of the moderately high gas content (5-15 m^3/t), mechanical fragility, and low permeability of the coal deposits. Long horizontal in-seam boreholes, applied successfully during the past decade in Shanxi Province's Qinshui Basin, simply are not practical here due to unstable coal conditions. Surface CBM and gob wells, vertical and horizontal, also have been ineffective. In-mine drilling has been limited to short in-seam and cross-measure gob boreholes. Methane concentrations often are very low (<10% CH_4) due to significant mixing with ventilation air, frequently in the explosive range of methane in air. This makes the CMM gas difficult and even potentially dangerous to transport and utilize at many of the Huainan mines.

Gas Utilization & Market Analysis.

Currently, the extremely low (7 to 10%) methane concentration of gas drained at Liuzhuang mine severely limits the range of feasible options for economically viable CMM utilization. In addition, the gas concentration is within the explosive range of methane and not considered safe for utilization or transport.

In addition, Liuzhuang mine's relatively remote location within a rural, principally farming region, approximately 70 km from significant urban and industrial gas markets, makes transportation via pipeline appear to be impractical. Local energy consumption relies mainly on low-quality "waste" coal that is quite inexpensive and unlikely to be displaced by higher-cost CMM. Furthermore, given the relatively small CMM production volume, as well as its low methane concentration, constructing a pipeline to transport the gas 70 km to Huainan city or other demand centers would be impractical. Huainan's town gas system is undergoing conversion to high-concentration natural gas, thus CMM would be incompatible.

The potential for processing the CMM to increase methane concentration using cryogenic or catalytic methods was evaluated but rejected as impractical and costly given the large energy requirements for upgrading CMM with such low concentration. Similarly, converting the CMM to liquified natural gas (LNG) or compressed natural gas (CNG) for sale would be far too energy intensive and the plant scale would be too small.

Power generation for local mine use appears to be the most viable approach for CMM utilization at Liuzhuang mine. Gas turbines have high efficiency and reliability but are not practical for utilizing low and characteristically time-variable CMM concentrations. However, in recent years reciprocating engines have enjoyed wide success in China for power generation utilizing low-moderate CMM concentration fuel. Assuming the recommended drilling and drainage improvements are able to achieve up to 40%-quality methane, reciprocating engines in the 1- to 2-MW unit size appear to be the best option for cost-effective CMM utilization at Liuzhuang mine.

Technologies for ventilation air methane (VAM) oxidation do not appear to be technically feasible for Liuzhuang mine given the extremely low methane concentrations in the ventilation system, averaging only 0.02% CH_4. Most commercially available thermal oxidizers for VAM oxidation require concentrations of approximately 0.2% methane or higher.

Preliminary Design of CMM Drainage and Utilization System.

Based on a review of the geology, reservoir conditions, mining design, and market opportunities at Liuzhuang mine and the Huainan Coal Field in general, the following potential improvements to the mine's CMM drainage and utilization system are recommended (Table A):

Component	Technology	Number of Units	Anticipated Benefit
Borehole Drilling	Directional Drills	2	Longer, precise borehole placement, higher methane concentration
Borehole Wellhead	Improved Grouting	-	Reduced air leakage, higher methane concentration
CMM Pipeline	Fused HDPE Pipeline	2	Reduced air leakage, higher methane concentration
Power Generation	IC Engine Generators	10 x 1.255 MW	CMM utilization, high efficiency & reliability

Table A: Summary of CMM Drainage and Utilization Improvements Recommended for Liuzhuang Mine

1. **Steerable Borehole Technology.** Drilling long (1000-m) horizontal boreholes into the top of the future gob zone -- situated precisely 15-20 m above the target coal seams with advanced downhole steerable drilling technology -- could dramatically increase both the quantity and CH_4 concentration of CMM drained at Liuzhuang mine. Reservoir modeling suggests that CMM production and methane concentration both could be increased several-fold, to approximately 100 m^3/min and 40% CH_4, increasing the potential magnitude and efficiency of methane utilization (estimated costs $3.5 million).

2. **Upgraded Collection System.** Improved borehole standpipe cementing could reduce contamination of the drained CMM by mine ventilation air. Replacing the existing flanged steel pipeline system with seamless HDPE (plastic) pipe would reduce corrosion and potential air contamination. Improved gas flow monitoring and installation of automatic shutoff valves could improve safety as well as gas quality in case of pipeline disruption (estimated costs $0.7 million).

3. **Larger Reciprocating Engines.** Depending on the success of the anticipated drainage improvements on CMM quality and quantity, it may be possible to use reliable and efficient gas engines in the 1- to 2-MW unit size, currently are manufactured by Caterpillar, GE Jenbacher, and Deutz, that are capable of utilizing the anticipated 40%-quality CMM. Power generated by the project would used by the mine to back out grid purchases. Total power capacity of approximately 12.55 MW could be achievable. The capital costs for this power station are estimated to be $17.33 million.

Key project parameters are summarized in Table B:

Topic	Key Project Parameters	Value	Unit
Timing	Project Initiated	2010	mid-year
	Project Fully Implemented	2012	January
	Project End	2034	December
Coal Production	Coal Production (2010)	3.00	million t/year
	Coal Production (2011 on)	7.85	million t/year
CMM Drainage	CMM Drainage Rate	37.50	m^3/minute
	CMM Utilized / CMM Drained	100%	percent
	CMM Concentration Expected	30-40	percent
Power Generation	Power Generation Capacity	12.55	MW
	Operating Efficiency	90%	percent
	Cumulative Project Power Production	2,448	GWh
Power Price	Power Price (base)	0.05	USD/kWh
	Power Price (escalation)	1%	per year
Investment Costs	Borehole Drainage Investment	3.42	million USD
	CMM Pipeline Investment	0.71	million USD
	Power Generation Investment	17.33	million USD
	Total Capital Investment	21.46	million USD
Operating Costs	CMM Drainage System Opex	same	as current
	Power Generation Opex	1.70	million USD
Financial Performance	Net Present Value (r = 10%; base case; pre-tax)	11.51	million USD
	Internal Rate of Return (base case; pre-tax)	17.6%	percent
GHG Reduction	Global Warming Potential of Methane	21	tCO2e/tCH4
	Total Emissions Avoided by Power Generation	9.18	million t CO2e
	Total Project Emissions	0.92	million t CO2e
	Net Total Emissions Avoided	8.26	million t CO2e

Table B: Summary of Key Project Parameters

Greenhouse Gas Emission Reductions.

By 2011, under full-scale coal production of 7.85 Mt/year, the annual emissions reductions for the proposed project are estimated to be approximately 337,193 tCO_2eq, calculated by subtracting project emissions of about 37,540 tCO_2eq from the baseline emissions of 374,733 tCO_2eq. Over the 25-year life of the project, total net emissions reductions are estimated to be approximately 8.26 $MtCO_2eq$ (+/- about 10%).

If the recommended upgrades to the CMM drainage system at Liuzhuang mine prove to be effective, they may be transferable to a number of other Huainan coal mines with similar geologic and mining conditions that are operated by SDIC, Huainan Coal Mining Group, or other mining companies in the region. Assuming a drainage and utilization penetration rate of 50% throughout the Huainan Coal Field, a conservative assumption based on similarities in the geology and mining techniques across this region, comprehensive application of these technologies could cut methane emissions from this mining area in half, perhaps avoiding 1 billion m^3/year (25 $MtCO_2eq$) of incremental annual methane emissions.

Project Economics.

The Liuzhuang mine CMM drainage and utilization project has the potential for favorable economic performance, including an attractive pre-tax internal rate of return (IRR) of 17.6%, with net present value (NPV) estimated at 78.6 million RMB, and a reasonable real pay-back period (10 years). Changes in capital and operating costs would significantly affect the project's performance, while changes in the power price and power plant operating efficiency would tend to have relatively smaller impacts.

The base case assumed a 2-year construction period, initial power sales price of $0.05/kWhr with a 1%/year real escalation, and 90% plant operating efficiency. The pre-tax NPR (PV-10) for this case is estimated to be approximately 78.6 million RMB ($11.5 million), with an IRR of 17.6%. Sensitivity analysis (+/- 25%) indicated that changes in the capital and operating costs for borehole drilling and power generation would have the largest impact on project economics.

Variable	-25%		Base Case		25%	
	IRR	NPV	IRR	NPV	IRR	NPV
Power Price Escalation	17.1%	71.60	17.6%	78.60	18.1%	85.82
Drilling/Power Capex	25.5%	118.47	17.6%	78.60	13.0%	38.74
Drilling/Power Opex	21.3%	113.47	17.6%	78.60	14.1%	43.74
Operating Efficiency	16.6%	68.78	17.6%	78.60	18.6%	88.43

Table C: Financial Sensitivity to Key Project Parameters

Other Project Benefits.

In addition to the anticipated economic gains and emission reductions, implementation of a more effective mine drainage system and recovery and utilization of the CMM for power generation for use on-site at the mine is expected to produce a number of additional benefits. These include enhanced safety and mining productivity at the Liuzhuang mine, a small increase in employment, reduced local air pollution from the use of a cleaner fuel (CMM) for power generation, and the wider adoption of advanced drilling and power generation technology in the Huainan Coal Field.

SECTION 1

Pre-Feasibility Study and Mine Site Selection

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1.1 Introduction

This pre-feasibility study was sponsored by the U.S. Environmental Protection Agency (USEPA) under the auspices of the Methane to Markets Partnership, of which both the U.S. and China are founding partners. It also supports the goals of the U.S.-China Strategic Economic Dialogue. It was conducted by Advanced Resources International, Inc. (Arlington, Virginia, USA), with support from REI Drilling, Inc. (Utah, USA), Valley Longwall International (Australia) and Organic Waste Technologies (Hong Kong, China).

The pre-feasibility assessment discusses the ARI Team's preliminary data gathering and analysis on Liuzhuang and two other nearby mines in the Huainan Coal Field that are operated by SDIC Xinji Energy Company Limited. The remainder of the report (Sections 2-8) provides a more detailed feasibility study on the application of advanced technologies for improving coal mine methane drainage and utilization at the Liuzhuang mine specifically.

The Liuzhuang mine is located in the western portion of the Huainan Coal Field, in central Anhui Province, east-central China. Liuzhuang mine is about 70 km west of the regional city of Huainan (population 1 million; Figure 1-1 and Figure 1-2). A large, modern, underground retreating longwall mine, Liuzhuang is scheduled for expansion from its initial design capacity of 3 million metric tonnes per year (t/year), with a current upgraded production target of 7.85 million t/year by the end of 2010.

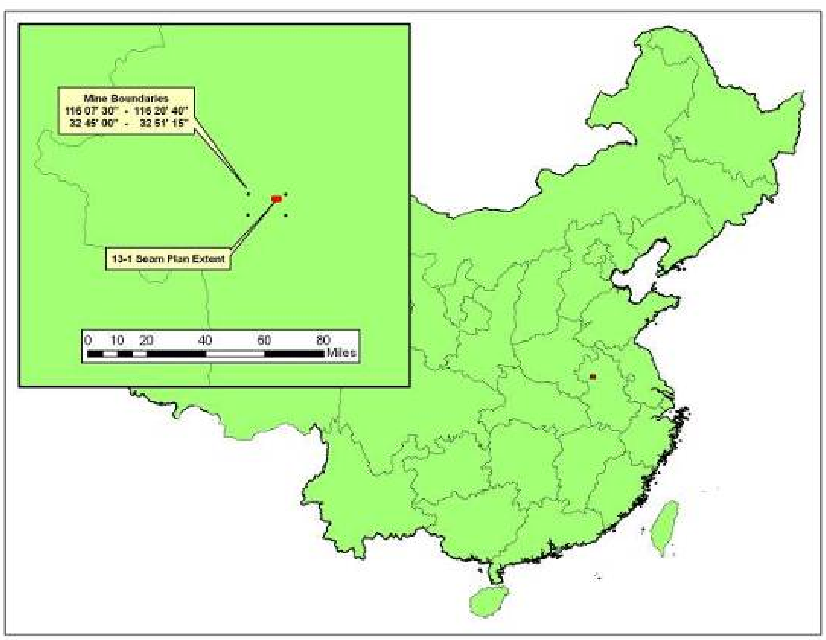


Figure 1-1: Location of Liuzhuang Mine, Anhui Province
(Source: ARI)

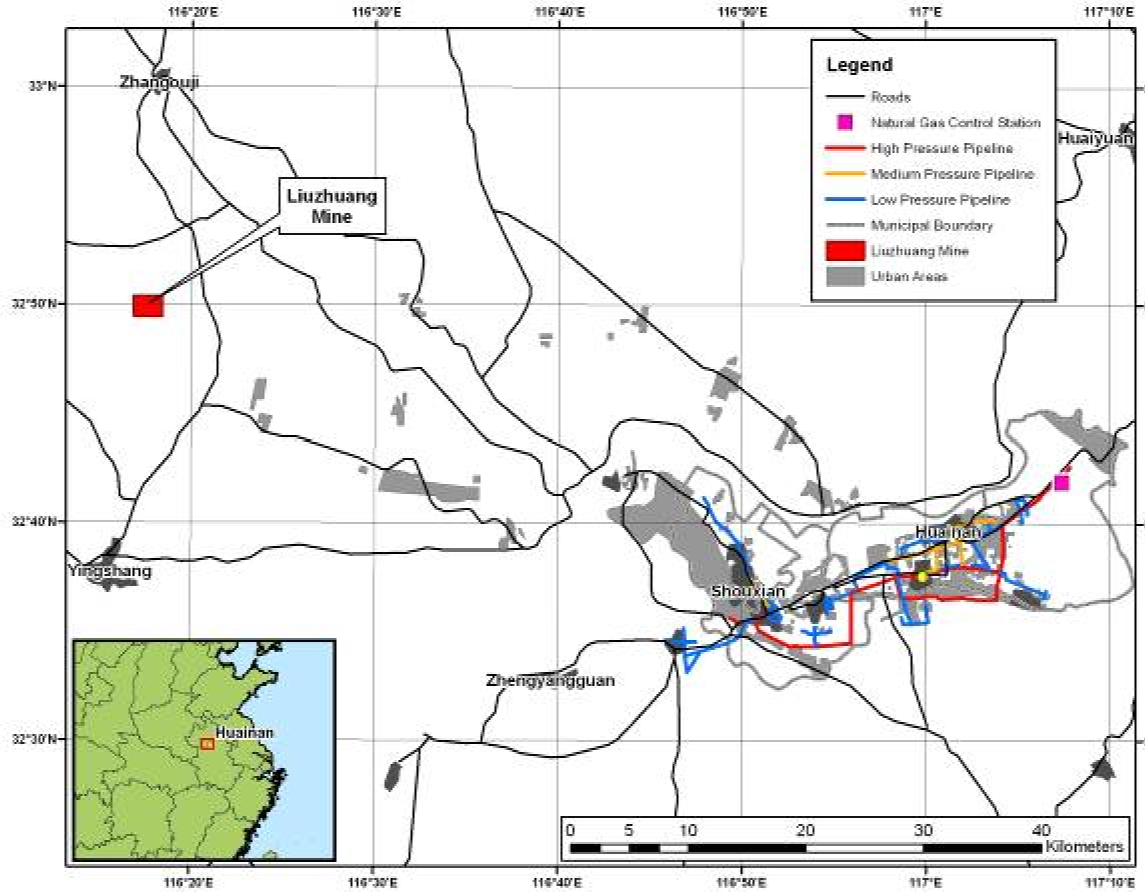


Figure 1-2: Large Scale Location Map of Liuzhuang Mine
(Source: ARI)

As of May 2009 the mine was draining about 21 million m^3/year of coal mine methane (40 m^3/min or 2.0 MMcfd, recalculated as pure methane). Currently, methane concentration in the drained CMM flow is very low, typically only 7 to 10% CH_4, which is difficult to utilize efficiently. Both CMM drainage volumes and methane concentration are expected to increase significantly with the installation of additional vacuum pumps as well as separate high-methane and low-methane collection systems. The installation is planned to be implemented along with mine expansion during 2010.

1.2 Mine Selection Process

In July 2007 ARI conducted an initial technical visit to all three of SDIC-Xinji's coal mines in the Huainan Coal Field, the Xinji No. 1 and No. 2 mines and the Liuzhuang mine. This visit included surface and subsurface mine tours and examination of initial technical data on these three mines. ARI's initial review identified Liuzhuang mine as the best candidate, primarily because it is the deepest, gassiest, and most modern mine owned by SDIC-Xinji. Liuzhuang clearly had the best potential for a CMM drainage and utilization improvement project.

Another factor favoring Liuzhuang mine in the selection process was the potential for extending technologies developed and proven in this mine to upgrade the CMM drainage and utilization at other coal mines in the Huainan Coal Field. As discussed more fully in Section 1.3, in addition to the three mines operated by SDIC-Xinji, several dozen other underground coal mines are in operation elsewhere in the Huainan region. Many of these, particularly in eastern Huainan, are considered moderate- to high-methane mines.

1.3 CMM Drainage in China

CMM drainage has increased rapidly in China from about 0.88 billion m^3/year (85 MMcfd) in 2000 to 4.79 billion m^3/year (464 MMcfd) in 2007, the most recent year for which figures are available (Figure 1-3). However, over this period the national utilization rate for CMM has slipped steadily to 30.6% in 2007 (vs. 57% in 2000) as more challenging low-concentration methane streams are captured.

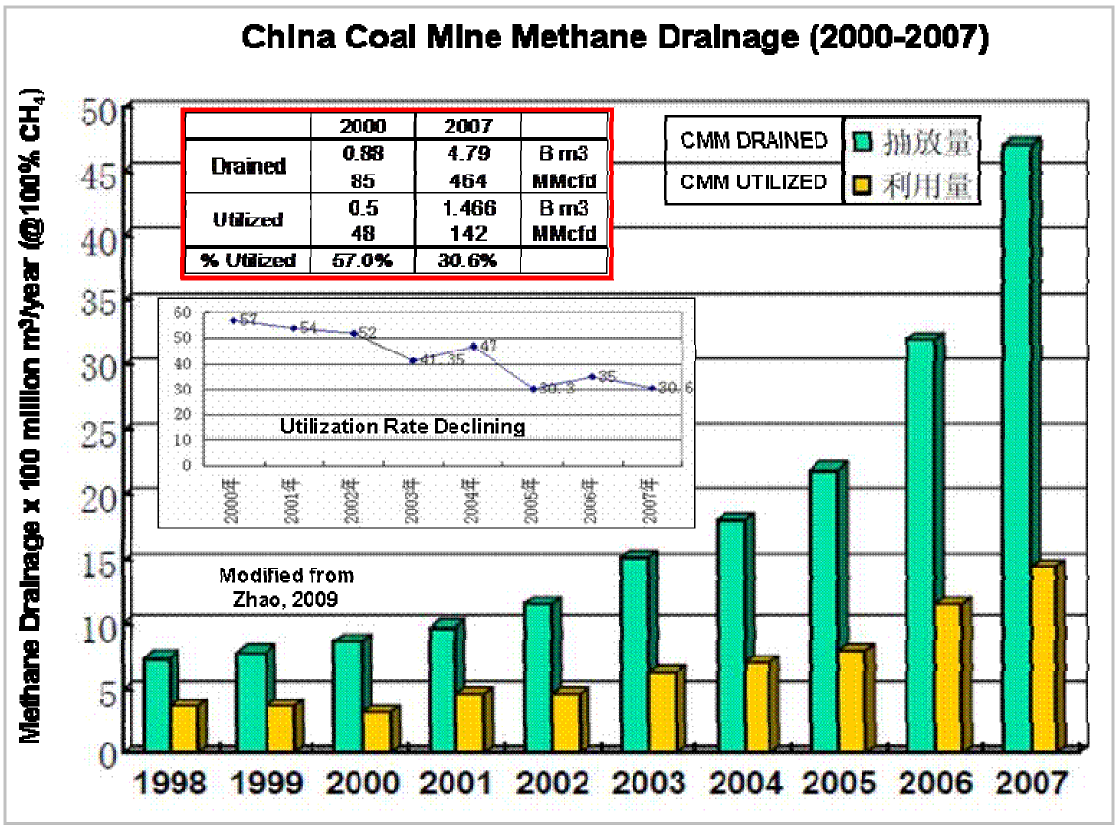


Figure 1-3: CMM Drainage and Utilization in China
(Modified from Zhao, 2009)

Nationally, much of the increase in China's total volume of CMM drainage and the directly related reduction in methane concentrations can be explained by increasing use of powerful vacuum pumps at the surface. These pumps can be highly effective at removing methane from the working face and maintaining methane concentrations in the mine at safe levels. However, the pumps also tend to draw considerable volumes of mine ventilation air into the gob and working areas of the mine. This tends to lower the CMM concentration of the captured methane and makes it harder to utilize.

In contrast, underground coal mines in the U.S. and Australia capture CMM with mostly medium to high methane concentrations (50-95% CH_4) and, not surprisingly, the captured CMM is utilized at a high rate. However, it should be noted that in several regards the mining and gas market conditions in Australia and the U.S. differ significantly from those in China (and generally are more favorable for CMM drainage and utilization):

- U.S. and Australian coal mines tend to have higher permeability than those in China, allowing them to drain additional methane from larger coal volumes.
- U.S. and Australian coal mines also tend to be less faulted than those in China, enabling longer horizontal boreholes to be drilled without sudden disruption.
- The U.S./Australian coals also tend to have more stable mechanical properties. In contrast, the coal seams in many parts of China (including Huainan) are fragile, collapse easily, and make long horizontal in-seam drilling nearly impossible.
- Although China is rapidly developing its national natural gas pipeline system, the pipeline networks in the coal mining regions of Australia and the U.S. are relatively better established, facilitating CMM sales and utilization.

Nevertheless, there are technical improvements employed in U.S. and Australian mines that are potentially applicable to China. Generally, U.S. and Australian mines tend to employ much longer horizontal boreholes (500 to 1500 m in length), improved borehole wellhead sealing techniques, leak-proof seamless HDPE pipelines, and advanced monitoring and control systems. They also avoid application of high vacuum levels to the CMM system. Together, these technical measures minimize contamination of CMM with ventilation air and help ensure high methane concentration in the drained gas stream.

Following a long-term trend in nearly all of China's coal mining areas, CMM drainage at the Huainan Coal Field has grown rapidly since 2000 (Figure 1-4). By 2007 CMM drainage had reached an estimated 190 million m^3 (18.4 MMcfd), placing Huainan third in the country for CMM drainage. Yet, the CMM utilization rate has not kept up with the growth in CMM drainage, creating multiple opportunities for a CMM drainage and utilization project in the Huainan Coal Field.

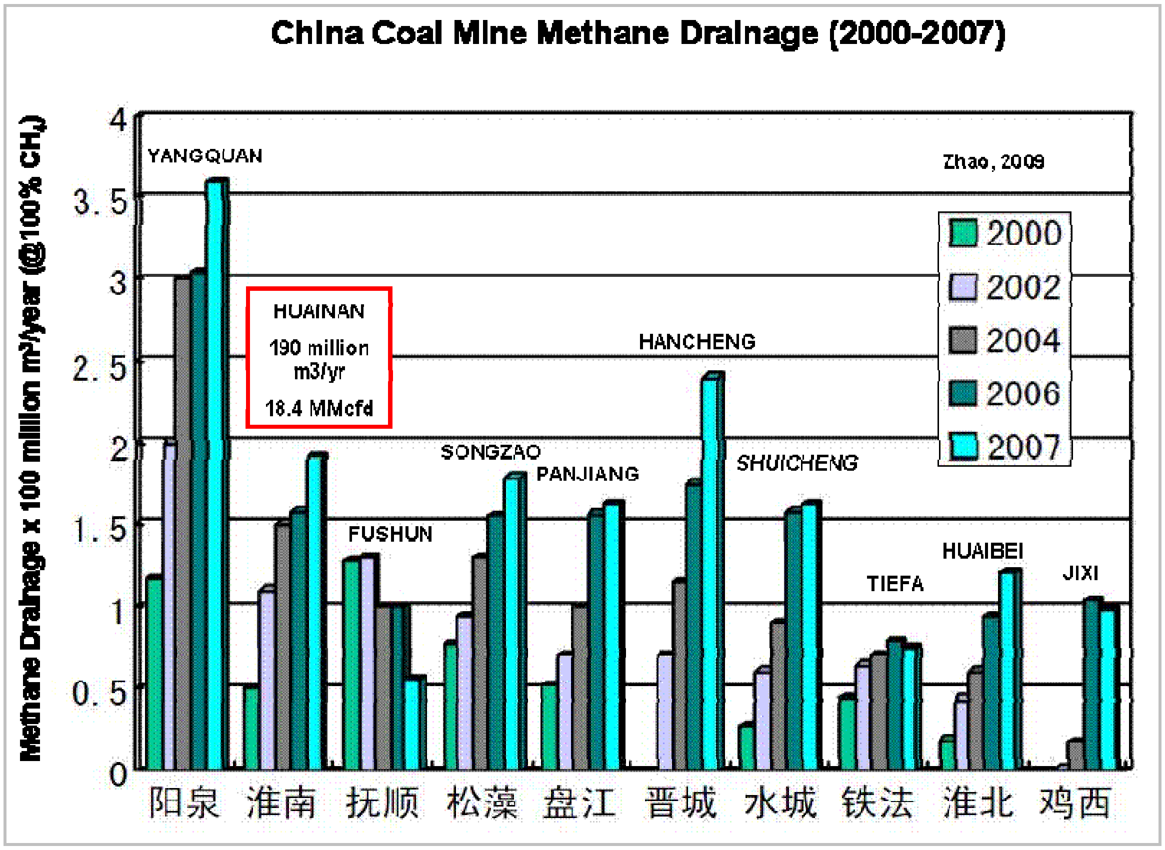


Figure 1-4: CMM Drainage by Coalfield
(Modified from Zhao, 2009)

1.4 Coal Mining Operators in the Huainan Coal Field

Two large companies controlled by the central government dominate coal production in the Huainan Coal Field. In addition, numerous smaller provincially and locally controlled mining firms operate coal mines there as well. The larger of the two central companies is the Huainan Coal Mining Group (HCMG), which operates 15 mines in the region, including one which has registered a CMM utilization project for Clean Development Mechanism (CDM) credits. Many of HCMG's other mines are deep and gas-prone. Some could be candidates for future CMM drainage and utilization projects.

ARI's evaluation at Liuzhuang mine was with the second most active centrally owned coal mining firm in the Huainan Coal Field, the State Development Investment Corporation's coal mining unit, Xinji Energy Company Limited ("SDIC-Xinji"). SDIC-Xinji currently operates three relatively modern mines in the Huainan Coal Field. SDIC-Xinji's largest and newest coal mine is called Liuzhuang, the focus of ARI's current evaluation. The company plans to open three additional mines in the Huainan Coal Field in the coming five years.

1.4.1 State Development Investment Corporation (SDIC)

The owner and host organization for the Liuzhuang mine evaluation is SDIC Xinji Energy Company Limited ("SDIC-Xinji"). SDIC-Xinji in turn is controlled by the State Development Investment Corporation (SDIC), a large Chinese central government organization which engages in investment and operation of state-owned industrial assets. SDIC's activities range from hydro- and thermal-power generation to mining, construction, and shipping. SDIC is active in many of China's provinces including Anhui, Shandong, Henan, Hebei, and Shanxi.

1.4.2 SDIC-Xinji Energy

SDIC-Xinji Energy focuses mainly on coal mining and processing with additional coal and small-scale CMM-fueled power generation. The company is listed on the Shanghai stock market (A share) and has recently attained market capitalization of over US$1 billion. SDIC-Xinji holds 10.16 billion t of certified coal reserves extending over a total area of 1,092 km^2. The company currently operates three production mines in the Huainan region with the total annual production capacity of about 8 million t/year. It also operates a trial operation mine, has a fourth mine under construction, and two additional mines under development. Other projects include two coal sorting plants and two coal-gangue-fueled power plants. The company plans to increase output to approximately 36 million t/year during the next five years.

Prior to developing the Liuzhuang mine, SDIC-Xinji had developed China's first coal mine (the Xinji mine in 1989; referred to later as the Xinji 1 mine after the Xinji 2 mine was constructed) that was established under the new market-oriented mechanism, as opposed to central planning. The Xinji 1 mine became a model for China's modern coal industry under the Legal Person Responsibility System. Xinji 1 has been inspected and praised by many of China's state leaders including Prime Minister Li Peng and Chairman Hu Jintao.

1.4.3 Huainan Coal Mining Group Co., Ltd.

Wholly separate from SDIC-Xinji, the largest coal mining operator in the Huainan Coal Field is the Huainan Coal Mining Group Co., Ltd. (HCMG). As of 2004 HCMG operated 10 underground coal mines, all characterized by coal and gas outbursts, with total production capacity of 34 million t/year. By 2007 HCMG was scheduled to bring another five coal mines into production, adding a further 46 million t/yr for a total production capacity of approximately 80 million t/year. By 2010 the company's production capacity is planned to reach 100 million t/year (accounting for about 5% of China's total output).

Over this period HCMG's coal mine methane drainage and utilization also has grown. Annual gas drainage is expected to reach 416 million m^3 by 2010 (40 MMcfd), of which 354 million m^3 (34 MMcfd) could be available for utilization. (For perspective, this is about twice the size of the largest U.S. coal mine methane utilization project, the Brookwood field in the Warrior basin, which drains high-concentration (>80% CH_4) CMM using gob wells and in-mine horizontal boreholes, then markets the gas via pipeline.)

HCMG operates seven small CMM power stations in various mine locations, with total installed generation capacity of about 19 MW (Table 1-1).

Mine	Units	Capacity (MW)	Total Capacity (MW)	Manufacturer
Xieyi	2	0.50	1.00	Chinese (mobile)
Pansan	2	1.80	3.60	Caterpillar
Panyi	2	1.36	2.72	Deutz
Zhangji	2	1.36	2.72	Deutz
Zhangbei	2	1.80	3.60	Caterpillar
Xinzhuangzi	2	1.36	2.72	Deutz
Xieqiao	2	1.42	2.84	Jenbacher
Total			**19.2**	

Table 1-1: CMM Power Stations Operated by HCMG

One of these power stations, at Pansan, is registered for CDM. Initiated in February 2003, and having registered since March 2007, HCMG is operating the Pansan Coal Mine Methane Utilization and Destruction Project (UNFCCC reference number 0840). The project has two components: first, to connect 4,000 local households to CMM, replacing coal; and second, to install 8.4 MW of CMM-fueled power generation. The power project utilizes reciprocating engines, comprising 4 x 1.2 MW Chinese-manufactured units and 2 x 1.8 MW Caterpillar units, with all engines on line as of January 2007. Electricity generated from CMM supplies a portion of the mine's energy demand, offsetting purchases from the East China Power Grid.

1.5 Pre-Feasibility Evaluation of Liuzhuang Mine and Xinji 1 and 2 Mines

The initial step of the evaluation was to assess the feasibility of conducting a larger study for optimizing CMM drainage and utilization at the three SDIC-Xinji mines in Huainan (Liuzhuang, Xinji 1 and 2). ARI personnel first visited these mines in July 2008 to gather initial data and conduct first-level discussions with mine management and technical personnel. The newer and more modern Liuzhuang mine appeared to have the most potential for CMM drainage and utilization optimization, although the two Xinji mines also have good potential. Given the potential for drainage and utilization improvement at Liuzhuang, this initial evaluation led to the decision that a larger feasibility study of the mine was warranted.

Data gathered during the July 2008 visit revealed that none of the three SDIC-Xinji mines are considered particularly high-gas mines by the Chinese government. In fact, they are characterized as low-moderately gassy mines.[1] On the other hand, the mines are also classified as Hardly Drainable, due to coal seam permeability of less than 0.025 mD,[2] and CMM control is an integral step for coal production at the three mines. Methane entry does interfere with mining operations at the SDIC-Xinji mines and thus these mines have active drilling and drainage efforts. Fortunately, to date there have been no major methane-related accidents at the Liuzhuang mine, which only started operation in 2006.

The SDIC-Xinji mines warrant evaluation because:

- CMM emissions into the mines are significant and require active in-seam pre-drainage as well as cross-measure gob borehole drilling during mining to control.
- Low-moderately gassy mines also have the potential to experience methane-related accidents.
- Low-moderately gassy mines frequently recover low-quality methane that is difficult to utilize effectively.
- Gas emissions and drainage are expected to increase significantly in these mines as the longwalls advance down into deeper mining areas (>800 m).
- The three SDIC-Xinji mines are representative of other low-moderately gassy mines with similar geologic and mining conditions in the Huianan Coal Field and perhaps elsewhere in eastern China. Improved CMM drainage and utilization technologies that can be demonstrated at these mines may be applicable elsewhere in the region. (Note that during recent years the Sihe mine has played a similarly important demonstration role for high-gas mines in Shanxi Province.)

Drained CMM volume from SDIC-Xinji's mines has been increasing, from 20 million m^3 in 2006 up to a projected 35 million m^3 in 2008 (total of the three mines; note that CMM volumes cited in this report are expressed as 100% CH_4 concentration equivalent unless otherwise specified). The increase in drained gas is due to a number of factors, including increasing mine depths as well as regulations which require that gas emissions into the mine workings be reduced through pre-drainage. The concentration of drained methane from the three mines was reported to be generally low, ranging from 5-30% and averaging about 15%.

Several different methods are employed to control the gas in the mine workings including cross measure boreholes, the driving of tunnels above the mined seam to collect gas, and cross-panel

[1] He, Xueqiu; Chen, Wenxue; Nie, Baisheng; and Zhang, Ming, 2009. "Classification Technique for Danger Classes of Coal and Gas Outburst in Deep Coal Mines." Safety Science, vol. 48, p. 173-178.

[2] Wang, Kai and Xue, Sheng, 2008. "Gas Drainage Practices and Challenges in Coal Mines of China." 2008 Coal Operators Conference, February 14-15, University of Wollongong & the Australasian Institute of Mining and Metallurgy, Australia, p. 178-185.

boreholes. During the pre-feasibility study it quickly became apparent that one of the primary focuses of a feasibility study would be to increase the concentration of drained methane produced from the degasification systems.

1.6 Xinji No. 1 and No. 2 Mines

1.6.1 Xinji No. 1 Mine

Located on the western side of the Huainan coalfield, the SDIC-Xinji Xinji No. 1 mine covers an area of 25.2 km^2. The oldest and one of the larger mines controlled by SDIC, Xinji No. 1 is a longwall operation currently producing about 4 million t/year from five seams. The mine currently drains about 160 million m^3 of CMM at relatively low concentration (10% methane). Drainage techniques include tunnels driven above and below the mined seam as well as an array of closely spaced cross-measure boreholes into the roof and floor. The mine plans to install six 500-kW (3 MW total) engines to utilize drained gas. The power will be consumed both internally as well as sold back to the grid.

1.6.2 Xinji No. 2 Mine

Located 10 km from Xinji No. 1, the Xinji No. 2 mine has a designed capacity of 3 million t/year, with current output approximately 2.6 million t/year. The 30 km^2 mine has 491 million t of total coal resources, about 160 million t of which is considered recoverable. The Xinji No. 2 mine has similar geology to the No. 1 mine, and mining targets the same five mineable seams (No. 1, 6, 8, 11, and 13). Total coal thickness is 33m. A large fault transects the mine area, along with one small local fault. Currently the mine is 650 m deep.

CMM drainage at the Xinji No. 2 mine averages about 33.16 m^3/min, extracted using two surface vacuum pumps. The specific gas content ranges from 10-12 m^3/t of coal mined. The methane concentration at the surface is low (10-15%), similar to Xinji No. 1 mine. CMM dilution is exacerbated by the high surface vacuum applied to the in-mine degasification boreholes, and the resulting contamination of ventilation air into the gob zone. Methane drainage has increased in recent years and is forecasted to reach 14 million m^3 in 2008, representing an estimated 51% drainage efficiency.

CMM drained at the Xinji No. 2 mine currently is being used as fuel for two 500-kW Shengli-manufactured reciprocating engines. Four more engines were scheduled to be installed as of mid-2008. Power consumption at the mine is about 80 million KWh, with peak demand of 12.2 MW. SDIC-Xinji Energy’s plan is to supply the mine’s power requirement through on-site generation and then sell 20-30% of the gas output to local industries.

1.7 Liuzhuang Mine

1.7.1 Introduction

Extending over an area of 82.2 km^2, Liuzhuang mine is nearly three times the size of the Xinji No.1 or No. 2 mines. It is one of China's newest and most modern coal mines, employing a retreating longwall design. Liuzhuang was constructed over a 44-month period, with mine construction commencing on February 20, 2003 and trial operation verified by the Provincial Economic Committee on October 13, 2006. Its coal resources total an estimated 1.56 billion t, of which 679 million t is considered proven mineable reserves, giving the mine a projected 61-year service life.

Liuzhuang mine is located in the Huajiahu district, which in terms of structural geology is a relatively simple portion of the Huainan Coal Field. The mine is situated on the southern flank of the Xieqiao Syncline. Several major regional faults -- notably the Shouxian Laoren and Fufeng Faults -- cut the district, but the Liuzhuang and Xinji mines are situated in between these major structures and are relatively undisturbed by faulting (Figure 1-5).

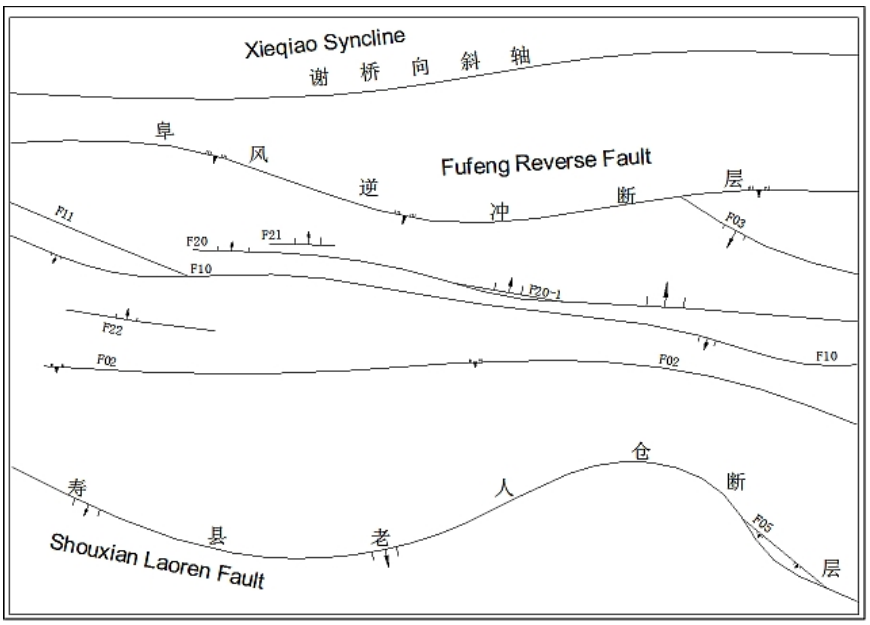


Figure 1-5: Structure Map of the Huajiahu Coal District
(Source: SDIC)

Liuzhuang mine comprises two vertical shafts, a system of main gate roads, separate mining development zones, separate ventilation zones, and centralized coal haulage. Advanced monitoring equipment has been installed to provide real-time data on methane flow rates, coal production, equipment location, and other coal production related information. These performance measures are monitored, recorded and managed from a modern control room at the surface.

Currently only Seams 13-1 and 11-2 are being mined at Liuzhuang. Eventually, SDIC-Xinji plans to target Seams 1, 5, and 8 as well from various levels using longwall mining. A single longwall currently is in operation with a second planned to commence in 2010.

During the period January to May 2009, coal production at Liuzhuang totaled approximately 3 million t, with an average monthly production of 600,000 t. Production is scheduled to be increased to 7.85 million t/year during 2010 and then 10 million t/year by 2015. The hoist system is capable of lifting 10 million t/year. SDIC-Xinji estimates CMM production at Liuzhuang to be approximately 13 million m^3/year (24.7 m^3/min) over the next five years. This seems conservative given rising coal production as well as the potential improvements to drainage system technology recommended in this study.

1.7.2 Coal Deposits

The two main mining targets at Liuzhuang are Seams 13-1 and 11-2 (Table 1-2). Seam 13-1 is of stable thickness (2.4 to 4.3 m, average 3.85 m), simple structure, and dips to the south at a 10° to 30° angle (average 15.1°). Hardness of the seam is classified as loose to soft, which suggests that long in-seam drilling would be hard to achieve. The density of the layer is 1.37 g/cm^3, porosity 2 to 3%, and the apparent electrical resistivity is approximately 100 ohm.

Coal seam 煤层名称	Thickness 煤厚(m) extreme value/average value 极值/平均值	Spacing of seam 层间距(m) extreme value/average value 极值/平均值	Stability 稳定性	Number of gangue layers 夹矸层数	Coal seam structure 煤层结构	Lithology of roof and floor 顶底板岩性 Roof 顶板	Lithology of roof and floor 顶底板岩性 Floor 底板
1	1.13～5.80/3.39	94～138/108	Stable 稳定	1	Simple 简单	Mudstone 泥岩	Mudstone, sandy mudstone 泥岩、砂质泥岩
6-1	1.02～8.19/3.36	15～61/33	Relatively stable 较稳定	1	Simple 简单	Mudstone, carbonaceous mudstone 泥岩、炭质泥岩	Sandstone 砂岩
8	1.59～4.73/3.41	51～138/83	Stable 稳定	0	Single 单一	Mudstone, sandy mudstone 泥岩、砂质泥岩	Mudstone, sandy mudstone 泥岩、砂质泥岩
11-2	2.29～4.84/3.64	66～92/76	Stable 稳定	1～3	Simple 简单	Fine and medium sandstone 细砂岩、中砂岩	Mudstone, sandy mudstone 泥岩、砂质泥岩
13-1	1.5～12.79/6.06		Relatively stable 较稳定	1～2	Simple 简单	Mudstone, sandy mudstone 泥岩、砂质泥岩	Mudstone, sandy mudstone 泥岩、砂质泥岩

Table 1-2: Coal Seam Thickness and Mining Characteristic Data – Huajiahu Coal District
(Source: SDIC)

The floor and roof rocks of Seams 13-1 and 11-2 comprise an interbedded sequence of sandstone, siltstone, and mudstone rocks (Figure 1-6). Although the coal seams themselves have undergone shearing, natural fracturing in the clastic section appears to be limited. This sequence may be expected to provide a stable drilling environment for drilling long horizontal degasification boreholes in the gob zone.

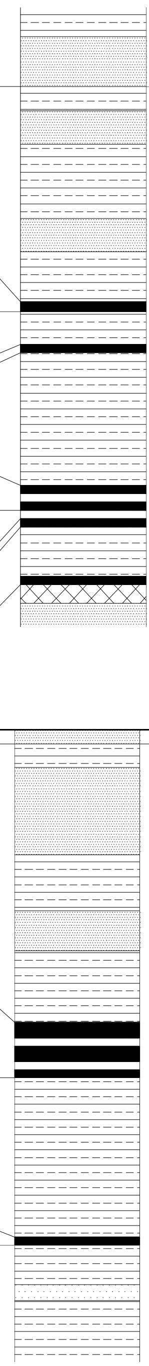
oal-bearing section 含煤段		Coal seam 煤层			Comprehensive column 综合柱状	Lithology 岩性描述
Section 段	Thickness 厚度	No. 编号	Thickness 厚度（m）	Spacing 间距（m）		
/	87.0					Purple brown-light yellow granitophyre, its bottom is the deep gray medium and fine size quartzose sandstone and the Quaternary coal-bearing section boundary 紫褐色-浅黄色花斑泥岩，底部以深灰色中细粒石英砂岩与第四含煤段分界
V				45.5-36.4 / 66.65		Consists of gray-deep gray sandstone, sandy mudstone, mudstone and grayish white fine and medium size sandstone. The middle coal-bearing seams are 5-7, wherein, 13-1# coal seam has the relatively stable growth, -300m and above were displaced by the decken structure. About 18m below 13-1# coal seam grows with one stable purple brown-grayish green granitophyre with oolite, commonly called the "large granitophyre", its bottom consists of grayish white medium sandstone and the Tertiary coal-bearing section. 由灰色-深灰色砂岩，砂岩泥岩，泥岩及灰白色细，中粒砂岩组成。中部含煤5-7层，其中13-1#煤层发育较稳定，-300m以浅被推覆体推失。13-1#煤层下约18m发育一层较稳定的紫褐色-灰绿色含鲕粒花斑泥岩，俗称"大花斑"。底部以灰白色中粒砂岩与第三含煤段分解。
		15* coal seam 煤层	0-1.46 / 0.57	1.60-17.40 / 6.89		
		15* coal seam 煤层	0-3.24 / 0.63	4.50-24.30 / 18.55		
		13-1# coal seam 煤层	1.51-8.47 / 4.61	1.95-1.37 / 0.98		
		Lower 13-1 #coal seam下#煤				
		12# coal seam煤层				
I	114.0			67.46-88.55 / 79.2		Consists of gray silty sandstone, mudstone and grayish white fine and medium sandstone, and quartzose sandstone. Its medium and lower parts has 3-4 coal-bearing seams, wherein, 11-2 seam is totally grown stably, with the complicated structure, with 1-3 gangue layers, from its east to west, the coal seam is thinner, the average thickness of 1-02 line is 4.31m, and that of 03-05 line 3.96m, the east part of 06 line is 2.97m, most of the 11-1 coal seam is recoverable, the mudstone or sandy mudstone at the top of 11-2# coal seam is abundant with phytolites, its bottom is divided with the second coal-bearing section with the grayish white quartzose sandstone or medium and fine sandstone由灰色粉砂岩，泥岩及灰白色细，中粒砂岩，石英砂岩组成。中下部含煤3-4层，其中11-2煤层全区发育稳定，结构复杂，夹矸1-3层。从东到西，煤层呈变薄趋势，1-02线平均厚4.31m，03-05线平均厚3.96m，06线以东平均厚2.97m，11-1煤层大部可采。11-2#煤层顶部泥岩或砂质泥岩中富含植物化石。底部以灰白色石英砂岩或中细砂岩与第二含煤段分界。
		11-2# coal seam 煤层	2.29-5.76 / 3.85	19.35-37.36 / 28.18		
		11-1# coal seam 煤层	0-2.72 / 0.97	39.93-52.71 / 44.89		
		Upper 9 # coal seam上煤层	0-1.73 / 0.95			

Figure 1-6: Coal Stratigraphy and Lithology at Liuzhuang mine

(Source: SDIC)

In addition to the mining targets Seams 13-1 and 11-2, the relatively thin coal seams 5 through 9 underlie the target coals and are not yet being mined. Figure 1-7 shows the detailed coal stratigraphy of these coals, as well as characteristics of the floor and roof rocks. These seams are not mined but contribute methane due to gob fracturing that occurs during longwall mining.

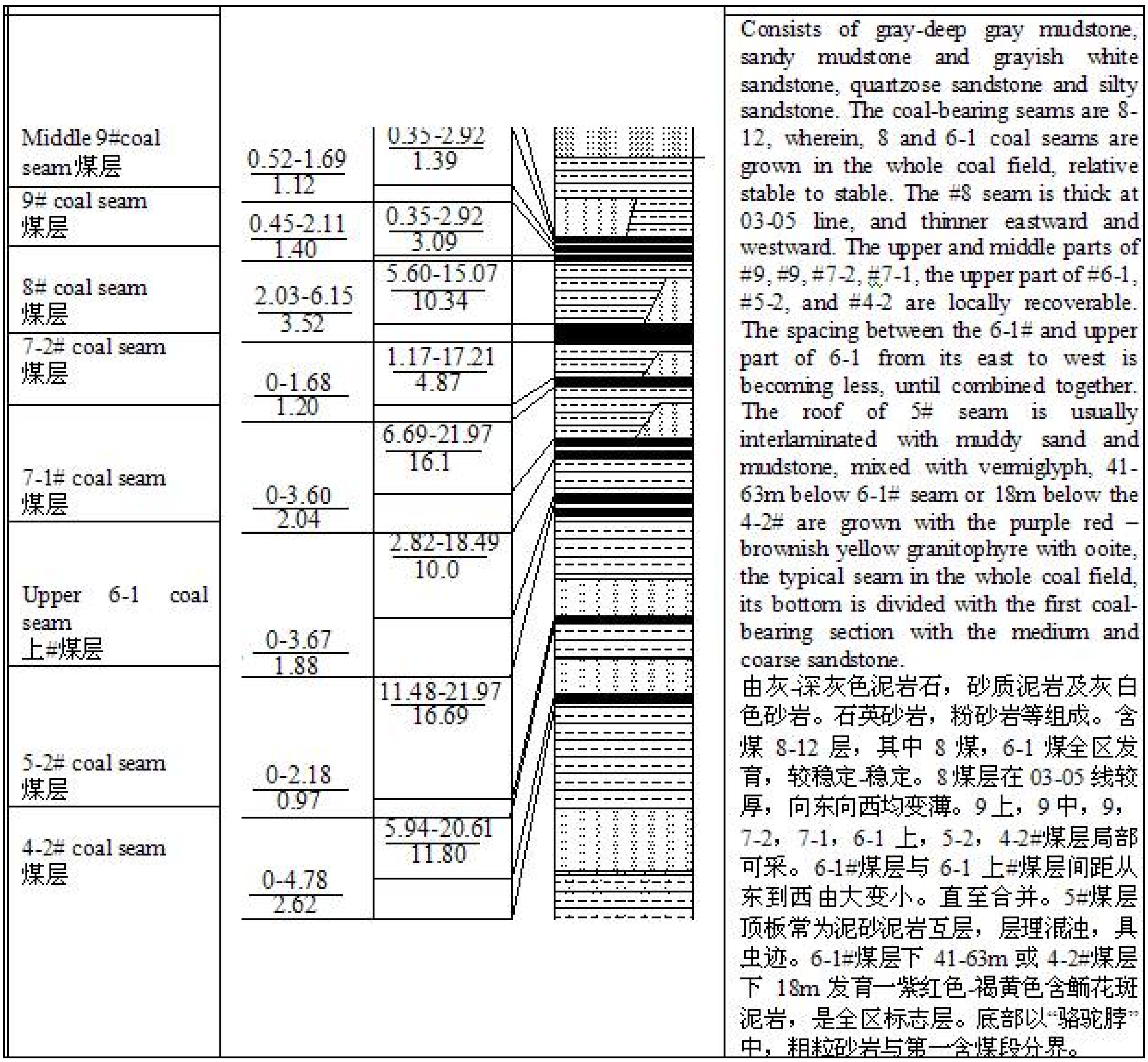


Figure 1-7: Detailed Coal Stratigraphy at Liuzhuang mine

(Source: SDIC)

Photomicrography of coal samples in the Huainan Coal Field clearly show the extensive natural micro-fracturing and shearing that they have undergone due to the complex structural history of the region (Figure 1-8). This deformation has weakened the coal and reduced its permeability, making it difficult to drill in seam.

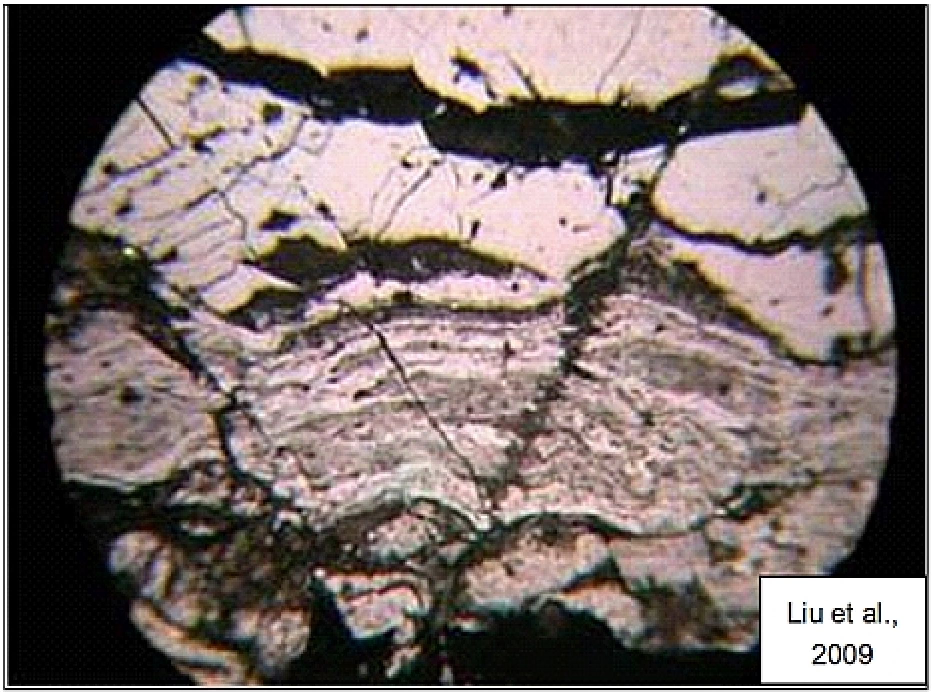


Figure 1-8: Photomicrograph (300x) of a Coal Sample in the Huainan Coal Field
(Liu et al., 2009)

1.7.3 High Temperature Hazard

A local geothermal anomaly has generated an abnormally high temperature gradient at the Liuzhuang mine (3°C per 100-m depth). At typical mining depths the initial rock temperature is quite hot, approximately 38.9° C. Ventilation applied during longwall retreat mining reduces the maximum temperature at the mining face to about 26 to 30°C. However, the elevated temperature is considered to be hazardous for mine personnel, who often work shortened and staggered shifts. Despite this, the elevated temperature is not considered to have a significant impact on CMM drainage at this mine.

1.7.4 Coal Dust

Unrelated to its CMM drainage potential, but still important for mining productivity, the coal mined at Liuzhuang is considered to have a high risk of coal dust explosion. Coal volatility is 35.95 and is characterized by a long flame (> 400 m). The mine takes standard measures to suppress the risk of coal dust explosion, mainly by maintaining the minimum rock content above 65%.

1.7.5 Gas Content and CMM Resources

Gas content at the Liuzhuang mine has not yet been precisely measured using CBM-industry standard techniques, but is believed to range from about 3 to 7 m^3/t, increasing with depth. The most accurate method for determining gas content -- direct gas desorption of core sampled from the virgin (non-mined) coal seams – has not yet been conducted at Liuzhuang, mainly because no modern CBM exploration wells have been drilled nearby.

Instead, the Fushun Coal Mine Research Institute used in-mine borehole core data to estimate gas content at approximately 5.29 m^3/t. However, it should be noted that the Fushun in-mine method is much less accurate than the CBM industry-standard direct desorption (US Bureau of Mines) method using surface cores. Thus, there remains some uncertainty about the actual gas content and CMM resources at Liuzhuang mine.

Gas content measurements obtained by Fushun show large variation and probably are not very reliable (Table 1-3). Methane contents measured range widely, from 0.42 to 12.47 m^3/t. Methane concentration measurements also show extreme variation, from 32.76% to 92.66%. This considerable data variability probably reflects contamination with mine ventilation air during the sampling procedure.

Coal seam 煤层	No. 序号	Hole number 孔号	Sampled depth 采样深度	Sampling method 取样方法	Natural methane composition 自然瓦斯成分(%)	Content of methane 瓦斯含量 ($cm^3/g.r$)	Quality evaluation 质量 评定
					CH_4	CH_4	
13-1	1	107	625.2	Desorption 解吸	92.27	5.14	Qualified 合格
	2	101	897.7	Desorption 解吸	92.66	12.47	Qualified 合格
11-2	1	0309	329.3	Desorption 解吸	40.46	0.89	Qualified 合格
	2	0604	433.5	Desorption 解吸	32.76	0.42	Qualified 合格
	3	0703	480.7	**Desorption 解吸**	36.83	1.10	Qualified 合格
	4	0002	343.7	Desorption 解吸	69.6	1.12	Qualified 合格
8	1	0202	459.4	Desorption 解吸	66.38	1.64	Qualified 合格
	2	0203	583.9	Desorption 解吸	83.5	4.13	Qualified 合格
	3	0309	438.3	Desorption 解吸	84.17	2.93	Qualified 合格
	4	0401	438.2	Desorption 解吸	73.87	1.41	Qualified 合格
	5	0501	459.1	Desorption 解吸	63.26	1.23	Qualified 合格
	6	0502	553.2	Desorption 解吸	84.16	5.02	Qualified 合格

Table 1-3: Coal Seam Gas Content and Composition Data from the Liuzhuang mine area
(Source: SDIC)

Desorption data measured from surface core taken from other portions of the Huainan Coal Field indicate that gas content at Liuzhuang is probably closer to 7 m^3/t at a depth of 700 m. Using the lower gas content estimate, Fushun estimated CMM resources to be approximately 69 billion m^3, of which some 22.8 billion m^3 are considered technically recoverable methane reserves; these figures may be underestimated by 20%.

1.7.6 Mining Practices

Mine Layout. The Liuzhuang mine uses a typical retreat longwall mining design with collapsing roof. The longwall panels are relatively large, measuring 250 by 1800 m. The current mining depth is 580 to 700 m below the surface. Seams 11-2 and 13-1 at Liuzhuang are not exceptionally thick (less than 4.5 m) and thus the coal can be readily exploited using a single-pass, full-height mining technique.

As a relatively recently developed mine, initial longwall mining face development at Liuzhuang took place in East Zone 2, which is located in the East Wing of the mine and bounded on the east by fault F30, with fault F31 providing a protective column contour. The western boundary of the mine is fault F19, while the northern boundary is the -500 m structural level of Seam 13-1. The initial dip slope was 13°～17° south, but the dip steepens to about 30° at greater depth.

The first mining face measured approximately 350 m across from east to west. A ventilation air way was constructed above this face. Situated below is the gateway for coal haulage. The upper zone is classified as the 1302 working zone, the lower area 1304 working zone, eastern side the East Mining Zone 3, and the western side the East Mining Zone 1. The longwall measured some 1,623 m long, with average slope length 244 m. Coal reserves for this panel were estimated at 2.079 million t, of which 1.933 million t is considered to be mineable (equivalent to 93% mining efficiency).

Roadway Development. Development of roadways at Liuzhuang mine utilizes road header machines as well as drill-and-blast methods. Development production at Liuzhuang mine is approximately 150,000 t/year. The main roadways have the following characteristics:

- 7 separate areas (zones).
- Advance rate is approximately 600 m per month per road header.
- Roadway dimensions are approximately 4.6 – 5 m (width) x 3.8 m (height).
- Longwall gate-roads (from mine plan) are single-heading entry development, double-heading entry development, or developed off from main roadways.
- Goaf drainage roadways (from the mine plan) appear to be offset to one side of the longwall block, 18 to 25 m above the coal seam.

Longwall Development. As of November 2009, one longwall was in operation at Liuzhuang mine. A second longwall is planned to be installed during 2010. After completion of the mine expansion, coal production related to mining of longwalls at Liuzhuang (as opposed to the roadways) will be expanded to about 7.85 million t/year.

Longwall blocks at Liuzhuang mine have the following characteristics:

- Length ranges from 1500 to 1700 m.
- Width ranges from 220 to 280 m (plan to go up to 340 m).

Mining height depends on the coal seam that is being mined, ranges from 1.95 to 4.55 m.

- Mine advance rate is approximately 8 to 10 m per day.
- Mining plan is to work from the upper coal seam down to the lower ones. Thus, the mining sequence starts with Seam 13-1, mining sequentially the seams below (Seam 11-2 currently. In the future Seams 8, 5-1 and finally Seam 1 are scheduled to be mined).

1.7.7 Methane Drainage Practices

To enhance safety and mining productivity, the Liuzhuang mine currently uses boreholes connected to a vacuum system to drain approximately 24.7 m^3/min of coal mine methane. Two types of CMM boreholes are drilled at the Liuzhuang mine. First, short (100-m long), non-steered, boreholes are driven horizontally into the coal seams in a cross-panel configuration. Second, cross-measure boreholes slanted upwards into the fractured rock (gob) zones are also installed to drain CMM that is released from overlying coal seams and sandstones that become fractured as the mining face advances.

Significant volumes of air contamination leak into the drained CMM stream at Liuzhuang mine, reducing the methane concentration from about 95% CH_4 as originally stored in the coal reservoir to only about 7 to 10% by the time the CMM is vented. Most of this air probably enters the gob area and/or is sucked into the boreholes as the mining face advances. Additional air likely leaks around the poorly cemented boreholes. Air also may leak into the steel pipeline system via loose flange connections.

The coal seams mined at Liuzhuang have low to moderate methane levels, are loose and soft, and have low permeability (probably 0.1 mD or less). This makes pre-drainage very difficult. Despite the modest gas contents, gas and rock outbursts are fairly common during mining because of low permeability.

For Seam 13-1, disruption of the overlying seams by longwall mining contributes a significant fraction (17-36%) of the methane encountered at the working face. Gas also desorbs from thin coal seams that are not mined or disrupted, due to desorption caused by the mine’s pressure sink. Much of this gas accumulates in the gob zone above the target seam and is difficult to deal with.

Several degasification methods are employed to control the methane emissions into the mine workings. The first is to excavate a 35 degree sloping tunnel to get above the mined seam. Then 10 boreholes are drilled from a small gallery to just above the working face. This sequence is repeated every 80 m or so above the working seam. The second method is to drill cross-measure boreholes from the roadways over the longwall panel. Both of these systems produce low-quality CMM, in the range of 15% methane.

The main method for methane drainage at Liuzhuang mine is gob gas removal using short boreholes drilled along strike, angled up into the roof of the coal seam. Gas production increases once the working face and gob zone reaches the end of the boreholes, but methane concentration is diluted severely by mine ventilation air. At Liuzhuang mine the concentration of drained gas is extremely low (generally 7-10% CH_4), which is in the hazardous explosive range for methane/air mixtures (between 5 and 15% CH_4 in air).

Longer horizontal in-mine boreholes drilled into the gob would seem an obvious improvement to the short holes currently drilled at Liuzhuang. For example, as early as 1998 at the Xieqiao mine, located just to the east of Liuzhuang, a horizontal borehole 360 m in length was successfully drilled using an Australian directionally controlled 1000-m-rated drill.[3]

1.7.8 Ventilation

At Liuzhuang centralized cross ventilation was utilized during the early stage of mining, ventilating the main and auxiliary shafts. Two main-track crosscut lines were employed: the central Track Line and the air inflow cross-cut line. The mine employs an exhaust system with a surface-mounted main ventilation fan. Manufactured in the United Kingdom by Howden, the fan is 2.8 m in diameter and has a flow capacity of 20,000 to 28,000 m^3/min.

Starting August 31, 2006, the mine commissioned two auxiliary ANN-2884/1400N axial-flow blowers, with 2-MW motor capacity and hydraulically adjustable rotors.

Slope shafts (Central Plastic Machine and Gangue Plastic Machine slope shafts) provide ventilation to the mining face and tunneling areas. Ventilation air exits through two cross-cut shafts. The first mining face area, developed in Seam 13-1, was ventilated with 2,520 m^3/min, fresh air passing through the central track cross-cut to all tunneling zones. At the early stage of mining, only five road tunneling face areas, three mining face areas, and one combined mining face area were present, thus the ventilation requirement was about 13,080 m^3/min.

[3] Yuan, Liang; Zhang, Liqing; Li, Ping; and Zhou, Deshui, 1998. "Underground Coalbed Methane Drainage in the Huainan Mining Area." Proceedings of the International Workshop on Coalbed Methane Recovery and Utilization, November 12-13, 1998, Beijing, China.

Ventilation control for the mine was established primarily through the use of permanent ventilation shaft, adjustable ventilation shaft, and air diversion walls.

Currently, the mine has two methane pumping stations, one on the east side and one on the west. On the eastern area, four pumps with a capacity of 415 m^3/min have been installed. On the west side, four pumps are scheduled to be installed during 2010; two more pumps are to be installed later.

In 2007 Liuzhuang mine drained 10.8 million m^3 (20.5 m^3/min) of methane, increasing to approximately 13 million m^3 (24.7 m^3/min) in 2008. The concentration of the drained methane is low, usually less than 10% CH_4. During the July 2008 pre-feasibility study visit, all captured methane was being vented to the atmosphere.

1.7.9 CMM Utilization

Currently, none of the CMM being drained at Liuzhuang mine is being utilized. SDIC-Xinji has been evaluating (but had not yet decided on) the use of Shengli-manufactured reciprocating engines that are capable of using low-quality CMM fuel with 7-10% CH_4 concentration. The project as originally envisioned would generate a total of 4.0 MW, comprising 8 units x 0.5 MW. Power generated would be used mainly by the mine.

Ventilation air methane mitigation or utilization does not appear to be practical at Liuzhuang mine. The methane concentration in the ventilation air is only about 0.02% CH_4. While such a low VAM concentration is favorable for mining safety purposes, it is significantly below the economic limit for VAM mitigation or utilization.

1.7.10 Methane Emissions

The Liuzhuang mine currently emits an estimated total 30.9 m^3/min (1.6 MMcfd or 0.41 MtCO2e/yr). These CMM emissions originate from two main sources. The most important component of methane emissions is the 24.7 m^3/min of 7-10% purity methane that is drained via the borehole and vacuum system. An additional 6.2 m^3/min of very low concentration VAM (average 0.02% CH_4) is also emitted.

1.8 Conclusions and Recommendations

The three SDIC-Xinji mines share similar geologic characteristics as well as certain mining and coal mine methane drainage challenges. The pre-feasibility evaluation indicated that each mine could qualify as a candidate for a more detailed CMM feasibility study. However, the Liuzhuang mine stood out as a particularly attractive candidate for several reasons, including:

1) The Liuzhuang mine is the newest and most modern of the three SDIC-Xinji Energy operated mines, having been in production for only three years.
2) It has the largest longwall panels being developed of the three mines, measuring 250 m by 1800 m, offering space for advanced longhole drilling strategies.
3) Liuzhuang has the largest designed capacity (8 million t/year), as well as recoverable reserves (679 million t) and the longest service life (61 years).
4) It has the largest total methane resources, estimated at 69 billion m^3 with a recoverable reserve of 23 billion m^3.
5) Mine management has installed an extensive real-time monitoring system of methane drainage, coal production, and other mine production related statistics.
6) Liuzhuang has experimented with surface drilled gob wells with some success, indicating that alternative degasification systems could be employed that would produce higher concentrations of methane.
7) The ARI team's initial finding is that long horizontal borehole drilling into the gob zone above the mined coal seams could dramatically improve methane recovery and concentration.
8) Additional improvements in borehole sealing effectiveness and the integrity of the pipeline system could boost methane quality several fold.
9) Once gas flow and quality is improved, larger more efficient reciprocating engines could be applied for power generation, with more reliability and efficiency gains over the current less reliable low-concentration units.

Section 2 through 10 of this report provide a detailed feasibility study of the proposed CMM drainage and utilization improvement project at Liuzhuang mine.

SECTION 2

Geologic Analysis and Resource Assessment

SECTION 2 CONTENTS

SECTION 2 FIGURES

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2.1 Introduction

Coal mining on a large scale first began at the Huainan Coal Field in the 1950's, while coal mine methane (CMM) drainage has been underway since 1961. Today, Huainan is one of China's largest and most important coal mining and coal mine methane production areas, ranking number three and two, respectively, in the country.

This section discusses the regional geology and CMM resources in the Huainan coal field. It also evaluates the specific conditions, challenges, and potential technical solutions for optimally draining and utilizing CMM at Liuzhuang mine.

Understanding first the regional geology, coal mining, and CMM drainage conditions and challenges in the large Huainan Coal Field is essential for ultimately improving the performance of CMM drainage at Liuzhuang mine. It also helps to quantify the potential benefits that improvements developed at Liuzhuang mine may provide for upgrading CMM drainage at the region's several dozen underground coal mines.

Coal mine production from the Huainan Coal Field totaled approximately 100 million t in 2008. Assuming basin-wide average specific methane emissions of 20 m^3/t, which includes methane that seeps into the mine from adjacent non-mined seams and fractured sandstones, approximately 2 billion m^3/year (200 MMcfd) of methane is liberated by coal mining in Huainan.

Of this total, only about 190 million m^3/year (or nearly 10%) is drained in CMM collection systems. Of the methane drained, about 40% or 95 million m^3/year is utilized, mainly as boiler fuel, residential town gas, and some power generation. In summary, methane emissions to the atmosphere from coal mining in the Huainan Coal Field are estimated to be 1.9 billion m^3/year. Clearly, the Huainan Coal Field offers a major opportunity for improved CMM drainage and utilization.

2.2 Location and Regional Tectonics

Liuzhuang mine is located in the western portion of the Huainan Coal Field in central Anhui Province. The Huainan Coal Field is part of the much larger and structurally complex East China Coal Region, a major coal deposit which extends up the length of eastern China into northeastern China's Liaoning and Heilongjiang Provinces (Figure 2-1).

Over the past 15 years several articles authored by Chinese researchers have described the geology, coal mine methane, and coalbed methane potential of the Huainan region.[1],[2],[3] This section is based on ARI's synthesis of others' previous work as well as our own interpretation of the raw data.

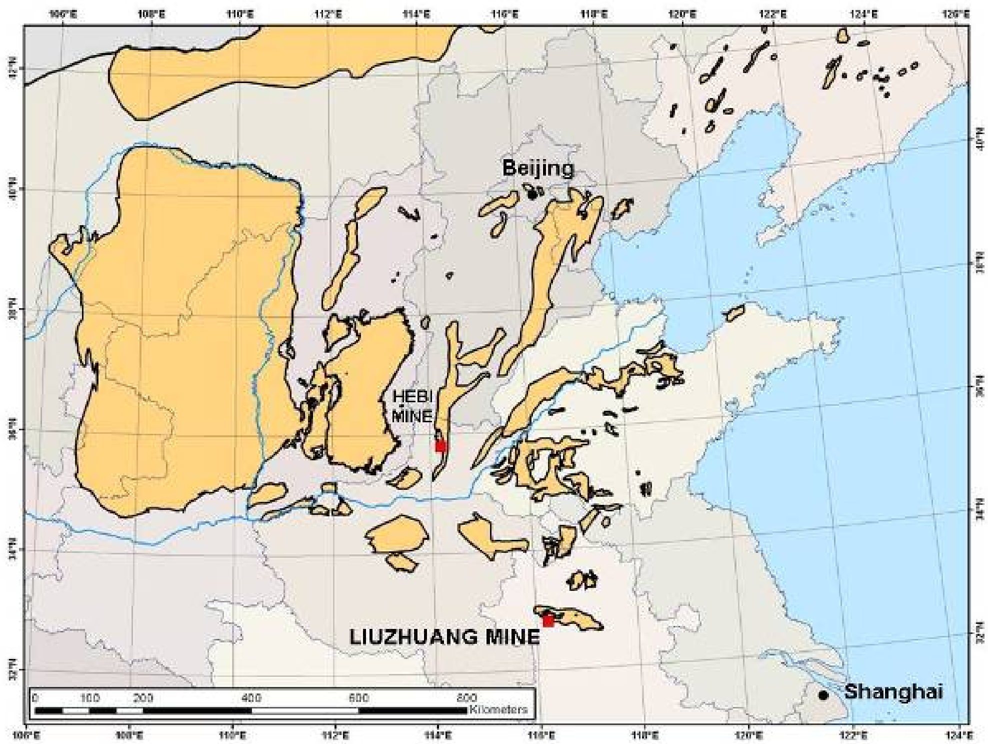


Figure 2-1: Liuzhuang Mine Location in relation to the East China Coal Region

The East China Coal Region is a tectonically active region characterized by numerous results and often rapid, recent regional subsidence. This tectonic activity is being driven by India's continued northward subduction under the Asian continent and the resulting northeastward extrusion of China. East China is structurally much more complex than the relatively quiescent Ordos and Qinshui basins of north-central China. These areas have experienced mostly up and down movement, much like in the Colorado Plateau of the U.S. The Ordos and Qinshui basin are relatively free of active faulting and therefore structurally much simpler than Huainan.

[1] Yang, Zhongzhen; Zhang, Bingguang; and Sun Maoyei (Huainan Coal Mining Bureau), 1995. "Evaluation of the Geological Characteristics and the Resources of Coalbed Methane in the Huainan Coal Field." Proceedings, International Conference on Coalbed Methane Development and Utilization, United Nations Development Program, Beijing, China, October 1995.

[2] Yang, Zhonzhen; Zhang, Bingguang; and Sun Maoyei ((Huainan Coal Mining Bureau), 1995. "Evaluation and Development Prospects of Coalbed Methane Resources in the Huainan Coal Basin." China Coalbed Methane, No. 1, May 1995.

[3] Liu, Dameng; Yao, Yanbin; Tang, Dazhen; Tang, Shuheng; Yao, Che; and Huang, Wenhui (China University of Geosciences), 2009. "Coal Reservoir Characteristics and Coalbed Methane Resource Assessment in Huainan and Huaibei Coalfields, Southern North China." International Journal of Coal Geology, v. 79, p. 97-112.

Mainly for this reason, advanced CMM drainage techniques that are being successfully employed in structurally simple (i.e., not faulted and folded) and stable (strong, intact coal) portions of Shanxi Province (e.g., the Sihe mine) – and in particular the 1000-m long in-seam borehole drilling technology imported from North America and Australia -- are not necessarily appropriate for Liuzhuang and other mines in East China.

2.2.1 Huainan Coal Field

The Huainan Coal Field is a major coal mining region in east-central China. Huainan is the southernmost coal field in the East China Coal Region. Covering a total surface area of approximately 3,000 km^2, the Huainan Coal Field measures about 100 km east-to-west and about 25 to 30 km north-to-south. It comprises several dozen large underground coal mines targeting Paleozoic age coal deposits.

Coal Stratigraphy. The coal deposits in the Huainan Coal Field are found mainly within the Permian Shihezi Formation, with a few economically less vital seams also occurring in the underlying Permian Shanxi Formation (Figure 2-2). (Note that the Shihezi Formation is a younger unit than the coal-bearing Carboniferous Taiyuan and Permian Shanxi Formations further to the north in Henan and Shanxi Provinces.) These coal seams were formed in a mostly paralic delta facies with numerous depositional cycles. Approximately 32 to 40 individual coal seams totaling up to 42 m net coal thickness occur within an overall 350-m thick coal-bearing sequence. Of these, about 9 to 18 seams are considered to be of mineable thickness and lateral continuity, though in a given mine typically only several individual seams are mined.

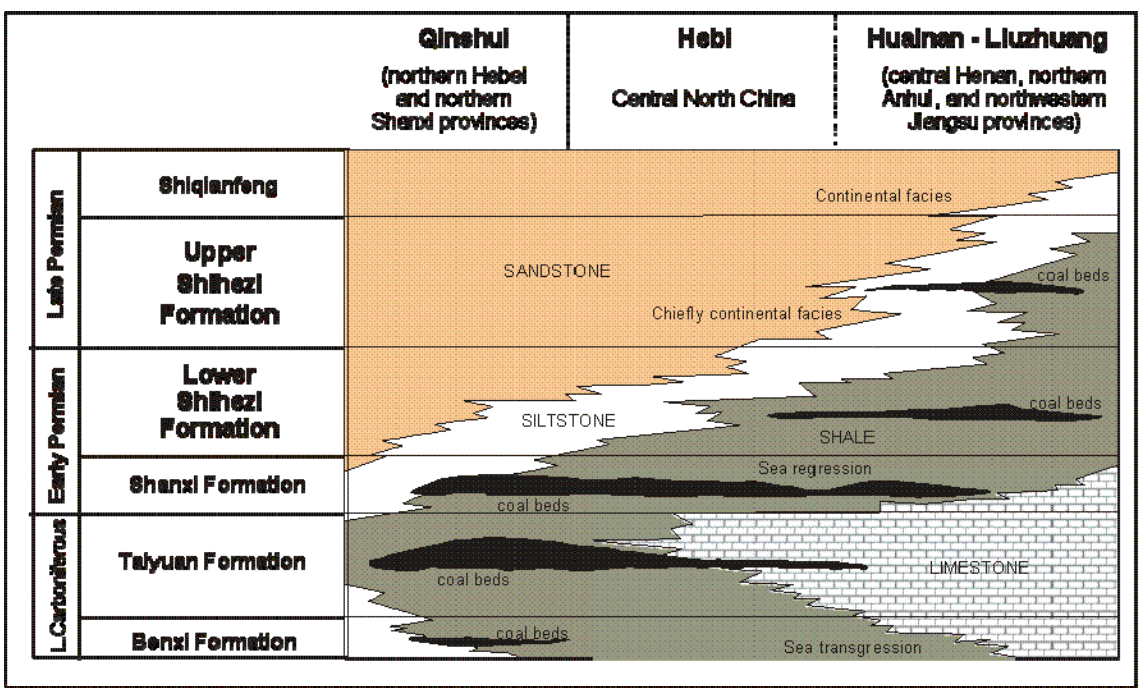


Figure 2-2: Stratigraphic Lithofacies of East-Central China

Regional Structure. The Huainan Coal Field is an east-west trending depression containing Paleozoic coal deposits (Figure 2-3). Major faults and folds in the basin also trend east-west and control coal depth distribution. Significant folds include the Pan Anticline in the east, the Xieli Syncline in the southeast, and the Xieqiao Syncline in the southwest, where the Liuzhuang mine is situated. Depth to coal ranges from less than 300 m deep in the west-central portion of the basin to over 2,000 m deep at its far eastern edge. Coal depth at Liuzhuang mine ranges from 400 m deep in the north to well over 1000 m deep in the south. Note that about a dozen coalbed methane exploration wells have been drilled in the basin since 1992, five of which are located on ARI's structure map, but none of them are located near the Liuzhuang mine.

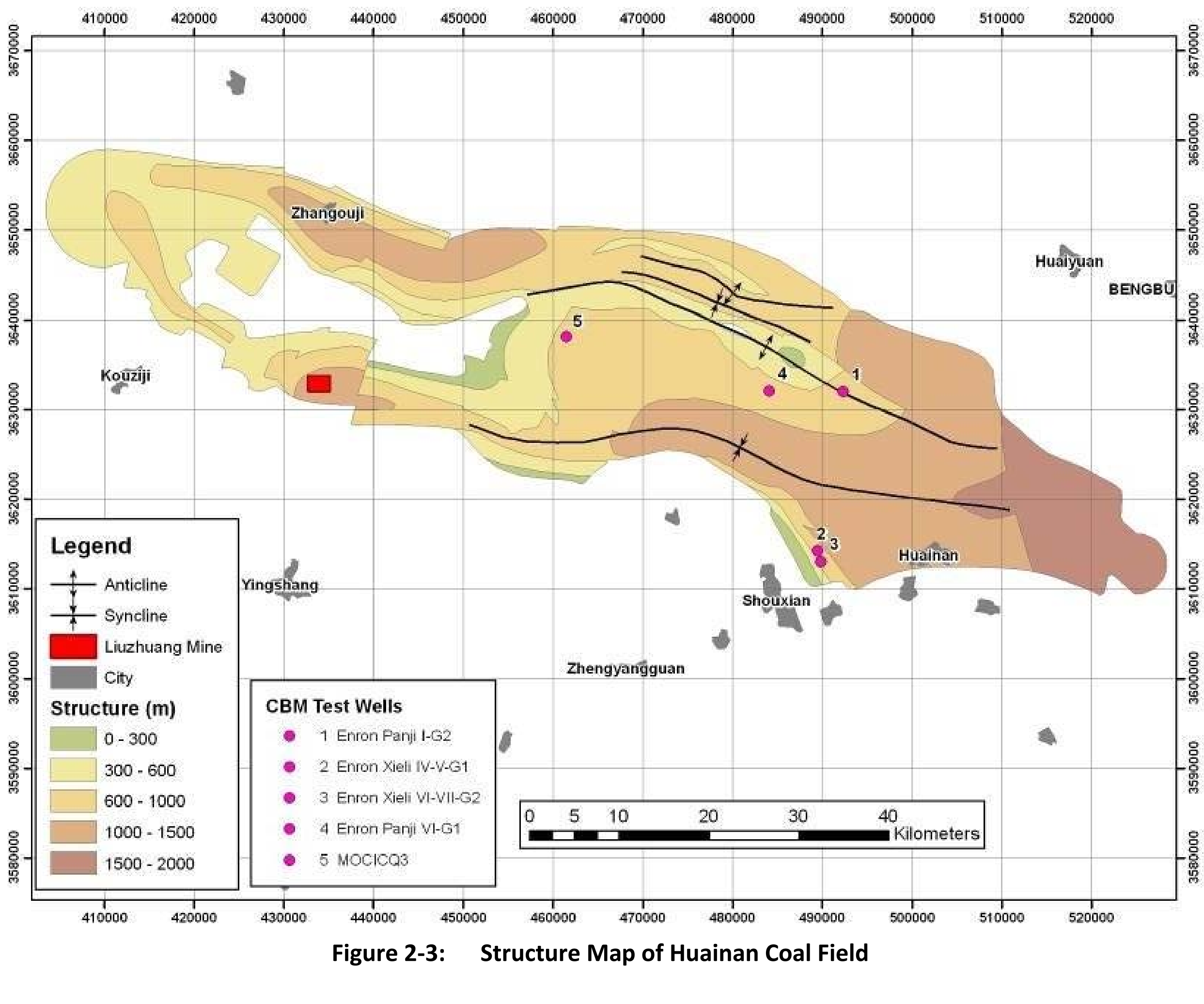


Figure 2-3: Structure Map of Huainan Coal Field

Coal Thickness. Total coal thickness reaches a maximum 33 m in the northeastern portion of Huainan Coal Field (Figure 2-4). Liuzhuang mine, located in the western portion of Huainan Coal Field, has moderate total coal thickness of approximately 25 m, which is still considered a very substantial coal deposit. A sizeable area just to the north of Liuzhuang mine is completely devoid of coal, having been denuded of Permian sedimentary rocks during the ancient uplift and erosional event that created the Permian-Quaternary unconformity. Coal thickness increases again to more than 30 m in the structural depression just south of Liuzhuang mine. Note that only a small fraction of this coal deposit is currently mined at Liuzhuang. The extensive coal deposits in the Liuzhuang mine area could enable coal (and CMM) production to be increased significantly.

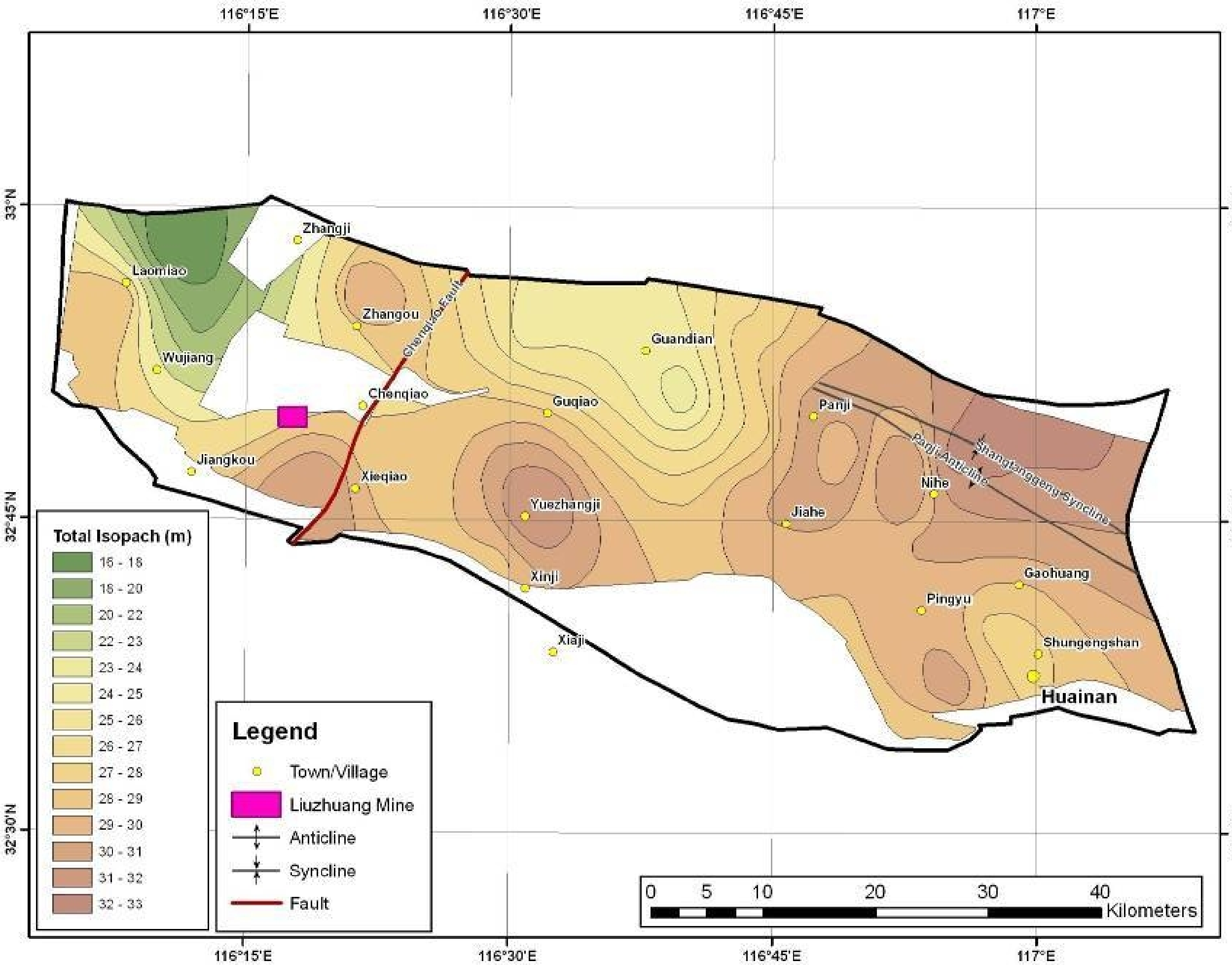


Figure 2-4: Total Coal Thickness Distribution in the Huainan Coal Field

Coal Rank. The thermal maturity (rank) of coal is a major control on its methane sorption capacity, as well as its cleat and permeability development. Figure 2-5 shows ARI's map of vitrinite reflectance (Ro) distribution in the Huainan Coal Field, a measure of thermal maturity. Vitrinite reflectance reaches a maximum of 0.85% in eastern Huainan Coal Field, equivalent to medium-volatile bituminous coal rank. Liuzhuang mine has relatively low Ro of approximately 0.72%, representing high-volatile bituminous A coal rank and indicating somewhat lower gas storage capacity.

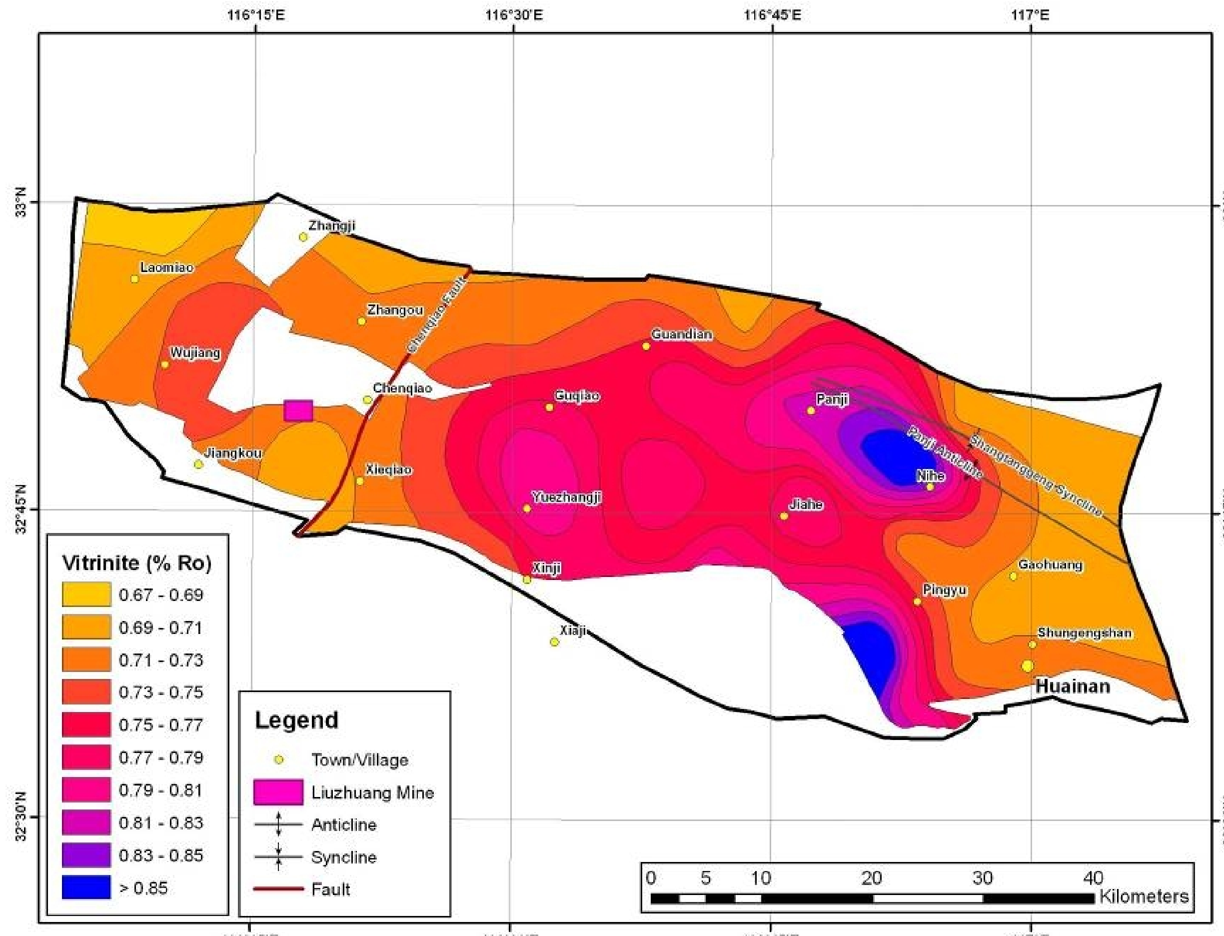


Figure 2-5: Vitrinite Reflectance Distribution in the Huainan Coal Field

Gas Content and Saturation. Core desorbed using the U.S. Bureau of Mines (USBM) method from surface coreholes, located in areas undisturbed by mining, is the only reliable measurement of coal seam gas content. In-mine measurement of gas content using short boreholes (<300 m) is much less accurate, because the mine development inevitably reduces reservoir pressure and causes gas to flow towards the pressure sink, even in low-permeability coals. Only very long in-mine boreholes (1000 m) would be able to reach virgin coal seam conditions.

There is extensive gas content data in the Huainan Coal Field, as well as some sorption isotherm measurements on the coals, but these data show a great deal of variability, both laterally and vertically. Part of the data scatter is due to sampling and measurement error, resulting in low precision. This is particularly true for samples analyzed before about the year 2000, when the US Bureau of Mines direct desorption method began to be widely used in China, replacing an earlier less accurate China Ministry of Coal method.

Figure 2-6 shows the distribution of coal seam gas content data in the Huainan Coal Field, comprising measurements from the Liuzhuang mine area as well as several other areas located in the eastern part of Huainan, such as the Xieli, Pan #2, and Pan #3 mines. Although there is considerable data scatter, gas content generally increases with depth in Huainan. Red data points on the graph show gas content measured using the former China Ministry of Coal desorption method, which uses smaller samples and shorter desorption time and thus is less reliable. Green data points show more recent gas contents measured using the US Bureau of Mines desorption method, utilizing larger coal samples desorbed for a much longer time, resulting in more reliable (and generally higher) values.

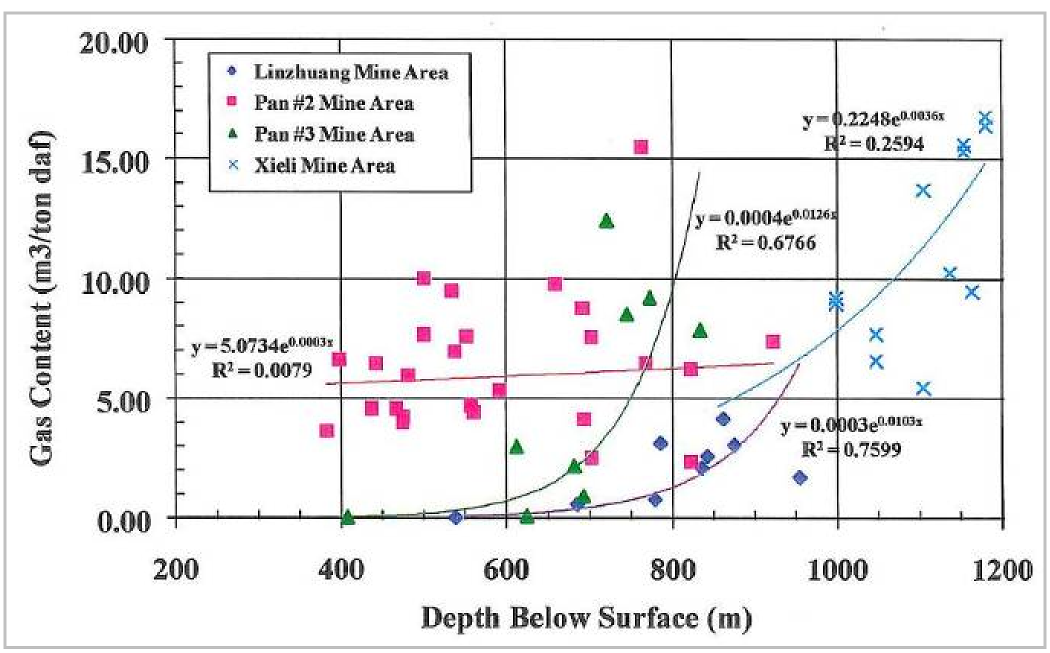


Figure 2-6: Gas Content Versus Depth in the Huainan Coal Field

Table 2-1 shows gas content data from various coal districts of the Huainan Coal Field, tabulated by individual coal seam. The Liuzhuang mine is located in the Xieqiao district, where Seams 11-2 and 13-2 have average gas contents of 7.96 and 7.25 m^3/t, respectively, at a depth of 1,000 m. However, much of the gas content data collected in this area are probably not based on the more robust USBM method and therefore are suspect. Gas content is higher in the Panji and Xieli areas of eastern Huainan, about 11 m^3/t at 1,000-m depth.

			Gas Content by Seam (m^3/t d.a.f. basis)			
Coal District	**Depth Range (m)**		**1**	**8**	**11-2**	**13-2**
Xieqiao West	**700**	**1000**	**5.05**	**3,19**	**2.75**	**4.72**
	1000	**1200**	**6.71**	**5.89**	**5.75**	**6.74**
	1200	**1500**	**7.01**	**7.75**	**7.00**	**7.45**
Xieqiao	700	1000	-	8.11	-	6.82
	1100	1200	6.09	8.45	7.96	7.25
	1200	1500	6.20	8.60	8.23	-
Guqiao	900	1000	-	10.45	7.51	8.15
	1100	1200	8.71	12.58	8.70	10.13
	1200	1500	11.18	14.05	10.10	11.10
Panji	700	1000	-	13.07	8.20	8.59
	1000	1200	11.44	14.38	10.11	9.93
	1200	1500	12.48	14.45	11.88	11.75
	-	>1500	13.10	14.45	12.10	12.40
Zhuji	900	1000	-	7.65	5.22	-
	1000	1200	-	10.39	6.27	8.90
	1200	1500	9.73	13.98	8.07	11.55
	-	>1500	12.80	14.30	11.39	12.10
Xieli	900	1000	-	-	9.75	8.45
	1000	1200	7.90	11.27	10.45	9.68
	1200	1500	10.13	14.46	11.95	11.00
	-	>1500	4.80	4.65	5.10	5.13
Zhangou	1000	1200	2.01	2.74	2.84	1.95
	1200	1500	3.22	4.03	3.56	3.55
	-	>1500	4.80	4.65	5.10	5.13
Madian	1000	1200	-	2.23	-	2.21
	1200	1500	3.28	4.45	3.23	3.99
	-	>1500	4.75	5.01	4.25	5.00

Table 2-1: Gas Content Data from Huainan Coal Field Districts

Sorption isotherm measurements indicate that coal seams in the Huainan Coal Field generally have gas content levels that are significantly below the theoretical sorptive capacity of the coal seams. Thus, the coals are in an undersaturated state (Figure 2-7). Extensive dewatering would be necessary to elicit methane desorption and eventual production in a vertical or horizontal surface CBM well. (Coal mine development reduces reservoir pressure to near-atmospheric levels, so CMM production is not as affected by reservoir undersaturation.)

Panji anticline area in eastern Huainan Coal Field is the most saturated area of Huainan, with gas content data approaching the sorption isotherm. The Xieli portion of southeastern Huainan is severely undersaturated. Liuzhuang mine in western Huainan is slightly undersaturated, with gas content in the range of 7 m^3/t plotting below the sorption isotherm curve at 9 to 11 m^3/t.

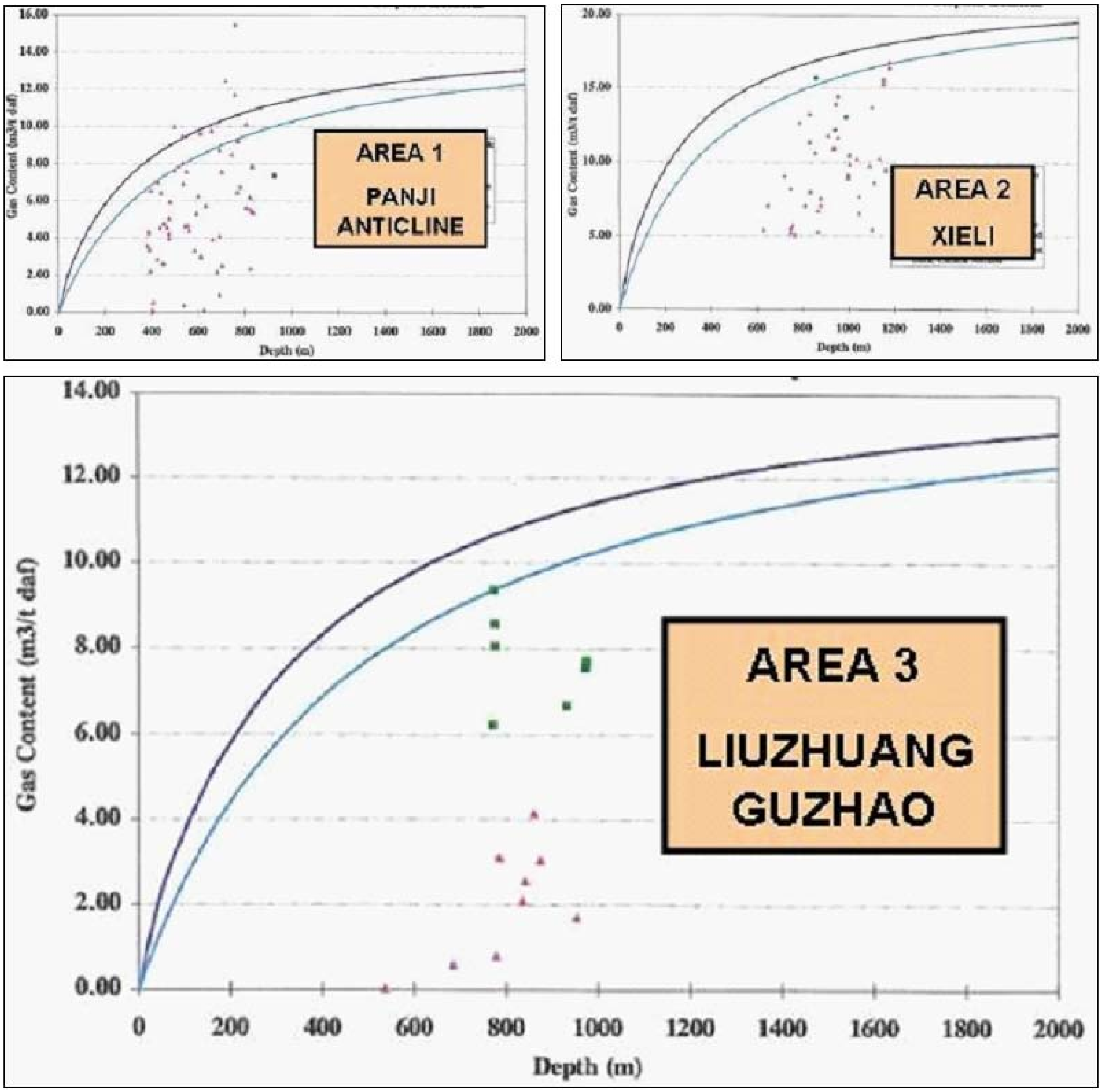


Figure 2-7: Adsorption Isotherms for Huainan Coals

Red data points are gas contents measured using the former Ministry of Coal desorption method, which uses smaller samples and shorter desorption time, thus is less reliable.

Green data are more recent gas contents measured using the US Bureau of Mines desorption method. This utilizes larger coal samples and desorbs for a much longer time, resulting in more reliable (and generally higher) values.

- Area 1 : Panji anticline area of eastern Huainan Coal Field. This area is the most saturated portion of Huainan, with gas content data approaching the sorption isotherm.
- Area 2 : The Xieli portion of southeastern Huainan is severely undersaturated.
- Area 3 : Liuzhuang mine in western Huainan is slightly undersaturated. Gas content in the range of 7 m^3/t plots below the sorption isotherm curve at 9 to 11 m^3/t.

Gas content distribution varies widely across the Huainan Coal Field (Figure 2-8). Gas content reaches a maximum 23 m^3/t in the Panji mining area, eastern Huainan Coal Field. The Liuzhuang mine has comparatively low (but still substantial) gas content of 7 to 8 m^3/t. This is because Liuzhuang is relatively low in rank and also is somewhat less saturated than the coal deposits of eastern Huainan.

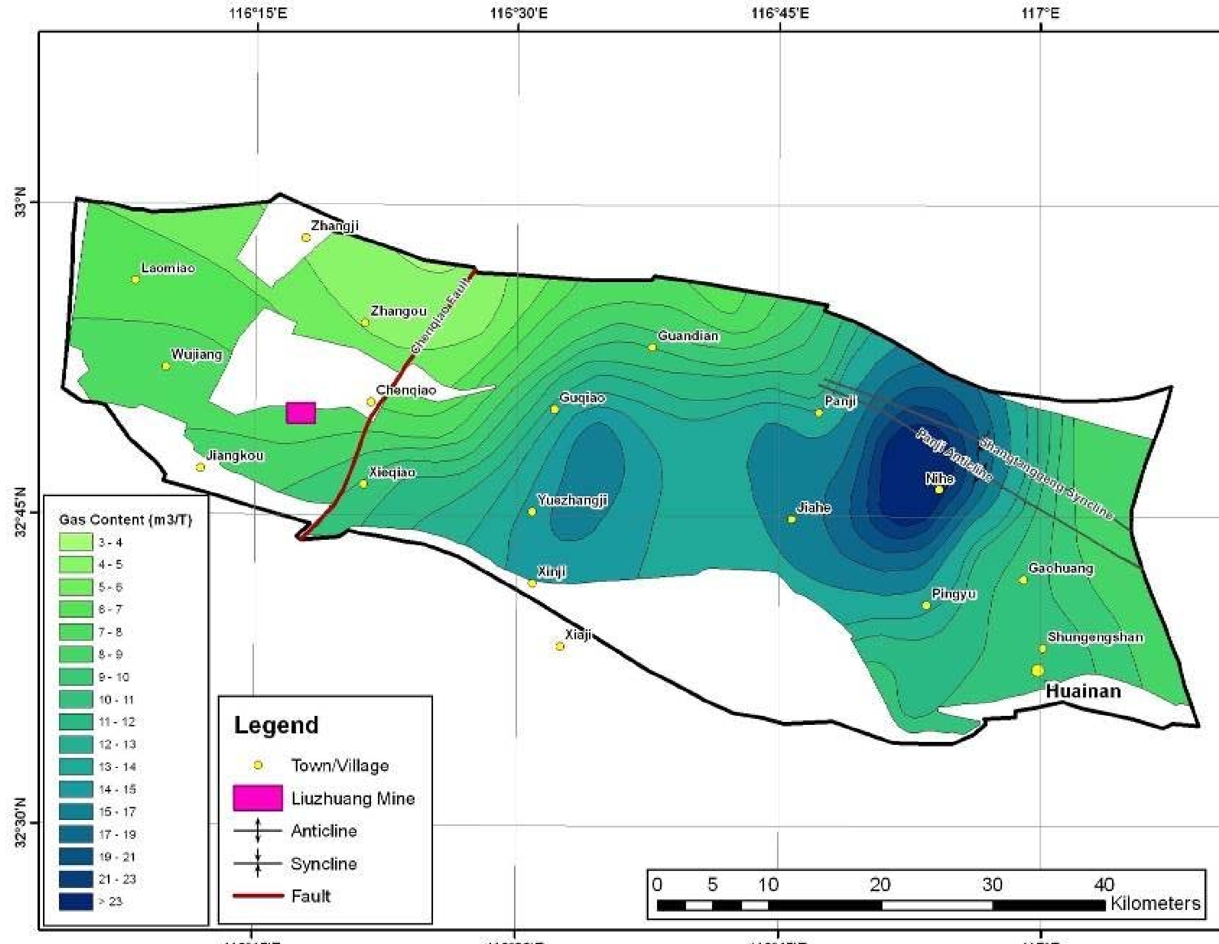


Figure 2-8: Gas Content Distribution in Huainan Coal Field

Gas Origin. Coalbed methane $\delta_{13}C$ values in the Huainan Coalfield generally are less than -55‰, which indicates a biogenic (rather than thermogenic) origin. However, the vitrinite reflectance level (R_o = 0.82%~0.97%) indicates that the coal already has passed through the early biogenic gas stage and already reached the stage of thermogenic methane generation.

Therefore, it is likely that CBM in the Huainan Coal Field is mainly secondary biogenic gas. The Yanshanian orogeny caused uplift, erosion, and degassing of the Permian coal-bearing sequence. Biogenic re-saturation of methane may have occurred after more recent regional subsidence and the deposition of the thick Quaternary overburden, which elevated formation pressure and allowed adsorption of biogenic methane.

Coal Reserves & Resources. The Huainan Coal Field contains proven coal reserves of about 15.3 billion metric tonnes (t). There are a further 10.8 billion t of detailed exploration coal reserves. In addition to these fairly conservative official reserve estimates, high-resolution seismic surveys indicate there is an additional 80 billion t of coal present at depths shallower than 2,000 m, of which 30 billion t is shallower than 1,200 m and 20 billion t is shallower than 1,000 m. This is a large resource base and Huainan is likely to remain a major coal producing area for many decades to come.

Figure 2-9 shows the 29 current and planned coal mining districts that have been developed in the Huainan Coal Field. Liuzhuang mine is located within the relatively newly established Xieqiao mining district (BB on ARI's map), in the western portion of Huainan about 70 km west of Huainan city.

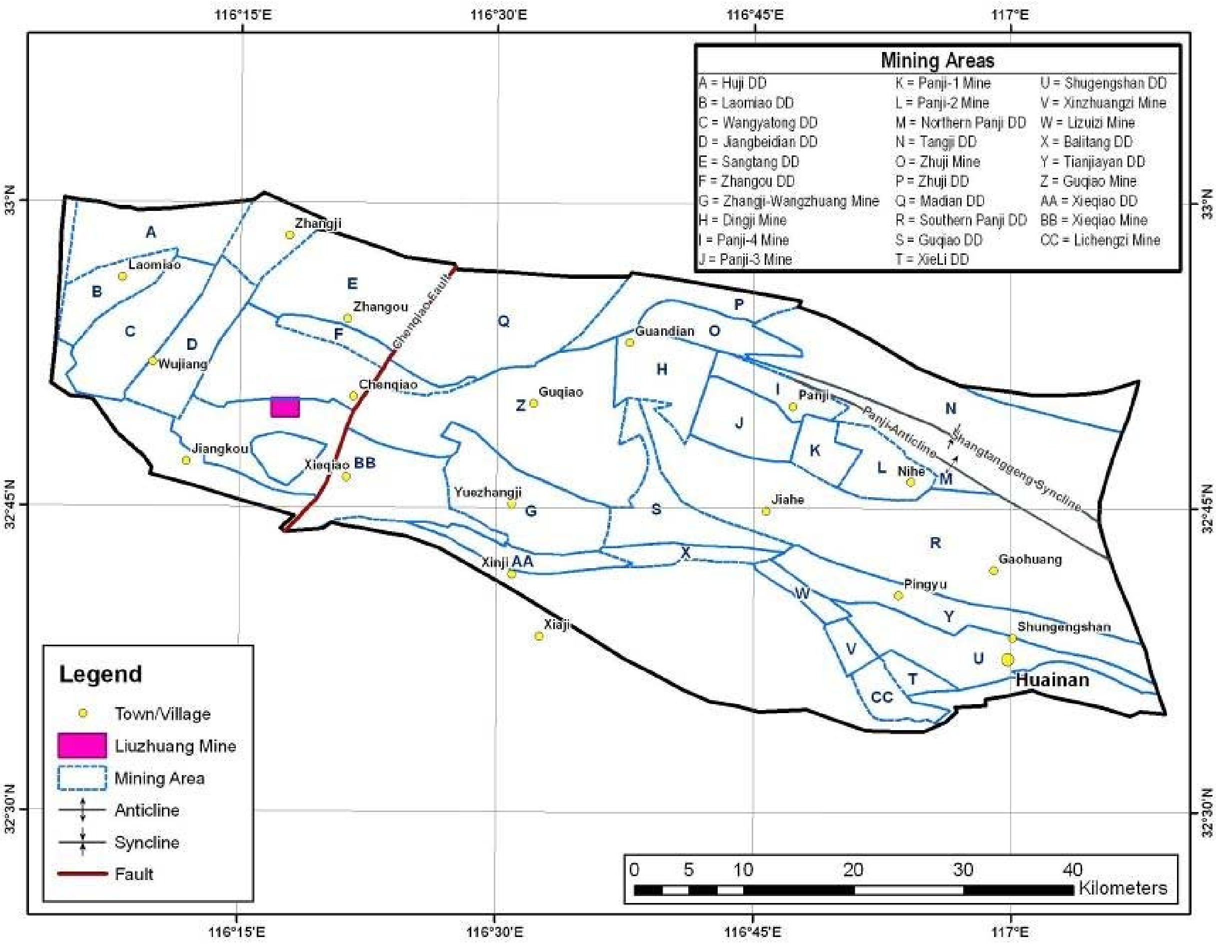


Figure 2-9: Coal Mining Districts in the Huainan Coal Field

The current depth of coal mining at Huainan is mostly in the range of 300 to 700 m. However, mining is expected to deepen in coming decades to 1,000 m and deeper. Given that gas content in the Huainan Coal Field increases significantly below about 700 m, methane emissions are expected to continue rising. Many mines that are not currently experiencing severe drainage challenges, including the Liuzhuang mine, could experience markedly higher gas levels as they target coals deeper than about 700 m.

Coal Mine Methane and Coalbed Methane Resources. In 2003 the Huainan Coal Mining Group estimated coalbed methane resources in the Huainan Coal Field, including the Liuzhuang mine area (Figure 2-10).[4] Based on the distribution of coal thickness and gas content, HCMG estimated the Huainan Coal Field has approximately 593 billion m^3 (20.9 Tcf) of CBM and CMM resources (Table 2-2).

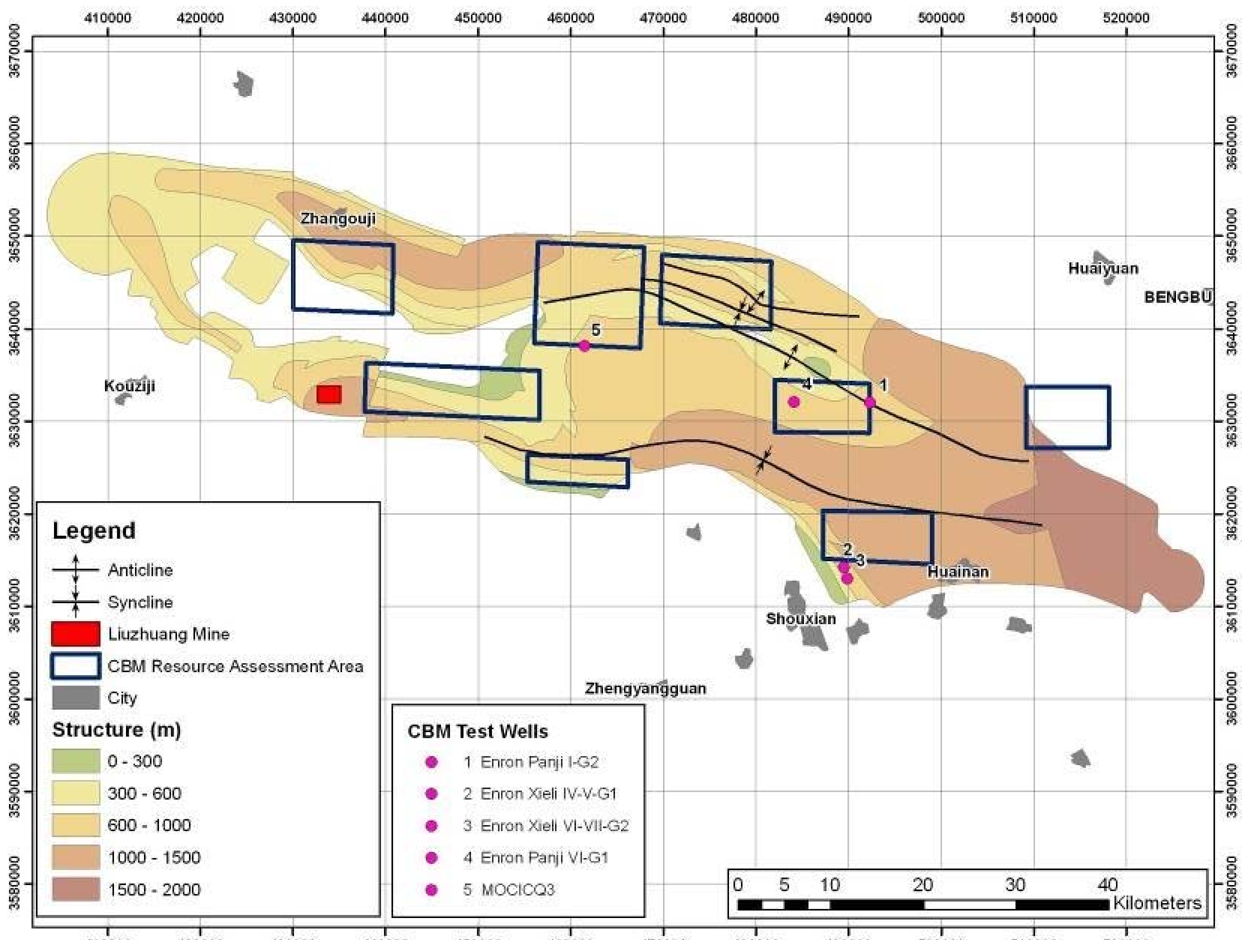


Figure 2-10: CBM Exploration Wells and Resource Estimation Blocks in the Huainan Coal Field

Only about 20% of this resource is at depths of less than 1,000 m, the current extent of the mining in the basin. However, mining is likely to advance into the 1,000-1,500 m depth range in coming

[4] Yuan, Liang and Li, Benyuan, 2003. "CBM Development and Utilization in Huainan Mining Area." Huainan Mining Group, p. 47-55.

decades. Based on this resource estimate, deeper mining could liberate up to ¾ of methane resources in Huainan or approximately 15 Tcf. Liuzhuang mine is located in Block 7 of HCMG's evaluation, one of the larger CBM concentrations in the Huainan Coal Field, with an estimated 123 billion m^3 (4.4 Tcf) of gas in place. Note that this covers only portions of the coal field where data control was adequate, thus total gas resources are likely to be significantly higher.

	Depth Range	CBM Resources	
	(m)	(B m3)	(Tcf)
	<1000	140	4.9
	1000 - 1500	284	10.0
	1500 - 2000	169	6.0
	Total	**593**	**20.9**
Block	**Name**		
1	Xieli	110	3.9
2	Panji/Guqiao	131	4.6
3	Zhangji/Xieqiao	26	0.9
4	Fuqiao/Dingji	47	1.7
5	Paner/Pansi/Zhuji	53	1.9
6	Zhangouzi	56	2.0
7	**Shangyao/Shenjiagang**	**123**	**4.4**
8	Xinji	47	1.7
		593	**20.9**

Table 2-2: 2003 Estimate of CBM/CMM Resources in the Huainan Coal Field
(Source: Huainan Coal Mining Corp.)

A more recent (2009) estimate of CBM and CMM resources in the Huainan Coal Field came up with a 10% larger estimate, or approximately 681 billion m^3 (24.1 Tcf; Table 2-3). This analysis covered a total of 2,120 km^2, representing more than 2/3 of the basin. Liuzhuang mine is located within the Xieqiao mine district (bb on Figure 2-9).

Mapping the CBM/CMM gas-in-place (GIP) distribution reveals trends in gas resource distribution and quality in the Huainan Coal Field (Figure 2-11). GIP concentration reaches an estimated maximum 5.5 x 108 m^3/km^2 in the eastern portion of Huainan Coal Field. This is one of the world's highest CBM/CMM GIP concentrations, reflecting thick, high-rank, and gas-saturated deep coals. Liuzhuang mine has moderate (but still substantial) GIP concentration of 3 to 3.5 x 108 m^3/km^2.

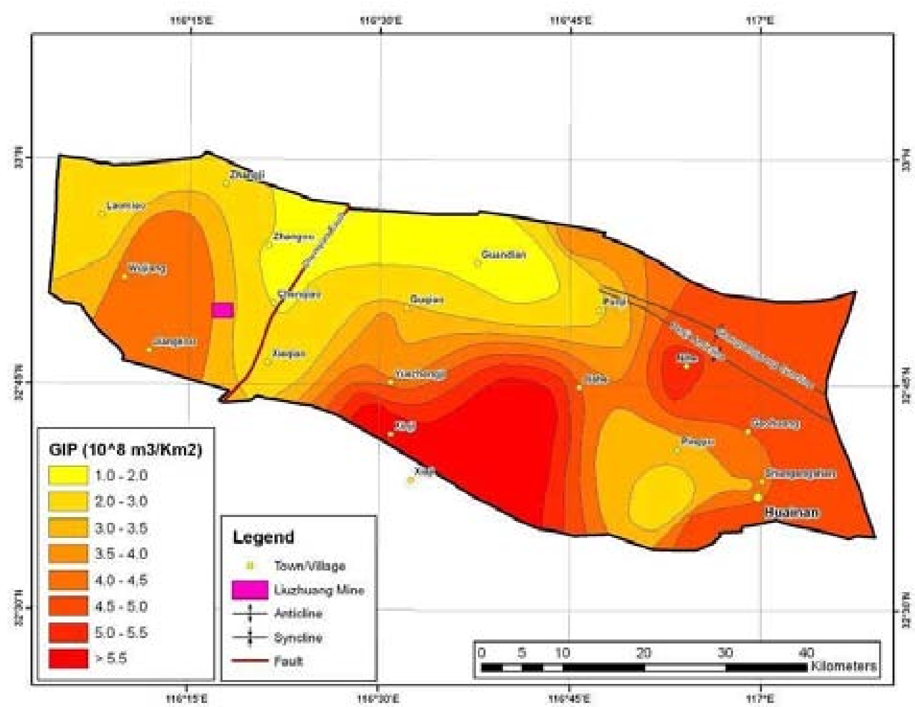


Figure 2-11: Gas-In-Place Distribution in the Huainan Coal Field

Map Label	Coal District	Area (km^2)	Total Coal Thickness (m)	Coal Reserve (10^4 t)	Gas Content (m^3/t)	CBM Resources Total (10^8m^3)	CBM Resources Total (Tcf)	Concentration ($10^8m^3/km^2$)	Concentration (Bcf/mi^2)
a	Huji	76.4	14.3	188,726	5.5	104	0.37	1.36	2.5
b	Laomiao	35.5	31.0	152,785	6.5	99	0.35	2.80	10.9
c	Wangyatong	30.3	24.8	106,798	7.0	75	0.26	2.47	11.2
d	Jiangbeidian	25.8	20.1	270,617	7.0	189	0.67	7.34	39.3
e	Shangtang	133.8	31.3	573,960	5.0	287	1.01	2.14	2.2
f	Zhangou	22.6	26.1	80,230	5.1	41	0.14	1.81	11.1
g	Zhangli Wangzhuang	97.0	33.3	217,977	15.0	327	1.15	3.37	4.8
h	Dingji	61.1	23.1	87,443	11.0	96	0.34	1.57	3.6
i	Panji-4	30.0	29.8	58,812	11.1	65	0.23	2.18	10.0
j	Panji-3	57.0	27.5	96,507	16.0	154	0.55	2.71	6.6
k	Panji-1	42.4	32.2	79,803	17.5	140	0.49	3.29	10.7
l	Panji-2	35.0	25.5	54,042	32.7	177	0.62	5.05	19.9
m	N. Panji	93.1	32.1	40,718	11.4	46	0.16	0.50	0.7
n	Tangji	156.9	32.1	685,860	11.0	754	2.66	4.81	4.2
o	Zhuji	45.0	28.0	79,670	7.0	56	0.20	1.24	3.8
p	Zhuji DD	48.2	27.1	181,975	11.6	211	0.75	4.38	12.5
q	Madian	141.3	24.6	475,107	4.8	228	0.81	1.61	1.6
r	S.Panji	288.1	30.1	1,179,800	12.5	1,475	5.21	5.12	2.5
s	Guqiao	85.0	27.5	322,297	13.0	419	1.48	4.93	8.0
t	Xieli	9.8	31.6	29,151	10.8	31	0.11	3.21	45.2
u	Shungengshan	116.9	27.4	448,954	10.0	449	1.59	3.84	4.5
v	Xinzhuangzi	12.8	29.0	34,987	10.8	38	0.13	2.95	31.8
v	Xiejiaji	17.5	29.0	13,051	11.2	15	0.05	0.84	6.6
w	Lizuizi	4.8	28.7	11,503	14.0	16	0.06	3.36	96.4
x	Balitang	4.3	28.6	19,959	14.5	29	0.10	6.73	215.9
y	Tianjiayan	57.6	27.4	221,157	11.0	243	0.86	4.22	10.1
z	Guqiao	93.0	26.6	223,439	16.0	358	1.26	3.84	5.7
aa	Xieqiao DD	18.4	31.2	80,225	8.2	66	0.23	3.58	26.8
bb	Xieqiao	220.0	31.2	339,627	11.1	377	1.33	1.71	1.1
bb	Xieqiao Deep	36.0	27.7	74,389	11.1	83	0.29	2.29	8.8
bb	Xieqiao Thrust	18.4	28.5	80,225	14.0	112	0.40	6.10	45.8
cc	Lichengzi	6.4	28.0	48,810	10.8	53	0.19	8.24	177.5
	Total *(Average)*	**2,120**		**6,558,604**		**6,813**	**24.1**	***3.2***	***29.0***

Table 2-3: 2009 Estimate of CBM/CMM Resources in the Huainan Coal Field

2.3 Liuzhuang Mine Geology and Resource Assessment

2.3.1 Mine Area Description

Topography and Logistics. Liuzhuang mine and the Huainan Coal Field are located at the southern end of the North China plain (Figures 1-1, 1-2, and 2-1). Positioned within the flood plain of the Huaihe River, which drains eastward out of central Anhui emptying eventually into the Yangtze River basin, the Liuzhuang mine is characterized by distinctly flat surface topography. (Again, this contrasts with the extremely rugged topography typically found in China's Qinshui and Ordos basins.) The average surface elevation at Liuzhuang is about 30 m above sea level, with very little topographic relief (+/- 5 m).

Transportation is well developed. A modern 4-lane divided provincial highway links the Liuzhuang mine area with the regional city of Huainan (population 1 million), about 1.5 hours drive by car. The nearest airport is at Hefei, the capital of Anhui Province, which is about 2 hours drive and provides connections to major cities inside China. Liuzhuang mine is located on the north bank of the Huaihe River, which only rarely floods and isolates the mine from Huainan (time scale of about once per decade).

2.3.2 Liuzhuang Mine Geology

Introduction. Measuring 3.5 to 8 km north-south by about 16 km east-west, the mine covers an area of approximately 90 km^2. Originally designed to produce 3 million t/year, the Liuzhuang mine is being expanded to 7.85 million t/year capacity.

Structure. Liuzhuang mine is situated on a south-dipping monoclinal flank in the Xieqiao mining district of western Huainan Coal Field. ARI used GIS computer mapping to convert the mine's detailed structure maps into depth maps (by adding surface elevation of about 30 m). These maps show that the Liuzhuang mine has fairly simple geologic structure, with only a few minor normal faults cutting the coal section.

For the initial 2007-2009 mining programs, Seam 13-1 was developed and mined at depths ranging from 500 to 770 m below surface (Figure 2-12), while Seam 11-2 was mined over depths of 500 to 840 m (Figure 2-13). The maps clearly show the fairly steep dip angle, consistently about 30° due south (although mine documents often quote a gentler dip of only 12-15°). The maps also show the six key corehole data points which constrain coal seam thickness, quality, and depth.

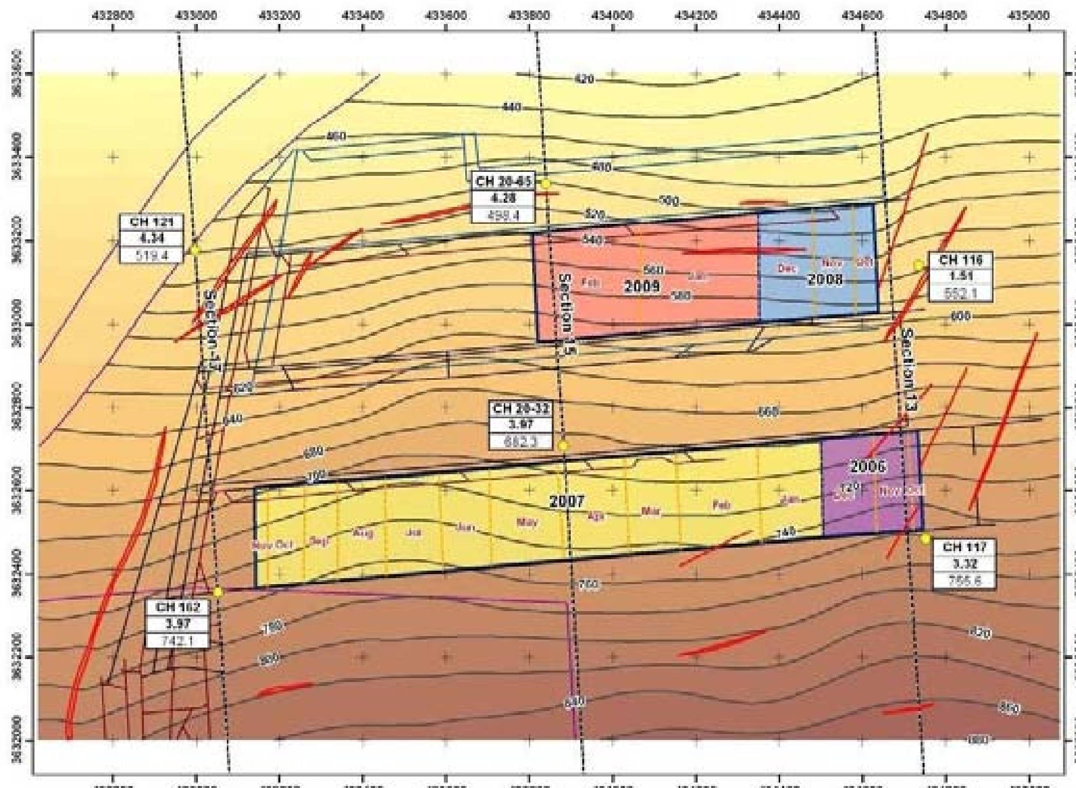


Figure 2-12: Structure and Depth to Seam 13-1 at Liuzhuang mine

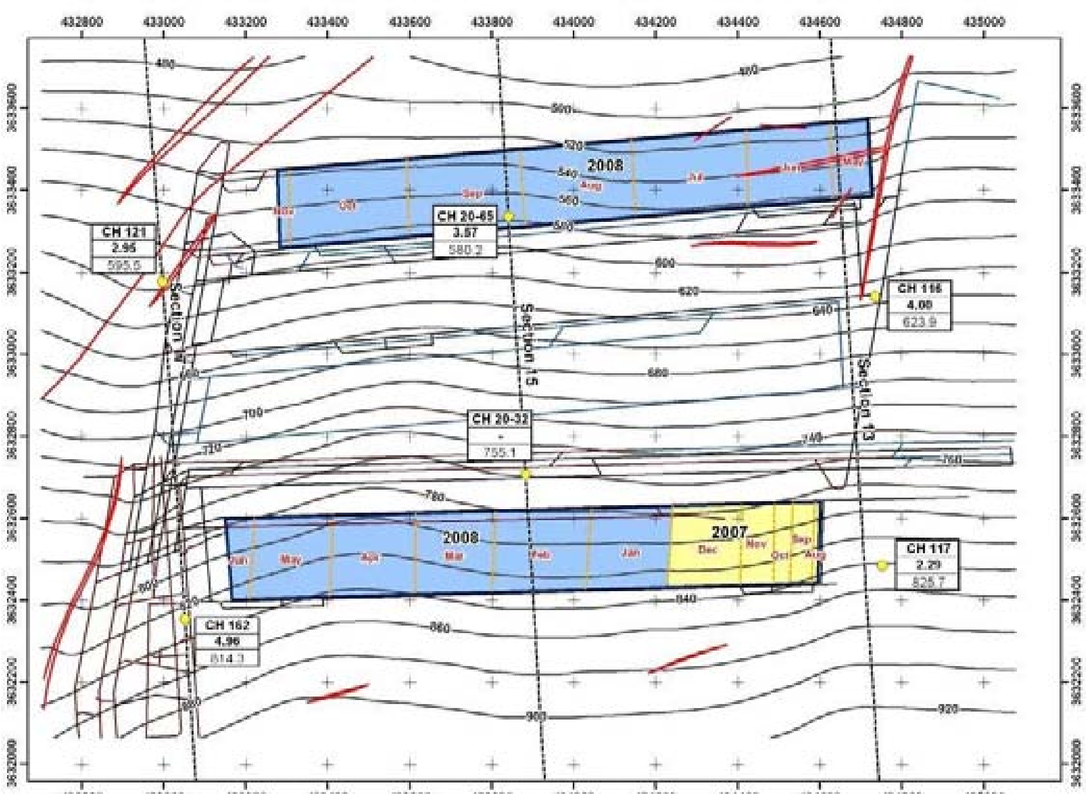


Figure 2-13: Structure and Depth to Seam 2-11 at Liuzhuang Mine

The mine boundaries are defined primarily by large faults. These include the F5 fault on the east side, beyond which lies the separate Xieqiao mine. The F12 fault defines the western boundary, bordering the Kouzi exploration area. The southern boundary is defined by the F1 fault as well as the -1000 m structural level for Seam 17-1. The northern boundary is defined by the erosional subcrop of Seam 1 and the large adjacent area that is barren of coal.

A north-south cross-section through the central portion of Liuzhuang mine shows the complex regional structure (Section No. 15; Figure 2-14; the location of which is shown by the dotted black line on Figure 2-12 and Figure 2-13). However, the Liuzhuang mine is positioned in between major faults and has locally simple structure (which of course was the principal reason for locating the mine here). The dip angle indicates that gas content and CMM drainage requirements are likely to increase significantly as the mining level deepens.

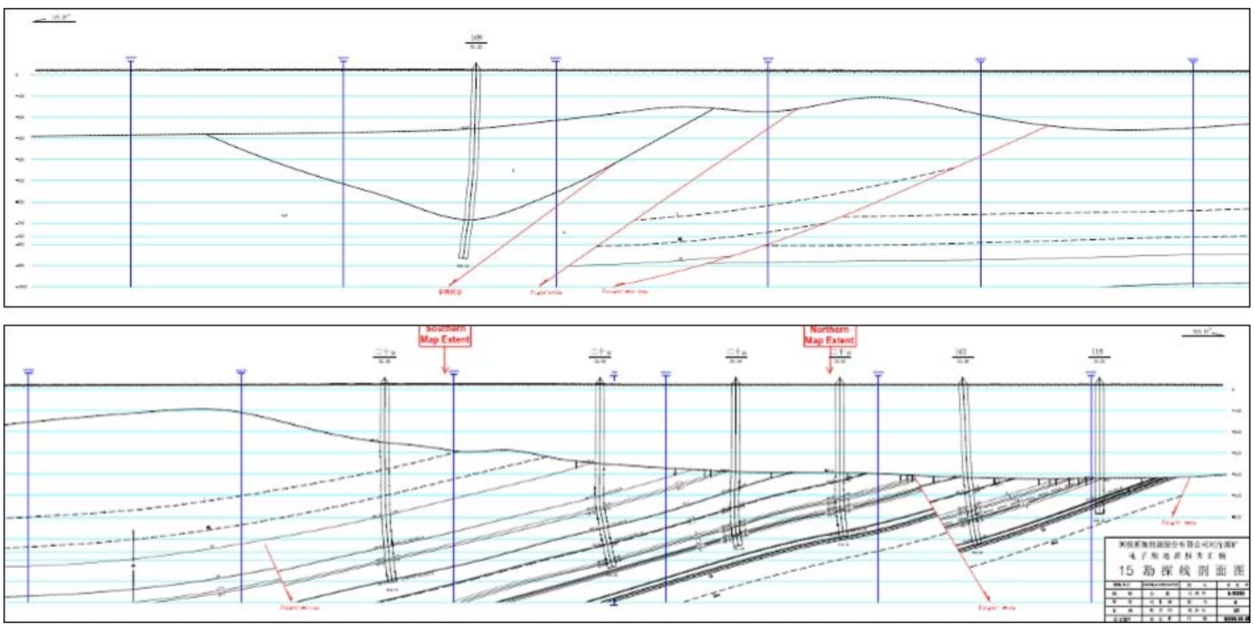


Figure 2-14: Structural Cross-Section 15
(Orientated N-S through the central portion of the Liuzhuang Mine)

As can be clearly seen on the expanded cross-section Figure 2-15, the coal sequence has been truncated by an angular unconformity, which was formed by regional uplift and erosion of a portion of the Paleozoic section during a later Mesozoic orogeny. Coal seams at Liuzhuang mine undoubtedly were degassed by this past uplift and erosional event. Following subsequent regional subsidence, the unconformity and underlying coal seams were buried by a 300-400 m thick deposit of unconsolidated Quaternary alluvium. The additional overburden boosted reservoir pressure in the Paleozoic section, allowing gas (probably biogenic) to partially resaturate the coal seams. This erosional event and later reburial had a major impact on the gas content and saturation distribution in the Huainan Coal Field in general and Liuzhuang mine in particular.

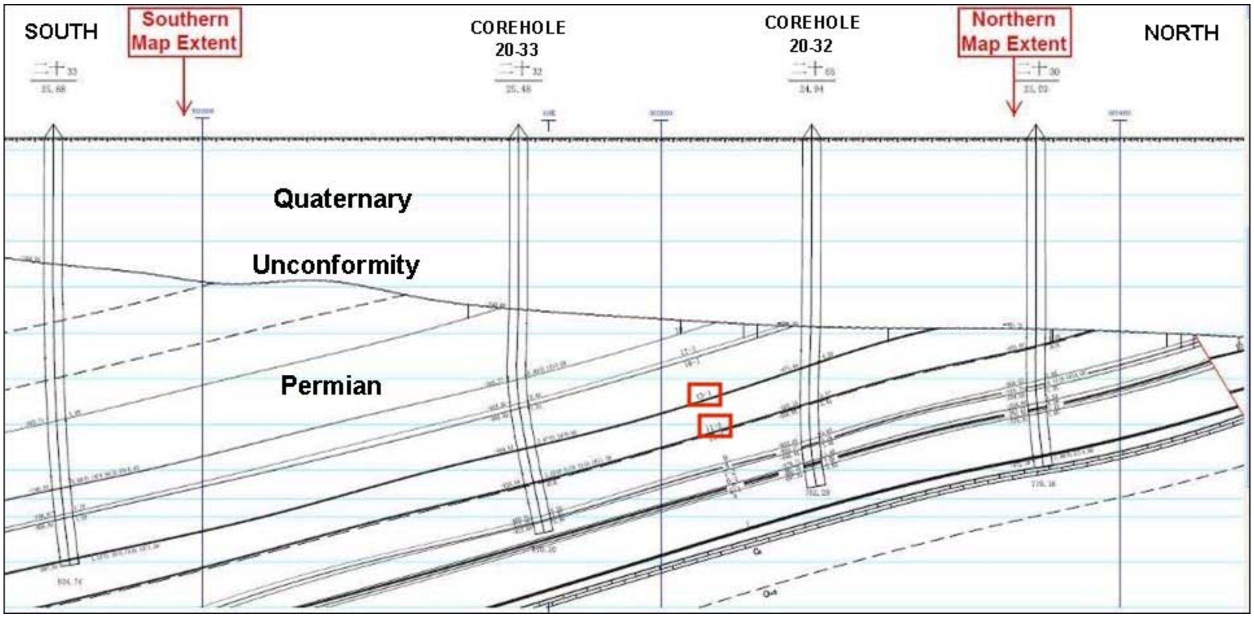


Figure 2-15: Expanded Section of N-S Cross-Section across Liuzhuang mine

Stratigraphy. Huainan Coal Field has a thick Paleozoic sequence of coal seams and interbedded clastic rocks (**Figure 2-16)**. Approximately 20 individual coal seams occur in the Permian Upper and Lower Shihezi Formations, while the Lower Permian Shanxi Formation also contains several coal seams. The principle mining targets at Liuzhuang mine are Seams 13-1 and 11-2, which average 4.87 and 2.82 m thick, respectively. The underlying Carboniferous Taiyuan Formation is barren of coal in this part of China.

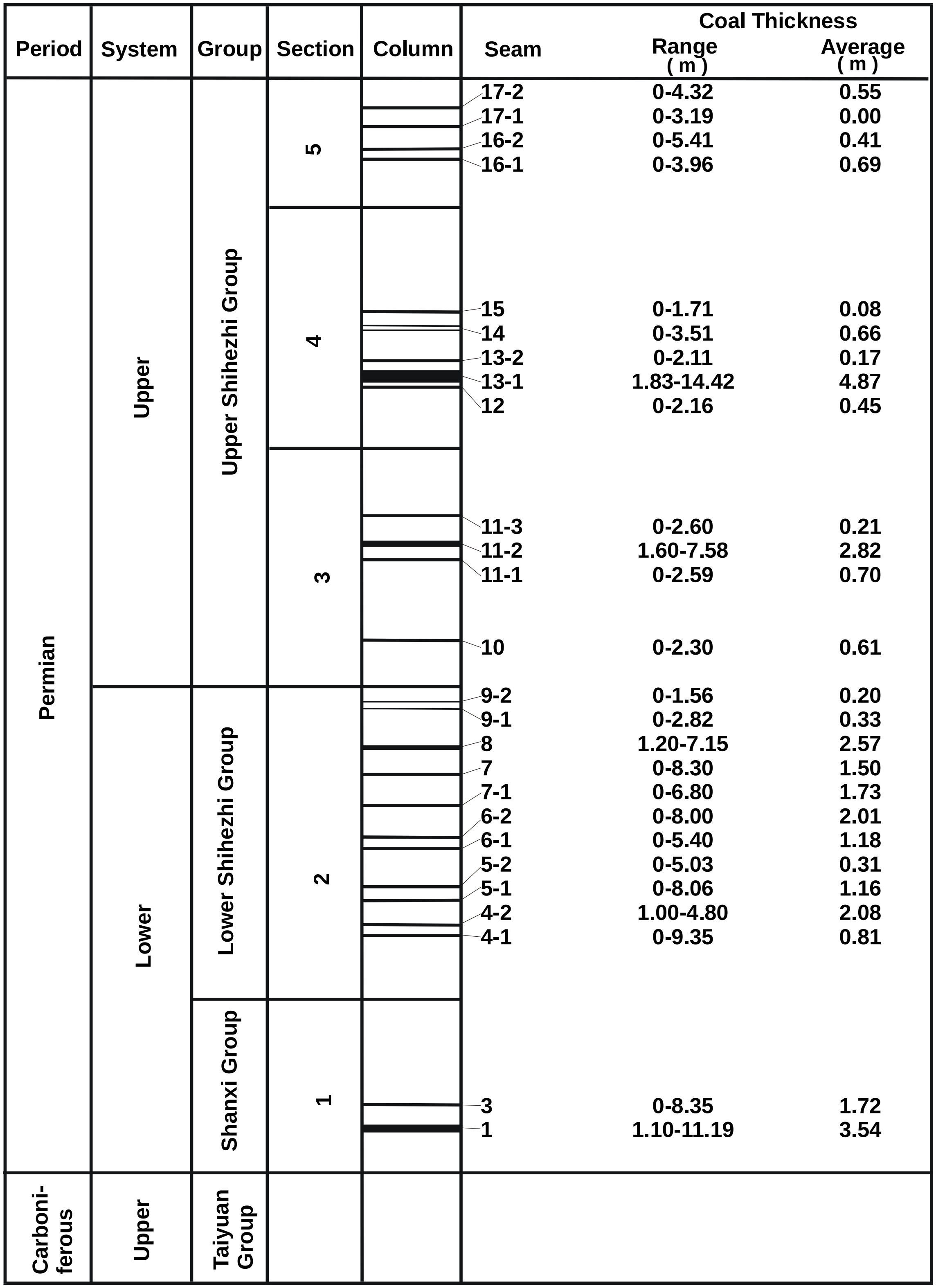


Figure 2-16: Stratigraphic Column showing Coal Seam Distribution in the Liuzhuang Coal Field

The stratigraphic formations at Liuzhuang mine, in order from oldest to youngest, comprise the following units:

- **Lower Ordovician** (250 m) : This high-permeability, karstic carbonate deposit lies below the coal-bearing sequence. A major regional aquifer, it is necessary to avoid drilling into this unit due to the risk of lost circulation and hole problems.
- **Upper Carboniferous Taiyuan Formation** (120 m) : Although a major coal-bearing unit in northern China, in the central China region this formation is entirely barren of coal seams. It consists mainly of carbonates interbedded with fine sandstone, siltstone, and mudstone.
- **Permian Shanxi Formation** (125 m) : Approximately seven coal seams occur in this unit, comprising about 4.5% of the formation. The depositional environment was primarily marine.
- **Permian Lower Shihezi Formation** (109 m) : One of the most important coal-bearing units at Liuzhuang, this formation was deposited in a deltaic-fluvial system. It contains ten coal seams, of which five are considered mineable. Seams 5 and 8 are laterally persistent and mineable, which Seams 4, 6-1, 7-1, and 9 are mineable in places; the remaining seams are not considered mineable. The bottom of this formation consists of grey-white medium-coarse or medium-fine sandstone. Overlying this is a distinctive aluminum-rich mudstone, grading into fine-grained sandstone and siltstone. The top of the formation is mainly grey mudstone.
- **Permian Upper Shihezi Formation** (535 m) : This commercially most important and relatively thick regressive unit was deposited in fluvial-lacustrine environments. It is divided into seven stratigraphic sub-units, of which five are coal-bearing. Seams 13-1, 11-1, and 11-2 are mineable in all locations, while Seams 16-1, 17-1, and 18-1 occasionally are thick enough to mine. Ash content is unusually high in the uppermost seams. Other seams in this unit are not considered mineable.
- **Permian Shiqianfeng Formation** (535 m) : This continental sequence of mostly sandstones, siltstones, and shales does not have commercially significant coal deposits.

The detailed stratigraphy of Seam 13-1 and adjoining roof and floor rocks at Liuzhuang mine is illustrated in Figure 2-17. Coal exploration corehole log No. 30-32 recorded the depth, thickness, and lithology of the coal section. Seam 13-1 is 4.02 m thick (net) and about 682 m deep here. The coal is bright and mostly blocky, along with some powdery coal. The roof rock consists of nearly 8 m of firm, grey mudstone to silty mudstone, overlain by 9 m of grey-white fine sandstone, which grades into another 7 m of siltstone. Underlying Seam 13-1 is about 5 m of fragile grey siltstone.

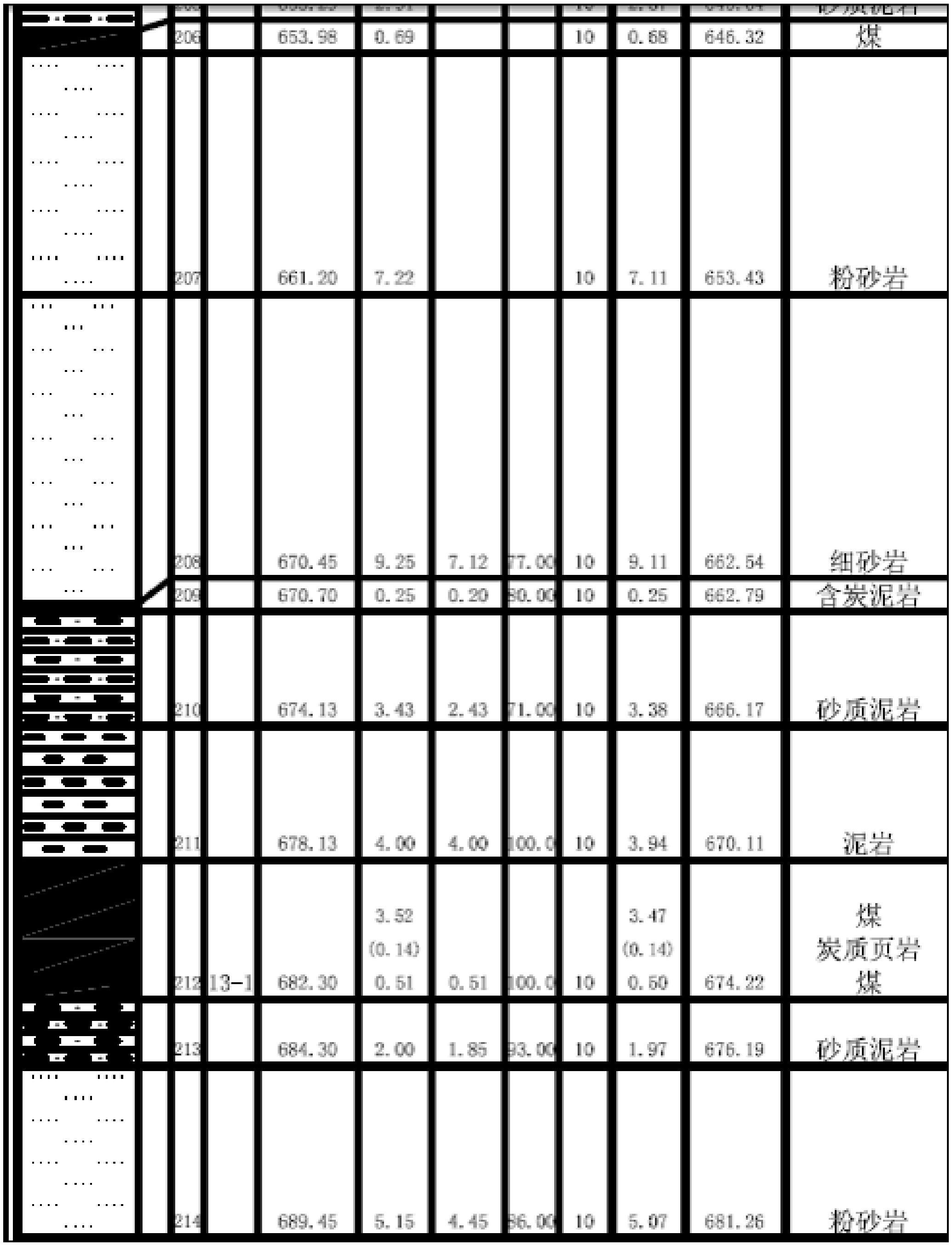
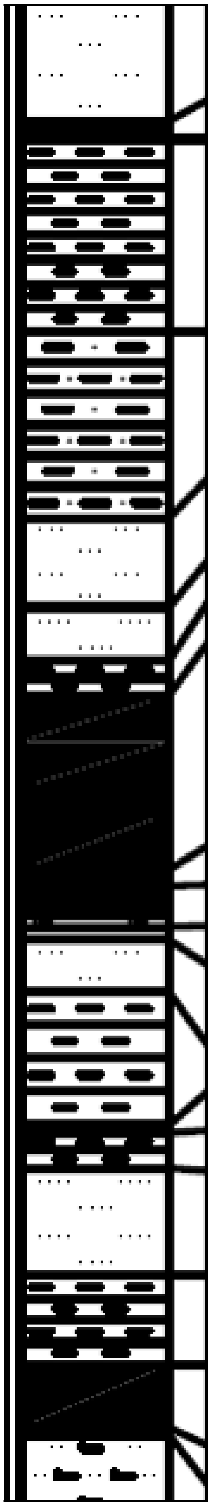


Figure 2-17: Coal Corehole Log 30-32 (Depth Interval 654-689m)

Seam 11-2's detailed stratigraphy is shown in Figure 2-18. Coal corehole log 30-32 records a thickness of 1.38 m (net) and depth of about 760 m for this mineable coal seam. Seam 11-2 is mainly powder coal with some blocky coal, indicating that it probably would be even more challenging to drill in-seam than Seam 13-1. The roof rock consists of about a 4-m thick coarsening-upward sequence of mudstone, siltstone, and fine sandstone, which is overlain by 9 m of sandy mudstone to pure mudstone. Underlying Seam 13-1 is about 1 m of fine sandstone, 3 m of mudstone, and then further thin interbeds of coal, mudstone, and siltstone.



235		741.80	2.95	1.10	37.00	10	2.91	732.78	细砂岩
236		742.25	0.45			10	0.44	733.22	炭质页岩
237		746.95	4.70	4.70	100.0	10	4.63	737.86	泥岩
238		751.50	4.55	4.31	95.00	10	4.48	742.33	砂质泥岩
239		753.70	2.20	2.10	95.00	10	2.17	744.50	细砂岩
240		755.00	1.30	1.00	77.00	10	1.28	745.78	粉砂岩
241		755.85	0.85	0.45	53.00	10	0.84	746.62	泥岩
242	11-2	760.10	2.25 (0.21) 0.21 (0.20) 1.38	1.38	100.0	10	2.22 (0.21) 0.21 (0.20) 1.36	750.82	煤 炭质页岩 煤 炭质页岩 煤
243		760.50	0.40	0.40	100.0	10	0.39	751.21	含炭泥岩
244	11-1	761.50	1.00	0.95	95.00	10	0.98	752.19	炭质页岩
245		761.83	0.33	0.25	76.00	10	0.32	752.51	泥岩
246		763.10	1.27	0.85	67.00	10	1.25	753.76	细砂岩
247		766.35	3.25	3.25	100.0	10	3.20	756.96	泥岩
248		766.55	0.20	0.20	100.0	10	0.20	757.16	煤
249		767.40	0.85	0.85	100.0	10	0.84	758.00	泥岩
250		770.05	2.65	2.65	100.0	10	2.61	760.61	粉砂岩
251		772.21	2.16	2.16	100.0	10	2.13	762.74	泥岩
252		773.75	1.54	1.54	100.0	10	1.52	764.26	煤
253		773.93	0.18	0.12	67.00	10	0.18	764.44	泥岩

Figure 2-18: Coal Corehole Log 30-32 (Depth Interval 741-774m)

2.3.3 Liuzhuang Mine Coal Properties

Proximate Analyses. Industrial (proximate) analyses of Seams 13-1 and 11-2 indicate moderate moisture content (1.94% and 2.31%, respectively) and ash content (20.04% and 20.80%, respectively). Volatile matter contents of 42.11% and 36.53%, respectively, are consistent with high-volatile A bituminous rank (Table 2-4).

Area	Coal Seams	Industrial Analysis				Density (g/cm³)	Heat Value (MJ/Kg)
		Moisture (%)	Ash (%)	Volatile Matter Vdaf (%)	Fixed Carbon (%)		
Xieli	13-1	1.58	20.18	29.04	49.20	1.43	28.37
	11-2	1.28	23.40	24.55	50.77	1.44	26.98
	8	1.13	22.39	23.36	53.12	1.40	27.36
	6	0.93	21.58	23.09	54.40	1.44	27.44
	4	1.19	21.16	21.49	56.16	1.45	28.13
	1	0.56	15.73	22.82	60.89	1.45	30.72
Panji	13-1	1.83	22.08	39.66	36.43	1.42	26.16
	11-2	1.68	22.51	35.86	39.95	1.42	25.78
	8	1.76	23.70	35.16	39.38	1.41	26.51
	6	2.01	24.30	35.71	37.98	1.44	25.14
	4	1.75	19.83	34.04	44.38	1.41	26.92
	1	1.61	15.76	28.49	54.14	1.44	28.60
Guqiao	13-1	1.50	19.10	41.65	37.75	1.41	27.67
	11-2	1.78	21.44	36.64	40.14	1.40	26.47
	8	1.71	21.15	36.66	40.48	1.41	26.47
	6	1.58	20.43	38.20	39.79	1.37	27.02
	4	1.74	27.57	35.73	34.96	1.38	24.07
	1	1.39	15.41	36.66	46.54	1.35	29.06
Liuzhuang	13-1	1.94	20.04	42.11	35.91	1.37	27.10
	11-2	2.31	20.80	36.53	40.36	1.41	26.64
	8	1.94	19.67	37.41	40.98	1.39	27.16
	6	2.18	17.82	37.56	42.44	1.37	27.80
	4	1.99	22.04	35.92	40.05	1.40	26.30
	1	1.96	16.16	37.31	44.57	1.35	28.66

Table 2-4: Industrial (proximate) analyses of Seams 13-1 and 11-2 at Liuzhuang mine

Gas Content & Saturation. Based on regional surface corehole data, ARI estimates that actual gas content at a depth of 700 m in Liuzhuang mine is about 7 m^3/t (dry, ash-free basis). This is higher than suggested by low-precision short cores retrieved from in the mine by horizontal boreholes. No sorption isotherms are available for the mine itself, but regional isotherms indicate that the coal is only about ¾ gas saturated.

Permeability. No in-situ well tests have been performed from surface wells at Liuzhuang mine to measure permeability. In-mine tests using horizontal boreholes, which are highly imprecise due to stress changes induced by the mine itself, indicate low permeability. Based on regional surface well testing in the Huainan Coal Field, ARI estimates that absolute coal seam permeability at Liuzhuang mine is quite low (<0.1 mD). Permeability is probably even lower in the powder coals (<0.01 mD).

2.3.4 Liuzhuang Mine Coal and CMM Reserves

SDIC-Xinji has estimated coal and CMM reserves at Liuzhuang mine based on computer GIS analysis of geologic data (Table 2-5). Although the ARI Team did not have access to the detailed raw data set, we have reviewed SDIC's calculations and determined that they are reasonable. SDIC's estimates are based on only six coal exploration coreholes, which were drilled to measure coal seam depth and thickness ahead of mine development. This original corehole data has been updated with the mining experience to date.

Coal Seam	Coal reserves (million t)	Methane content (m^3/t)	Methane resources (million m^3)	Degassing efficiency (%)	Drained gas (million m^3)	Net Coal Thickness (m)	Main or Secondary Target
17-1	27.69	3.5	97	20	19	0.43	secondary
16-1	64.14	3.5	224	20	45	1.53	secondary
13-1	266.06	4.0	1,064	30	319	4.55	Main
11-2	226.06	4.0	904	30	271	3.90	Main
11-1	14.94	3.5	52	20	10	0.48	secondary
9	26.63	3.5	93	40	37	0.93	secondary
8	179.86	3.5	630	40	252	3.29	Main
7-1	27.17	3.5	95	40	38	1.50	secondary
6-1	81.82	3.5	286	40	115	1.51	secondary
5-1	324.7	4.0	1,299	40	520	1.95	Main
4	29.29	4.0	117	40	47	0.84	secondary
1	84.48	3.0	338	40	135		Main
TOTAL	**1,353**		**5,200**	**35%**	**1,809**		

Table 2-5: Estimated Coal and CMM Reserves at Liuzhuang mine
(Source: SDIC-Xinji)

Liuzhuang mine has an estimated 1.35 billion t of total proved coal reserves. Seams 13-1, 11-2, and 8 account for half of this total. Nine thinner seams, which are not yet being mined, comprise the remaining half. Coal mine methane resources, often mislabeled as "reserves" in China but actually representing in-place CMM gas-in-place resources, are estimated to be 5.2 billion m^3 (184 Bcf). Recoverable CMM reserves (true reserves in the Western definition) are estimated at approximately 1.8 billion m^3 (64 Bcf), representing about 35% of gas in place in the panels and roadways.

Because they were based on only six coreholes, there is some uncertainty in the reserve estimates, probably on the order of 10% for coal reserves and 20-30% for CMM reserves. In addition, the CMM reserve estimate is based on currently applied coal mining and CMM drainage technologies. CMM reserves could be further increased with improved drainage technologies. Overall, coal and CMM reserves appear to be adequate to support a large-scale CMM capture and utilization project at Liuzhuang mine.

SECTION 3

CMM Market Assessment

SECTION 3 CONTENTS

SECTION 3 FIGURES

SECTION 3 TABLES

3.1 Introduction

China is one of the largest and fastest growing energy users. The latest BP Statistical Review of World Energy ranks China as the second largest primary energy consumer, behind only the United States (based on traded energy only).[1] China's primary energy production grew rapidly over the past decade, to nearly 2.4 billion t of standard coal equivalent (SCE; Figure 3-1).

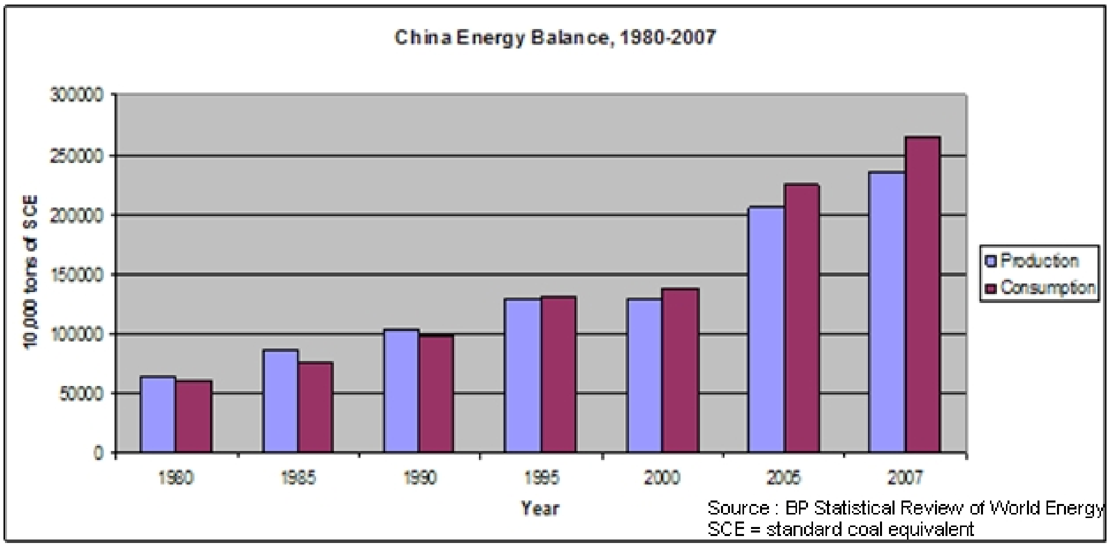


Figure 3-1: China Energy Balance, 1980-2007

China's overall energy production growth averaged 7% per year during 1995-2007, accelerating to 12% annually during the economic boom years of 2000-2007. However, China's energy consumption grew even faster than its production during these periods, by 9% and 13%, respectively. China's energy production shortfall has been offset largely by imports of coal, petroleum and liquid natural gas (LNG).

Fuel	Rank	Mtoe
Coal	1	1,406
Hydro Electric	1	132
Oil	2	376
Natural Gas	8	73
Nuclear Energy	9	15
Total	**2**	**2,003**

Table 3-1: China Primary Consumption by Fuel
Source: BP Statistical Review of World Energy
Mtoe = Million tonnes of oil equivalent

China still depends heavily on coal to satisfy its primary energy needs. Natural gas accounted for only about 3.5% of total energy requirements in 2007 (Table 3-1). China's overall energy consumption, and particularly for coal, has been driven primarily by industrial sector demand growth. For example, in 2007 approximately 51% of the energy from coal was consumed in the production and supply of electric power and heat power, while the

[1] BP, 2009. "Statistical Review of World Energy." June, 48 p.

manufacturing sector consumed about 36%. However, future growth in energy consumption increasingly is likely to come from growing consumer demand for automobiles, air conditioning, residential natural gas, and electricity.

China's government has promulgated policies promoting the production and use of its more environmentally benign natural gas resources. Starting from a very low base production level in 1995, China's natural gas production nearly quadrupled by 2007, much faster than the 82% growth in coal production over the same time period. Several large inter-provincial and numerous smaller provincial natural gas pipelines have been constructed during the past 10 years, notably the West-to-East pipeline from Qinghai to Shanghai. Despite this rapid growth, the natural gas pipeline system in China remains relatively undeveloped, presenting a continued challenge for natural gas resource development.

With an extensive mostly underground coal mining industry and numerous high-methane coal mines, China leads the world both in coal production (2 billion t in 2007)[2] and coal mine methane emissions (Figure 3-2**)**.[3] China is expected to continue to rely heavily on coal in future decades. As China's coal production increases and its coal mines extend to deeper levels below the surface, CMM emissions are expected to continue to increase significantly, to approximately 150 million t of CO2 equivalents (MtCO2eq) in 2010 and nearly 200 MtCO2eq by 2020.

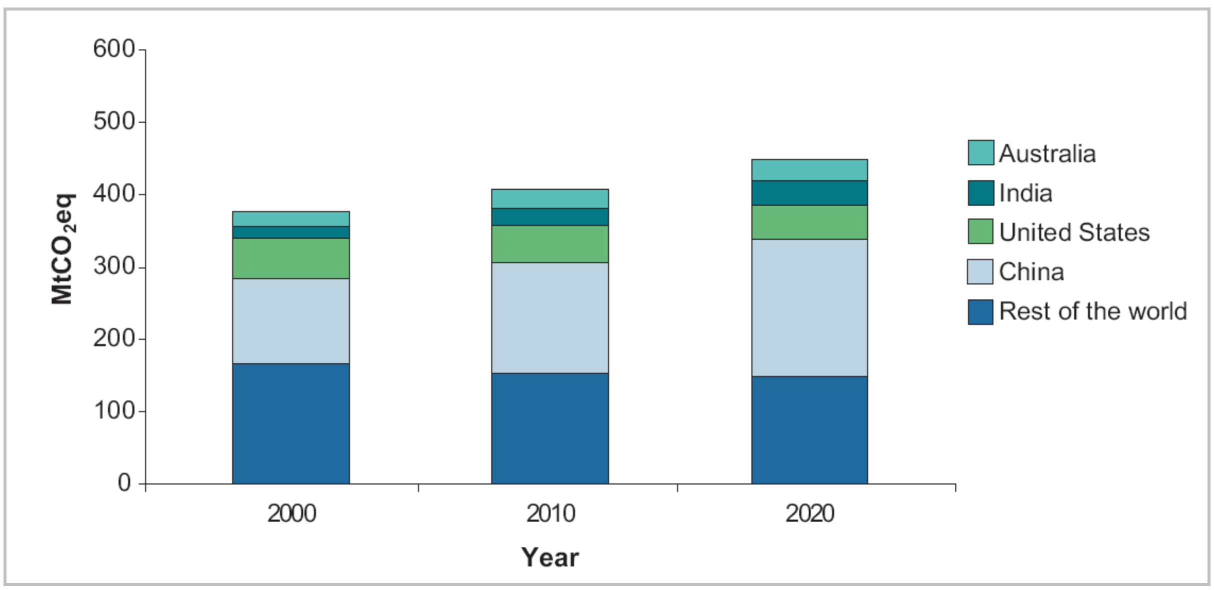


Figure 3-2: CH_4 Emissions from Coal Mining, by Country: 2000-2020
(Source: USEPA, 2006)

[2] U.S. Department of Energy, Energy Information Administration, 2009.
[3] U.S. Environmental Production Agency, 2006. "Global Mitigation of Non-CO_2 Greenhouse Gases. EPA 430-R-06-005, Section II – Energy, 46 p.

Most of the CMM liberated by coal mining in China is still vented to the atmosphere. Considering China's growing energy demands, this vented CMM represents a large, under-utilized energy resource. Some coal mines in China, such as Sihe mine in Shanxi Province, are adopting world-class CMM drainage and utilization technology. However, extensive opportunities still exist at many mines for improving the technical performance of CMM drainage and utilization, as well as resolving CMM market challenges. All levels of China's government (central, provincial, and local) have recognized the benefits of improved mine safety, resource conservation, environmental protection, and energy security.

Section 3 presents an assessment of the market for the CMM produced by a potential Liuzhuang mine drainage improvement and CMM utilization project. The specific technology options for CMM utilization that are available are discussed in detail in Section 5. Briefly, these options range from direct sale to urban or industrial users via pipeline; transport in CNG or LNG tanker trucks to urban or industrial users; sale as a transport fuel; or conversion to electrical power at the mine site. The selection of the optimal end-use for the CMM is heavily dependent on the demand and pricing for gas itself (and its potential converted products, such as electrical power) at Liuzhuang mine and in surrounding areas, which is the focus of this chapter.

3.2 Natural Gas Pipeline and Transport Routes

Despite rapid growth in recent years, China's natural gas transportation system still is in the early stages of development. The first Ordos (Shaanxi)-to-Beijing gas pipeline was completed in 1997, while a second Ordos-Beijing Pipeline, largely along the same route, was completed in 2005 with a capacity of 12 billion m^3/year. During the runup to the 2008 Olympics, the government accelerated fuel diversification from coal to natural gas to reduce air pollution in the Beijing area.

More recent major natural gas infrastructure projects in China include the 4,000-km long West-to-East Pipeline, which has an annual natural gas transportation capacity of 17 billion m^3/year. Construction of the second 4,843-km long West-to-East Pipeline project, with annual capacity of 30 billion m^3/year sourced from Turkmenistan, was initiated in February 2008. The western portion of this pipeline was recently completed, while its eastern portion is scheduled to be finished by 2012. By the end of 2008, the total length of the national pipeline network in China had reached 31,000 km.

Located about 70 km west of the medium-sized provincial city of Huainan (population approximately 1 million), Liuzhuang mine is administered and regulated under Yingshang County, Anhui Province. However, Liuzhuang is quite far from existing or planned natural gas pipelines and thus fairly isolated from the developing regional gas market.

Several large gas pipelines are now in place and being operated, including a few located within about 100 km of Liuzhuang mine (Figure 3-3). The CMM produced at Liuzhuang is low pressure and low concentration, thus not at all suitable for sale via these inter-province pipelines, which are operated at extremely high pressure and require high-purity and dry methane. Nevertheless, these regional pipeline systems are relevant because they indirectly compete with Liuzhuang CMM and also play the largest role in establishing natural gas sales prices in the region.

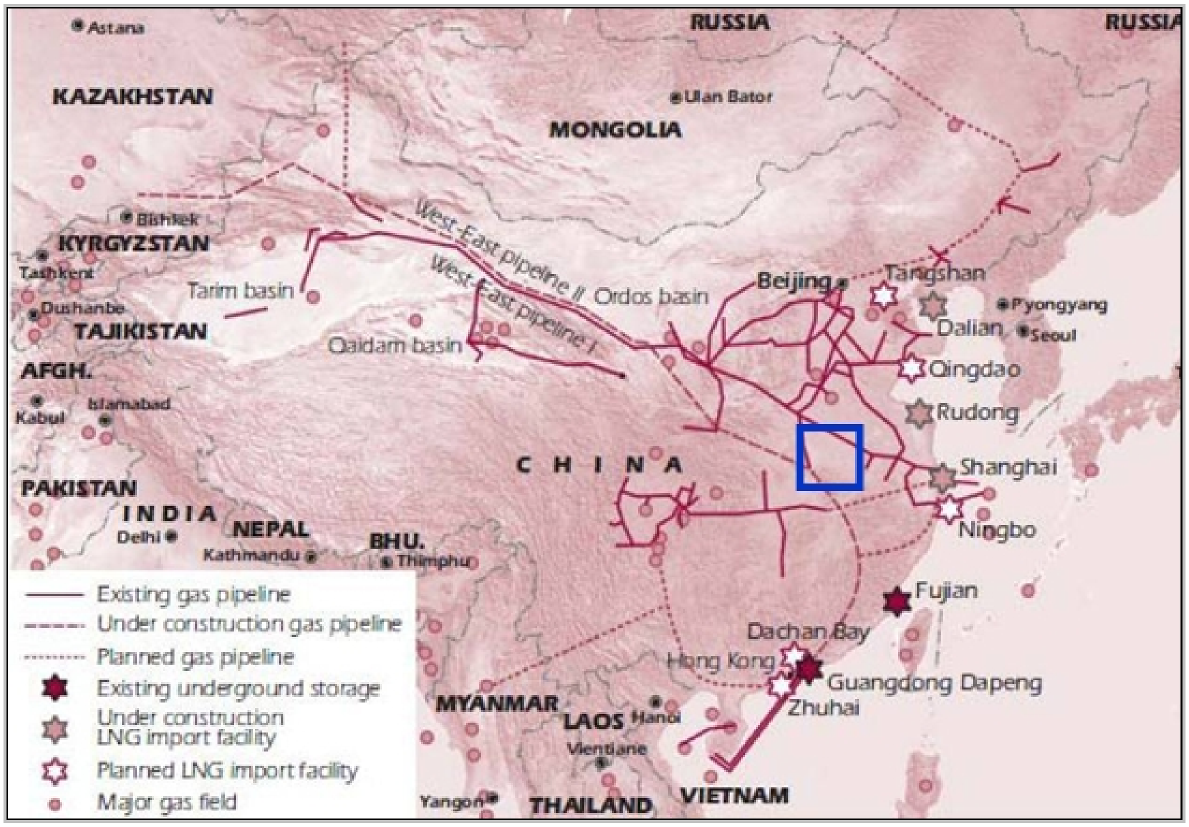


Figure 3-3: Natural Gas Pipeline in China

(Blue box shows location of Liuzhuang Mine) (Source: Higashi, 2009)

3.3 China's Natural Gas Market

China's natural gas market is undergoing rapid expansion, as well as shifting profoundly from self-sufficiency just ten years ago to increasing dependence on gas imports. After decades of focusing almost exclusively on coal and oil, the government began to emphasize natural gas development starting in the late 1990's. Previously, natural gas generally had been viewed in China as a prohibitively expensive and scarce fuel relative to coal and thus was not heavily promoted.

Natural gas consumption in China has been increasing at an accelerating rate since about 2000, when the national consumption level remained a modest 23.5 billion m^3 (2.3 Bcfd). By 2007, the latest year for which complete figures are available, China`s natural gas consumption had reached 69.5 billion m^3 (6.7 Bcfd), representing an increase of nearly 300% over 2000 (Figure 3-4).[4] Consumption is estimated to grow further, reaching 135 to 250 billion m^3 by 2020 (Figure 3-5).

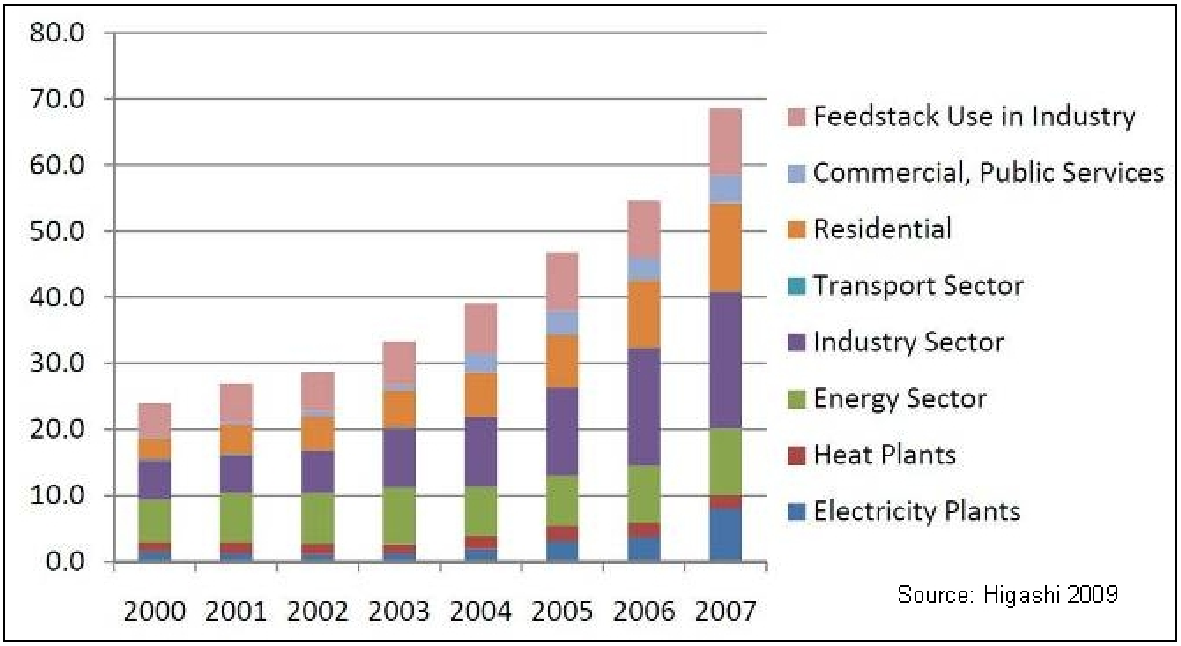


Figure 3-4: Natural Gas Consumption in China Since 2000
(Billion m^3/year)

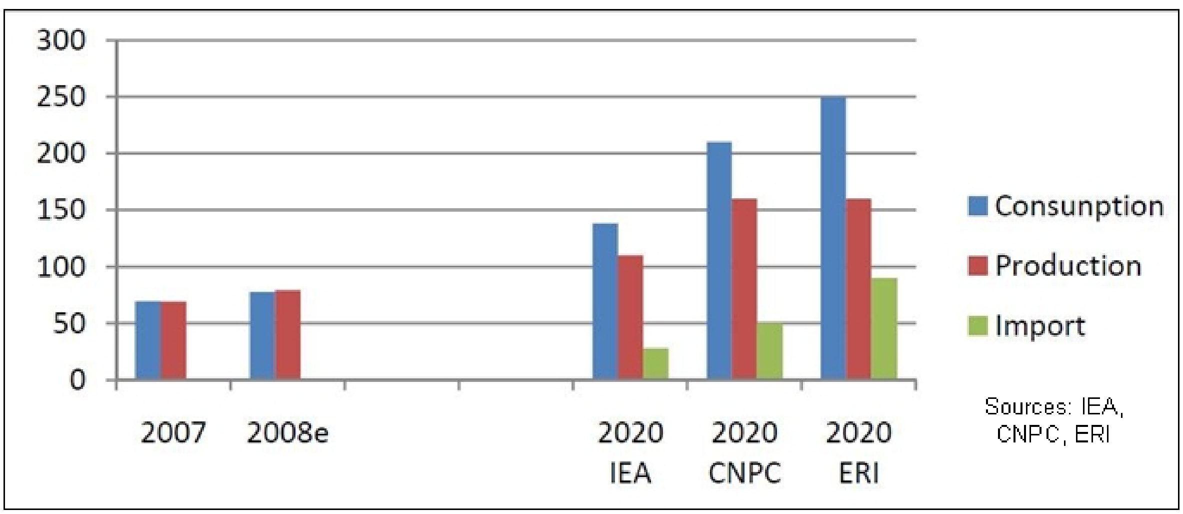


Figure 3-5: Projected Natural Gas Demand in China in 2020
(Billion m^3/year)

[4] People's Republic of China, National Bureau of Statistics.

During the period 2000-2006 China's natural gas consumption averaged a very high annual growth rate of 14% per year. As natural gas fields are developed, additional long-distance natural gas pipelines are constructed, and LNG import facilities are expanded, China's natural gas consumption is expected to reach 115 billion m^3 (11.1 Bcfd) in 2010 and 200 billion m^3 (19.4 Bcfd) in 2020.

China currently ranks in the world's top 10 countries for natural gas consumption and is expected to overtake Japan as Asia's top gas market by 2015, if not sooner.[5] However, despite the rapid growth China's gas consumption still stood at only about 11% of the U.S. level in that year (which was 672 billion m^3 or 59.5 Bcfd), indicating that considerable growth potential remains in China's natural gas sector.

3.4 Natural Gas Policy in China

China's natural gas investment and pricing policies are controlled at the central level by the National Development and Reform Commission (NDRC), with many details of regulation and implementation left to the provincial level authorities. China's central and provincial governments generally have supported rapid natural gas growth through policy, regulation and the direct development of infrastructure, such as the West-East Pipeline. The government set targets under the 10th Five-Year Plan (2001-05; reiterated under the 11th Five-Year Plan of 2006-2010) for natural gas to expand to provide 10% of China's total primary energy consumption by 2020.[6]

The driving forces behind China's natural gas industry growth include continued and accelerating urbanization; the penetration of natural gas into new and existing urban areas; and the expansion of industrial use, including the petrochemicals industry and the power sector.

Urban city gas demand represents the fastest growing segment of overall natural gas demand in China. This growth is occurring due to favorable supply costs, environmental protection advantages, increased urbanization rates, government support including an increasingly open utilities market, and the granting of exclusive concessions by the government to private and state-private firms to construct and improve China's natural gas transportation infrastructure.

[5] U.S. Department of Energy, Energy Information Administration, 2009. 2008 World Energy Outlook, Reference Case Scenario.
[6] Higashi, Nobuyuki, 2009. Natural Gas in China: Market Evolution and Strategy, International Energy Agency, Working Paper Series, June, 39 p.

3.5 Natural Gas Production in China

China's upstream natural gas (and oil) production sector is dominated by its three national oil companies: CNPC, Sinopec and CNOOC. These companies originally were formed during early economic reforms in the 1980's, which replaced the previous system wherein the government had directly planned and developed the oil and gas sector.[7]

CNOOC was established in 1982 to manage offshore petroleum development. Sinopec was established in 1983 originally to control downstream refining. In 1988, CNPC was formed to manage development of onshore oil and gas resources. In 1998, the sector underwent a further broad restructuring, wherein CNPC and Sinopec were assigned geographic regions and permitted to fully engage in integrated activities from upstream to downstream, much like international major oil companies. In 2000 all three companies were listed on the international stock exchanges in Hong Kong, New York and London.

CNPC is the dominant natural gas operator in China, holding about 75% of domestic gas resources and 80% of China's pipeline network (including major inter-provincial trunk lines). CNPC also controls several major gas import projects, such as the Central Asia pipeline and LNG imports in Jiangsu and Dalian. Sinopec`s core gas resources are located in Shandong and Sichuan, and it is also seeking LNG business opportunities. CNOOC provides offshore gas by pipeline from the South China Sea to Hong Kong, and from the East China Sea to Shanghai. Having established the Guangdong and Fujian LNG projects, CNOOC has become China's leading LNG company.

China's natural gas production reached nearly 70 billion m^3 in 2007 (Figure 3-6), heavily dominated by CNPC (54 billion m^3). Several small-size natural gas producers – mainly owned by local governments – also are active in China but are relatively un-important on a national scale. To promote development of CBM resources, the government established the China United Coalbed Methane Corporation (CUCBM) in 1996 as the sole state-owned company with access to foreign investment, although this right was

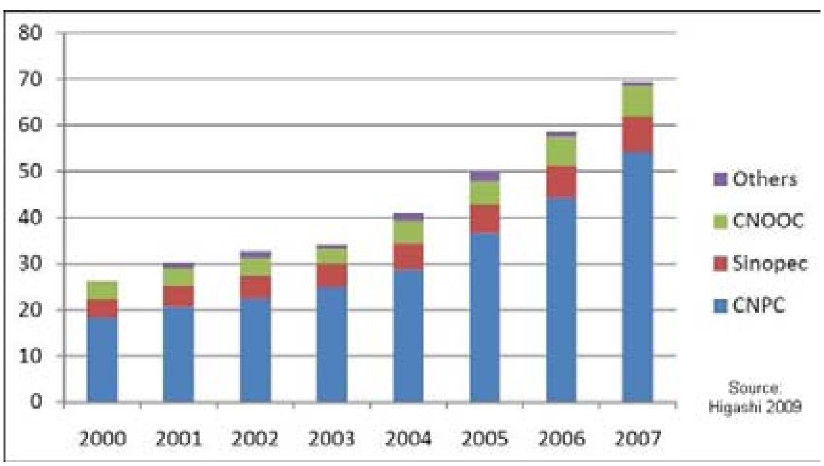


Figure 3-6: Natural Gas Production in China since 2000, by Company
(Billion m^3/year)

[7] Higashi, Nobuyuki, 2006. "Energy." In: R. Kokubun, ed., The Governability of China, Tokyo.

expanded in 2008 to CNPC and Sinopec. Although growing, coalbed methane production remains quite small in China, about 0.38 billion m^3 in 2007.

3.6 Natural Gas Distribution in China

A significant government policy in recent years has been to allow major privatization to take place in the urban gas distribution markets. Currently, there are hundreds of small formerly government-controlled city gas enterprises that are being consolidated into approximately one half-dozen much larger, modern, and mostly publicly listed companies. The private companies have better access to technology, capital, and management expertise. This privatization has helped to markedly accelerate China's consumption of natural gas in urban areas.

Today, these half-dozen major and mainly Chinese-owned gas companies compete to invest in China's rapidly growing urban markets, using capital funds raised on domestic, Hong Kong, and other stock markets. These companies aggressively bid on city gas assets at auction, acquire the equity interests of city gas enterprises through direct negotiation, or obtain indirect control of city gas operating concessions by jointly constructing and operating the systems with current municipal-owned city gas enterprises.

For example, China Gas Holdings Limited (China Gas), listed on the Hong Kong Main Board, is a major owner and operator of urban natural gas distribution systems in China. Notably, China Gas controls the city gas distribution company in Huainan, which is the nearest major city to Liuzhuang mine. China Gas invests in, operates, and manages the city gas pipeline infrastructure, the distribution of natural gas to residential and industrial users, and the construction and operation of natural gas refilling stations. The company only just entered the natural gas distribution business in 2002, when China approved construction of the West-to-East Pipeline.

Today, China Gas has grown quickly and holds exclusive piped gas development rights in some 64 cities and regions in China, including in Huainan (Figure 3-7). The company has a pipeline network more than 15,000 km long that serves 3.2 million household users and nearly 19,000 industrial and commercial users. In addition to city gas systems, China Gas also owns six high-pressure intermediary natural gas pipelines and 11 LPG terminals along China's southeast coast with capacity 220,000 tons and LPG storage facility with 270,000 m^3 capacity.[8]

[8] Liu, Minghui, 2008. "The Development and Opportunities of China's City Gas Market." China Gas Ltd.

Figure 3-7: China Gas City Gas Distribution Areas
(Source: China Gas, 2009)

3.7 Commercial and Industrial Gas Markets

There are no significant commercial or industrial users of low or moderate-quality natural gas within about 30 km of the Liuzhuang mine. Much further to the east near the major cities of Huainan (population 1 million) and Hefei (5 million), approximately 100 km from Liuzhuang, there are a number of commercial and industrial plants that could utilize natural gas. These include plants operated by the Hefei Iron and Steel Corporation, Hefei Chemical Group, Hefei Chemical Fertilizer Group, Anhui Huaibei Mining (Cement) Group, as well as other groups.

However, as discussed later in Section 5.5, the longest pipeline that could conceivably be justified from Liuzhuang mine to an end user would be approximately 10 to 30 km. Consequently, none of the commercial and industrial users in Anhui Province are considered to be viable markets for CMM produced at Liuzhuang mine.

3.8 Local Gas Markets

Unusual for a modern Chinese coal mine, Liuzhuang mine is located in a rural farming area quite far from sizeable towns and cities. There is no established natural gas market and very little local demand. Consequently, as discussed in Section 3.9, it is necessary to rely on data from regional pricing for natural gas in Huainan city as well as in the rest of central Anhui Province.

Liuzhuang mine currently utilizes low-quality "waste" coal in boilers for generating hot water. A total of four boilers (each 10 t steam/hour at pressure 0.4-0.5 MPa) consume approximately 14,400 t/yr of low-quality coal. The coal used to fuel the boilers is low-quality coal that are mined locally but not considered viable for transport outside the Liuzhuang area due to its poor quality. This waste coal is abundant and quite inexpensive (essentially free).

SDIC-Xinji Energy has evaluated the villages close to the Liuzhuang mine but does not consider any to be viable end-users for CMM produced at the mine. Currently, these villages utilize either agricultural waste (straw) or waste coal for heating. The coal also tends to be low-quality coal supplies that are mined locally but not considered viable for transport outside the Liuzhuang area due to poor quality. This waste coal is abundant and quite inexpensive. Liuzhuang CMM would need to be sold at an extremely low price to displace this waste coal, certainly much lower than its alternative value for more profitable utilization approaches, such as power generation.

3.9 Natural Gas Pricing in China

The price of natural gas in China is regulated by both the central and local governments. Rather than set by supply and market demand, natural gas prices are determined largely on the basis of production, transportation and distribution costs, often (but not always) with some allowance for a rate of return on investment. Prices are almost completely de-linked from the international gas price and the prices of other forms of energy in China.

Currently, China has three types of gas prices: well-head price, city gate price and consumer price. The well-head price is the price at which the gas producers sell to the long-distance transmission companies and is set by the National Development and Reform Commission (NDRC). The city gate price is the wholesale price set between the transmission and the municipal gas companies; it also is regulated by the NDRC.

The consumer price is the price at which the municipal gas companies retail their gas to the various end users, set by the different municipal companies. The consumer price varies with the category of consumers and depends largely on their perceived ability to pay, rather than the costs of supply.

Coalbed methane prices are theoretically not subject to NDRC regulation and can be negotiated between the buyers and sellers. But when CBM is supplied through long-distance transmission pipelines, the regulated (lower) natural price in the same areas is normally used as the reference for negotiating and determining the CBM price. LNG prices are the most unregulated, being freely negotiated between the sellers and the buyers at every stage.

Increasingly since 2000 the Chinese government has sought to employ energy pricing to help promote natural gas use as a substitute for coal and oil. However, the power sector, which relies primarily on coal as the dominant fuel, has been reluctant to use the more costly natural gas fuel. Thus, most of the natural gas growth has occurred in the residential and industrial sectors.

The residential sector has demonstrated the ability to absorb higher prices and strong demand growth which accompanied the penetration of city gas. Likewise, industrial sectors have been able to absorb relatively expensive natural gas as feedstock or by substation with fuel oil. Meanwhile, the chemical fertilizer industry has largely retained its low gas prices for its main feedstock, as the government allocates gas to this industry based on political and social considerations as well as economics.

In large part, the government determines the price of natural gas on a cost-plus basis, with variations by sector. Consequently, natural gas prices in China often deviate from those on the international market. When China was still self sufficient in natural gas production, this price regime was effective in developing China's natural gas market. However, controlled pricing is less viable now that China's LNG and pipeline gas imports are growing rapidly. It also can lead to distortions where some petrochemical plants produce too much output based on controlled low natural gas fuel prices, which can be much less than those for oil.

Although some price rationalization has occurred in recent years, the Chinese government still controls the price of natural gas in most markets. China has been raising gas prices rapidly since LNG imports began in 2006 and is expected to continue increasing gas prices. However, domestic gas prices remain significantly lower than international prices. In 2006, when the first LNG regasification terminal in Guangdong was completed, for the first time China`s natural gas market was linked with the international market. Until recently the differential between domestic and international prices has been limited because China's gas imports are still small, but with imports growing rapidly it is likely that China's gas prices will rise towards international levels.

In December 2007 the NDRC reformed and simplified the natural gas pricing system, establishing a more market-oriented price mechanism for China's gas industry. The principal changes made to China's natural gas pricing policy were as follows:

- **Fewer Price Categories**. Price categories were simplified by reducing the numerous categories used previously to only three categories: city gate, fertilizer, and industrial. Fertilizer plants pay the lowest city-gate price, industrial users generally pay an intermediate price, while urban end-users pay the highest prices (Table 3-2).
- **Shift to Guidance from Direct Control.** In addition, the NDRC moved from a mix of government-set gas prices with some government guidance (for gas sold within the allocated quota) to a more flexible approach of simply government guidance alone (for gas sold above the quota). The government-set price represents the city-gate price including well-head price and pipeline transportation tariff, which were set by the NDRC. The government guidance price indicates that city-gate prices can fluctuate within a certain range based on the government-set price.
- **Linkage to Other Fuels.** The NDRC also linked the wellhead gas price with the prices of alternative fuels, establishing a market-oriented price mechanism. As a result, the wellhead price rose in direction (but not magnitude) with the prices of crude oil, LPG and coal (basket weighted 40:20:20). The maximum year-on-year adjustment is 8%. The reference oil price is a weighted freight-on-board (FOB) price of West Texas Intermediate (WTI), Brent and Minas crudes. LPG reference prices are FOB prices in Singapore. Coal reference prices are the average price delivered to Qinghuang Island from Shanxi (Datong's high-grade) and Shanxi (thermal coal).

$4.15 = 1 RMB/m3	End User Category	Gov't Set City Gate Price (RMB/m3)	Gov't Set City Gate Price ($/Mcf)
Sichuan - Chongqing	City Gas	920	$3.81
	Fertilizer	690	$2.86
	Industrial	875	$3.63
Changqing (Ningxia)	City Gas	770	$3.19
	Fertilizer	710	$2.94
	Industrial	725	$3.01
Qinghai	City Gas	660	$2.74
	Fertilizer	660	$2.74
	Industrial	660	$2.74
Xinjiang	City Gas	560	$2.32
	Fertilizer	560	$2.32
	Industrial	585	$2.43
Liaohe, Zhongyuan (Henan)	City Gas	830	$3.44
	Fertilizer	660	$2.74
	Industrial	920	$3.81
West-to-East Pipeline	City Gas	1270	$5.27
	Fertilizer	1120	$4.64
	Industrial	1100	$4.56

Table 3-2: Natural Gas Prices According to End User Category
(Source: Ni, 2007)

Delivered gas prices can vary significantly across China's diverse gas fields, depending both on geography as well as the type of end user and its ability to pay. For example, even after the 2007 deregulation decree, the price of natural gas delivered to fertilizer plants in western China's Xinjiang region was as low as 0.56 RMB/m^3 ($2.32/Mcf), whereas the gas price sold off the West-East Pipeline to city gas markets in eastern China was much higher at 1.27 RMB/m^3 ($5.27/Mcf; Table 3-2).[9] Since 2007 gas prices have been rising by about 8% per year, based on continued strong economic growth in China, and are expected to increase further in coming years as incomes rise.

3.10 Natural Gas Pricing at Liuzhuang Mine

Gas pricing mechanisms in China are complex. There is no local gas market close to Liuzhuang which can serve as a proxy for estimating the theoretical price of CMM produced at Liuzhuang mine. Without a formal application to the Anhui NDRC, it is not possible to precisely determine the approved Liuzhuang CMM price. However, it is possible to approximate the theoretical gas prices based on the current regional pricing regime.

Table 3-2 indicates that the most relevant price for Liuzhuang would be the city-gate price delivered off the West-to-East gas pipeline, which in 2007 was about 1.27 RBM/m^3 ($5.27/MMBtu). This approximates the gas price that Liuzhuang CMM could expect if it were delivered to Huainan city (an unlikely option as discussed in Section 5).

3.11 Demand for Natural Gas for Vehicle Use (CNG)

The number of civilian use motor vehicles in China was 64.67 million vehicles at the end of 2008, up 13.5% from the previous year. Of this overall total, which includes both cars, trucks, and farm equipment, some 24.38 million were cars (up 24.5%). This large increase in vehicular traffic is a major cause of increasing pollution problems in many of China's cities.

Consequently, both the central and local governments are promoting the use of CNG as an alternative vehicle fuel, as one way to reduce pollution levels. CNG-fueled vehicles emit 90% fewer particulate emissions than diesel or gasoline powered vehicles, with significant reductions in carbon monoxide and nitrous oxide emissions. Greater use of CNG in transportation also could help slow China's oil import growth.

[9] Ni, Chun Chun, 2007. "China's Natural Gas Industry and Gas to Power Generation." Institute of Energy Economics, Japan, July, 40 p.

Especially at current gasoline prices, which due to continued price increases by the Chinese government during 2009 are currently about 25% higher than in the U.S., it can be up to 40% cheaper for Chinese consumers to fuel their vehicle with CNG rather than gasoline and diesel. The costs to convert a car to run on CNG fuel, rather than gasoline, can be as low as RMB 1700 ($250). The number of CNG filling stations in China is increasing, but their distribution is constrained by their distance from the CNG processing plant, which in turn is generally located close to a suitable methane source, whether it is a natural gas field or pipeline, or a CBM/CMM project. The central government is encouraging the building of new CNG filling stations and in the latest economic stimulus plans has included incentives such as a fast-track approval process and credit support from lending institutions.

3.12 Demand and Pricing for LNG

In parallel with the growth of China's natural gas pipeline system, LNG production and consumption also are growing rapidly. Large-scale LNG expansion continues, with the new Guangdong and Fujian LNG Terminals along the east coast having started up in 2009, with annual capacities of 3.7 and 2.6 million t, respectively. Several additional large LNG import terminals are planned to start within the next few years. In addition, there are increasing numbers of small-scale LNG production facilities throughout China that offtake natural gas from pipelines and then convert it to LNG for local/regional transport and use.

The key advantages of LNG include that it can be transported flexibly over varying distances to relatively small demand centers that are spread over a wide geographic area. In addition, LNG can be stored where needed in relatively large volumes to allow for daily or weekly fluctuations in demand. In China LNG is particularly competitive because only a small number of cities are connected or adjacent to the existing gas transmission pipelines. Numerous other cities are still not connected to gas pipelines.

The potential consumers of LNG include: (a) municipal and town gas companies which have no access to the gas transmission system; (b) large industrial and commercial establishments which are not connected by pipeline; and (iii) municipal gas companies which are connected to the pipeline system, but which require storage of LNG to meet fluctuating gas demand. Despite the growth in China's gas pipeline system, it will be decades before all Chinese towns and cities are connected through an extensive pipeline system. Therefore, LNG is likely to retain a share of the market for some time.[10]

[10] World Bank, 2009. "Shanxi Coal Bed Methane Development and Utilization Project." Report 4200-CN, April 20, 101 p.

Another significant advantage of LNG is that its prices are the most unregulated, being freely negotiated between the sellers and the buyers at every stage. Thus, LNG prices can be significantly higher than other more regulated natural gas prices.

Recently, small-size inland LNG producers operated by private companies, such as Fortune Oil PLC, also are emerging. In Xinjiang, for example, a new private company recently built a small LNG plant with production capacity of 0.6 billion m^3/year (432,000 t/year), with delivery of LNG by tanker trucks. Such a flexible business can makes sense for inland and rural consumers.

3.13 Power Markets and Pricing

Huainan is the largest city near the Liuzhuang mine, with a population of approximately 1 million and growing rapidly. The city has a wide range of industrial and manufacturing operations. In 2008, the city purchased about 2 billion kWh of electricity from the national grid and also obtained power from an 1,800-MW coal-fired power plant within the city limits. Major electricity consumers include electricity-intensive aluminum and cement factories, which accounted for over 200 million kWh of power demand in 2007.

Electrical power pricing is important for the economic feasibility of the most likely utilization option at Liuzhuang mine, which (as discussed in Section 5) was determined to be power generation using small-scale reciprocating engines.

China's electricity prices are complex and still mostly regulated by the government. There are three general price categories: the wholesale price, the transmission and distribution price, and the retail price. The wholesale and transmission/distribution prices are approved by the NDRC, whereas the retail price is set by the NDRC. The pricing system for wholesale power is based on a "cost plus profit" approach and a "same grid, same price" principle. [11]

Since 2002, a uniform wholesale price for similar types of power plants has been introduced with the aim of reducing the high overall cost. This pricing system does not take into account efficiency and environmental performance even among the same types of power plants.

A coal-fired power price adjustment mechanism was introduced in May 2006, allowing power generators to pass on coal price hikes within their wholesale rate at a cap of 8% per year. Only about 70% of any increase in coal price can be added to the wholesale price for coal-fired power plants, while the remaining 30% must be absorbed. The mechanism applies only to coal prices, not to natural gas fuel prices. Given that the government intends to raise the price for natural gas by

[11] Ni, 2007.

8% per year, gas-fired power generators will have more difficulties competing with coal-fired generators and operating their plants if any increases in gas fuel cannot be included into their wholesale power prices.

To promote the installation of flue-gas desulphurization (FGD) equipment, which reduces SO2 pollution, an environment premium has been set at 0.015 RMB per kWh for qualifying coal-fired power plants. However, there are no environmental premiums or taxation preferential policies for gas-fired power plants.

Table 3-3 shows the wholesale power price for thermal coal-fired power plants in China. The recent wholesale power price for Anhui Province is 0.345 RMB/kWh (with FGD), which is similar to the off-peak price that Liuzhuang mine pays for grid power (0.36 RMB/kWh). However, during more typical periods Liuzhuang mine pays 0.57 RMB/kWh, while peak-period power rates can reach as high as 0.85 RMB. The average power price during April 2009 was 0.65 RMB/kWh, during which the mine utilized 12.4 million kWh costing 8.11 million RMB.

Region	Province	Wholesale price (RMB/kWh)			
		Thermal			Hydro
		Coal-fired power plants		Gas-fired power plants	
		with FGD	without FGD		
North China	Beijing	0.320	0.305	-	-
	Tianjin	0.320	0.305	-	-
	Hebei	0.320	0.305	-	-
	Shanxi	0.250	0.235	-	-
	Shangdong	0.325	0.310	-	-
	Inner Mongolia	0.252	0.237	-	-
East China	Shanghai	0.390	0.375	-	-
	Jiangsu	0.370	0.355	-	-
	Zhejiang	0.400	0.385	-	-
	Anhui	0.345	0.330	-	-
	Fujian	0.365	0.350	-	-
Cental China	Hubei	0.335	0.320	-	-
	Hunan	0.360	0.345	-	0.315
	Jiangxi	0.350	0.335	-	-
	Henan	0.305	0.290	-	-
	Sichuang	0.310	0.295	-	0.280
	Chongqing	0.310	0.295	-	-
South China	Guangdong	0.420	0.405	-	-
	Guangxi	0.335	0.320	-	0.260
	Yunnan	0.255	0.240	-	0.215
	Guizhou	0.250	0.235	-	0.215
	Hainan	0.365	0.350	0.350	0.260

Table 3-3: Wholesale Power Price for thermal Coal-Fired Power Plants in China
(Source: Ni, 2007)

SECTION 4

Evaluation of Degasification Technologies and Reservoir Simulation

SECTION 4 CONTENTS

SECTION 4 FIGURES

SECTION 4 TABLES

4.1 Introduction

One of the most important opportunities for increasing the capture and utilization of methane at Liuzhuang mine is to improve the performance of the borehole drainage and gas collection systems. Early on in the evaluation, the ARI Team and mine operator SDIC-Xinji concluded that in-seam drilling at Liuzhuang was not going to be extremely productive because of the unstable mechanical condition and low permeability of the coals.

However, an innovative drainage program centered on longer, directionally controlled horizontal boreholes drilled into the gob zone above the coal seams appeared to be a much more promising approach. These improved drilling methods would be augmented by upgrades to the CMM borehole completion and in-mine pipeline system, with the main strategy being to reduce the unintended entry of ventilation air into the drained CMM gas stream.

These steps have a good chance of increasing the concentration of methane to around 40% CH_4 from the current 7-10%, which would make the higher quality CMM easier and more economic to utilize. A test drilling program would be needed to verify that medium-quality CMM is achievable. If successful, as discussed in Section 5, power generation using international-class CMM-fueled reciprocating engines in the 1- to 2-MW size range would be the most feasible utilization option at Liuzhuang mine.

Consequently, considerable effort was spent on evaluating the proposed alternative drilling design option. Hosted by SDIC-Xinji, the ARI Team's work began a review of technical data on the mine at SDIC-Xinji's modern office building, followed by surface and underground inspection of the entire CMM collection system and related equipment (**Figure 4-1**). The evaluation assessed each of the seven CMM drainage methods that are currently in use or have been applied at other coal mines in the Huainan Coal Field.

Figure 4-1: Site Visit to Liuzhuang Mine
(Left): ARI, Valley Longwall and OWTC personnel with SDIC-Xinji management
(Right): Liuzhuang mine operations building (Source: ARI)

The evaluation concluded that substantial improvements to the CMM drainage at Liuzhuang mine could be achievable. Using advanced downhole steerable drilling technology, very long (1000-m) horizontal boreholes could be drilled into the rock strata along the top of the future gob zone, precisely situated 15-20 m above the target coal seams.

Simultaneously, extended (225-m long) in-seam boreholes spaced approximately 10 to 20 m apart could be implemented. These holes would be longer and more widely spaced than the current 100-m, 5-m spaced boreholes. These drilling upgrades are expected to significantly increase both the quantity and CH_4 concentration of CMM drainage at Liuzhuang mine. That could improve mine safety while increasing the efficiency and economics of CMM utilization as well as greenhouse gas recovery.

4.2 CMM Drainage Techniques Applied in Huainan Coal Field

CMM drainage methods need to be selected depending on the mechanical and gas storage properties of the coal deposits. In general, the mechanical properties of coal seams across the Huainan Coal Field are fairly uniform. The coal seams in this region tend to be weak and sheared, with very low permeability. It should be noted that Huainan coal seams are much more difficult to drill than typical U.S. or Australian coals. In-seam boreholes in Huainan frequently collapse easily and do not drain very effectively.

As discussed in Section 2, the Liuzhuang mine is typical of coal mines located in the western half of the Huainan Coal Field, which have low-to-moderate gas content. In contrast, the coal mines in the eastern and northeastern part of Huainan more typically are highly gassy and may require an alternative approach to drainage.

At least seven distinct CMM drainage methods, comprising both cross-measure and in-seam boreholes, are or have been employed in various portions of in the Huainan Coal Field (Figure 4-2).[1] These methods are briefly summarized below.

After reviewing the performance to date of coal seam drainage in the Huainan Coal Field, reservoir simulation was used to evaluate alternate CMM drainage strategies at the Liuzhuang mine (discussed in Section 4.4). In summary, based on the modeling analysis, the most cost-effective approach for CMM borehole drainage at Liuzhuang (and probably many of the other western Huainan mines as well) very likely would be to utilize modern direction drills to precisely place a small number of long horizontal boreholes into the gob area about 15 to 20 m above the mined seam, where induced fracture permeability and methane concentration are likely highest.

[1] Yuan et al., 1998.

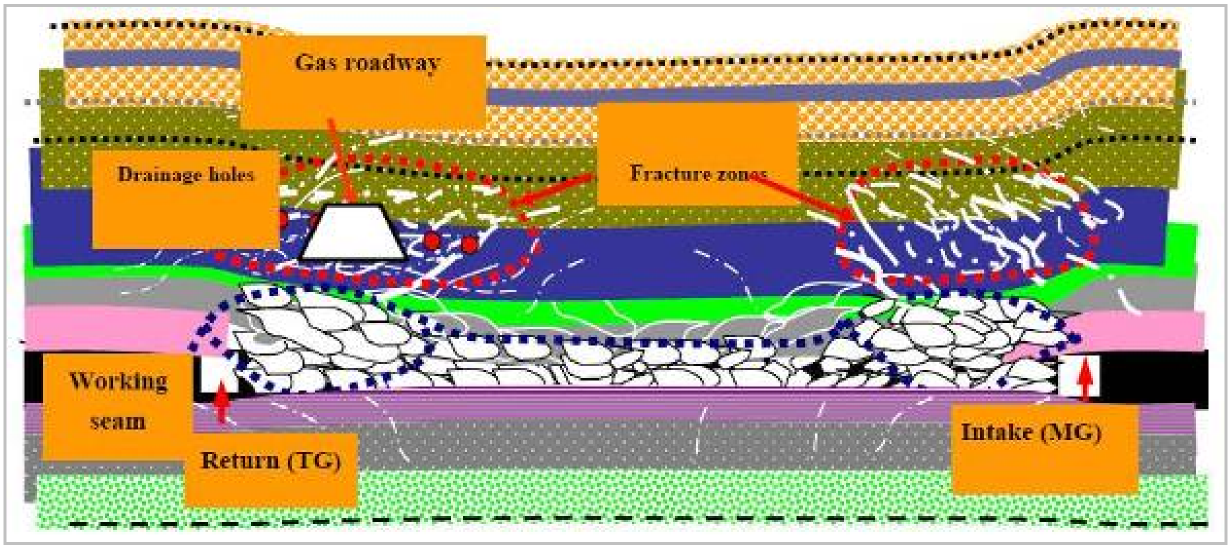


Figure 4-2: Cross-Section Typical of Liuzhuang and Other Mines in the Huainan Coal Field
(Source: REI Drilling)

However, before adopting this practice, an initial low-cost test drilling program is recommended to determine whether this technology is suitable for the site-specific conditions at Liuzhuang mine. Valley Longwall Drilling's experience in a mechanically similar coal mine in northeast China, which has similar unstable coal drilling conditions, suggests that this approach also could be successful at Liuzhuang.

4.2.1 Cross-Measure Boreholes in the Floor

Widely used in the older mining areas of Huainan, short boreholes are drilled into outburst-prone mineable seams from drilling galleries in roadways located below the seam. Typically 9 to 15 boreholes in three rows and spaced 8 to 12 m apart are developed in a fan-shaped pattern. Each borehole's drainage diameter is estimated to be only 4 to 6 m due to the low coal seam permeability. The CMM drainage rate typically is quite low at only 0.01 to 0.05 m^3/min for Seam 13-1 and even less at 0.005 to 0.01 m^3/min for Seam 11-2. Drainage efficiency can reach 15 to 30% if one to three years of pre-drainage is conducted.

4.2.2 In-Seam Borehole Drainage at the Working Face

At least ten Huainan mines have attempted in-seam borehole drainage at the working face of Seam 13-1. However, this method usually is not very effective because the coal seams are fairly impermeable. Using this approach boreholes are drilled into the seam in the strike direction from the upper and lower airways. The boreholes generally are 73 mm diameter, 30 to 50 m in length, and spaced 8 to 10 m apart. Clusters of 50 to 60 boreholes typically would drain only 0.3 to 0.4 m^3/min in total and then rapidly decline.

4.2.3 Borehole Drainage from the Working Face

This method was adopted at some Huainan coal mines to reduce outbursts in older areas at the driving face, which is a problem even in areas that had been drained using cross-measure boreholes from the roadway below the floor of the seam. Additionally, in new mines there is no roadway access from which to drill cross-measure boreholes below the outburst-prone seams. This technique was first widely applied starting 1998 at the Pan-1 mine in the eastern portion Huainan Coal Field.

Typically, 15 boreholes, 75 mm in diameter and 16 m long, are drilled at the driving face. The boreholes have an estimated drainage diameter of 3 to 4 m. The boreholes are sealed air tight using CPW-II type rubber sealer. Once sealed, the holes are placed on vacuum and produced for about 16 hours, achieving total methane flow rates of 0.8 to 1.2 m^3/min.

Drainage at the face is then stopped, driving is resumed, and drainage continues from the boreholes in the roadways. This process is repeated for every 8 m of roadway excavated. Although not considered the most efficient approach, this method has been effective in high-outburst areas with high stress and residual pressure, which tend to have the lowest permeability (<0.1 mD), notably the Xieli and Pan mines.

4.2.4 Gas Drainage from Overlying Coal Seams

One of the most effective drainage techniques employed to date at Huainan is to focus on draining low-outburst seams that stratigraphically overlie the less accessible and outburst-prone seam targeted for mining. For example, at the Xinzhuangzi mine, the mining target Seam 6 is outburst-prone, whereas the overlying Seam 8 situated about 15-30 m above Seam 6 has much lower gas content. Clusters of 9 boreholes in three rows (total 27 boreholes) are drilled every 20-m interval from a drilling site in the floor roadway of Seam 6. As mining of Seam 6 proceeds, the methane drainage rates tend to spike about 20 m ahead and 40 m behind the working face. This drainage method is fairly effective, with individual boreholes draining an average 0.17 m^3/min and the cluster draining a total of about 4 m^3/min.

4.2.5 Gas Drainage from Underlying Seams

A similar method to that described in Section 4.2.4, except that boreholes are drilled from a low-outburst seam stratigraphically underlying the outburst-prone seam. For example, at the Xie No. 1 mine in the eastern Huainan Coal Field, boreholes are drilled from rock roadways near Seam 10 up into Seam 11. One advantage of drilling in an upward direction is that water does not soak into the coal seam, which otherwise tends to create a soft paste, further reducing permeability and gas drainage effectiveness.

4.2.6 Gob Gas Drainage Using Roof Boreholes

Throughout the Huainan Coal Field, and apparently at Liuzhuang mine (although no specific data were available), a significant fraction (estimated 17-36%) of CMM released comes from adjoining non-mined seams which nevertheless become highly fractured during longwall collapse. Drilling boreholes along strike into the roof above the seam can be an effective technique to drain methane from these non-mined coal seams.

This approach was first used in the Huainan Coal Field in 1975, at the Xie No. 2 mine. It is most effective when boreholes are positioned about 15 to 20 m above the roof of Seam 13-2. For example, a rate of 6 m^3/min was achieved at Pan No. 1 mine. At the Xieqiao mine just east and adjacent to Liuzhuang, a 360-m long, 150-mm diameter borehole was drilled into the fractured roof above Seam 13-2 using an Australian steerable 1,000-m-rated drill. Basically, this is the technique recommended for Liuzhuang mine, although multiple and significantly longer (>1,000-m) horizontal gob boreholes are envisioned.

4.2.7 Gob Gas Drainage From Overlying Tunnels (Rock Galleries)

Using a similar principle of targeting the fractured gob above the target coal seam, this method employs roadways instead of boreholes for gas drainage. For example, the Li No. 1 mine in southeastern Huainan Coal Field (located within the XieLi area "T" on Figure 2-9 in Section 2) experienced high methane influx rates of 12-17 m^3/min while mining Seam 13-2. Gas influx was too high to be handled by conventional short borehole drilling.

Instead, a 130-m long roadway was developed along strike of the 1-m thick Seam 15, located 15 m stratigraphically above the mining target Seam 13-2. This roadway was connected to the permanent drainage system. When the working face in Seam 13-2 advanced about 10 m past the roadway, stress fractures were induced, initiating methane drainage of about 1.0 m^3/min. Once the face passed 20 m beyond the roadway, CMM drainage increased to 5 to 7 m^3/min, representing about 25-60% of total emissions.

The tunnel (or "rock gallery") technique has also been used in certain other Chinese coal mines with low coal seam permeability, such as in the Yangquan Mine No. 5 in Shanxi Province.[2] The principal drawback of this method is that excavating large-diameter roadways is extremely expensive. Overall, this method appears to be much less cost-effective than the proposed drilling of horizontal gob boreholes using directional drills.

[2] Stevens, S.H., Brunner, D., and Liu, Z., "Yangquan Mine CMM-to-Power Project: Technical and Economic Evaluation." The 2001 International CMM/CBM Investment Exposition/Symposium, November 7-8, Shanghai, China.

4.3 CMM Drainage and Ventilation at Liuzhuang Mine (Current Methods)

This section discusses the CMM drainage and ventilation system and techniques that are currently employed at the Liuzhuang coal mine. Overall CMM drainage and ventilation currently is conducted using an integrated system consisting of a) boreholes drilled into the seams that are to be mined for pre-drainage, as well as boreholes drilled into the gob zone for drainage during mining; and b) the ventilation system, which comprises surface vacuum pumps, the CMM pipeline system, and an array of completed boreholes.

4.3.1 Borehole Drilling

Currently, methane drainage boreholes are drilled at Liuzhuang mine using an array of 13 individual rock drills, two of which are shown in Figure 4-3. None of these drills are equipped with modern downhole directional control technology. Only one of the drills is capable of drilling 500-m length boreholes, while the others are rated to maximum 200-m length. Because Liuzhuang is a relatively new mine and not extremely gassy (although gas levels are anticipated to increase as mining proceeds into deeper areas), borehole drilling is not as intensively employed as in other high-gas mines.

Figure 4-3: Short Horizontal Borehole Drills Used as Liuzhuang Mine
(Source: ARI)

In-seam drilling at Liuzhuang mine currently utilizes the following techniques:

- In areas with favorable coal conditions, drilling rates of 100 m per shift may be expected. The shift length is 8 hours, which includes an estimated 5 to 6 hours of actual drilling time (16 to 20 m-per-hour advance rate).
- Short boreholes (50- to 110-m long and 50- to 93-mm in diameter) are drilled in advance of the development headings to drain the gas prior to mining. Where there are no outburst prone conditions, drilling in advance of the headings may not occur.
- Normally, the lead time for drainage (where drilling occurs in advance of headings) is about three months.

- Boreholes 50 to 110 m long and 50 to 93 mm diameter are drilled at 5-m spacing (parallel holes, perpendicular to the longwall gate roads) to drain the gas from the longwall prior to mining.
- Boreholes 50 to 110 m long and 50 to 93 mm diameter are drilled in a fan pattern from drill stubs (at intervals along the gate-roads), at an angle of 15 to 30 degrees from the coal seam up into the strata above the coal seam prior to Longwall extraction. The typical vertical section of these boreholes includes 4 m of coal and 16 m of stone.
- A small number of 480-m long holes have been "directionally" drilled by a drilling contractor. Drilling rates were not specified.
- Drilling problems encountered to date include no return water, drill bit and drill string becoming stuck, very hard roof, and zero penetration rate.

4.3.2 Ventilation Design

The Liuzhuang mine currently employs a comprehensive exhaust system with a surface-mounted main ventilation fan. Manufactured in the United Kingdom by Howden, the fan is 2.8 m in diameter and has a flow capacity of 20,000 to 28,000 m^3/min. Underground (forcing) auxiliary fans in sizes of 0.6, 0.7, and 0.8 m also are in use, delivering local flows where needed of 400 m^3/min via ventilation air tubes.

The main gas extraction plant located on the surface consists of two vacuum pumps (Figure 4-4). A third pump is planned to be installed by 2011. CMM is extracted from the working faces of the mine via 200- and 300-mm diameter pipes, and from the main roadways using 600-mm diameter pipe. There are 2 x 400-mm diameter pipes installed in parallel in the shaft from underground to surface and an 800-mm diameter pipe from the shaft to the gas plant.

Figure 4-4: Liuzhuang Mine Gas Extraction Plant
(Source: ARI)

Ventilation air in the underground roadways usually has a concentration (by volume) in the range of 0.01 to 0.12% CH_4 (average 0.02%), which is quite low and considered safe for mining operations. SDIC-Xinji estimates that 80% of the gas from the working face is drained by the borehole drainage system, which helps to keep the ventilation air methane concentration very low. Currently, this drained gas is vented to the atmosphere, pending adoption of a utilization program. The total gas volume from drainage is 1.0 to 1.1 million m^3 per month with a yearly volume of 13 million m^3 (24.7 m^3/min). During the period January to May 2009, the total volume of gas extracted was 5 million m^3.

The underground-to-surface CMM pipeline system consists of conventional steel pipe of varying sizes (Figure 4-5). Gas is extracted from the working face in the mine via 200-mm and 300-mm diameter pipe. CMM extracted from the main roadways is transported via 600-mm diameter pipe. 2 x 400-mm diameter pipe is used in parallel in the shaft from underground to surface, while an 800-mm diameter pipe transports CMM from the shaft to the gas plant. Figure 4-6 shows the surface to in-seam drilling rig & hole opening drill bits (up to 600-mm diameter).

Figure 4-5: Steel Pipe Used in the Underground-to-Surface CMM Pipeline System
(Source: ARI)

Figure 4-6: Surface to In-Seam Drilling Rig and Hole Opening Drill Bits

Table 4-1 shows the monthly average methane flow and concentration of the drained CMM from Seam 13-1 from one of the longwall panels at Liuzhuang mine during the first five months of 2009. The methane flow rate ranged from about 10 to 14.4 m3/min, experiencing significant monthly fluctuations of about 50%. The methane concentration ranged from 5 to 10% by volume, averaging 10.02% during the month of May 2009. As discussed in Section 5, the significant variability in CMM flow rate and concentration significantly impacts the utilization potential of this gas stream. Furthermore, such low CH4 concentrations actually indicate a certain level of safety concern, as they fall within the explosive range of 5 to 15%.

	Time (min)	Concentration CH4 in Pipeline (%)	Gas Mixture Flow (m3/min)	CH4 Flow (m3/min)	CH4 (m3/day)
	Area: 13煤首采面采空区				
	Sum	Average	Average	Average	Sum
Jan-09	44640	14.41	67.57	9.74	434578
Feb-09	40320	14.37	73.33	10.53	424754
Mar-09	44640	14.24	73.24	10.43	300351
Apr-09	43200	12.57	68.32	8.60	371347
May-09	44640	10.02	53.12	5.34	238339

Table 4-1: Average Methane Flow and Concentration of Drained CMM from Seam 13-1
(Source: SDIC)

Figure 4-7 shows the more detailed hourly methane flow rate and concentration from Seam 13-1 from the 121301 Working Face at Liuzhuang mine during the period January through May 2009.

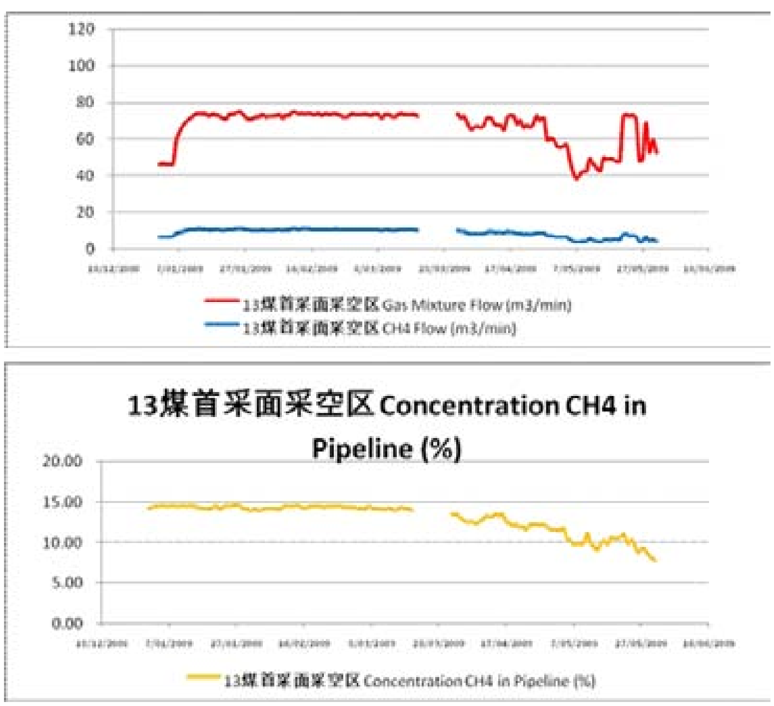


Figure 4-7: Detailed Hourly Methane Flow Rate and Concentration
Seam 13-1 – Working Face 121301 – Jan-May 2009 (Source: SDIC)

Similarly, Figure 4-8 shows the methane flow rate and concentration during December 2008 through May 2009. Flow rates and concentration initially were fairly stable but operational events later in the period caused large fluctuations. Again, these fluctuations have implications for utilization : variability of this magnitude could be handled by reciprocating engines but probably not by turbines.

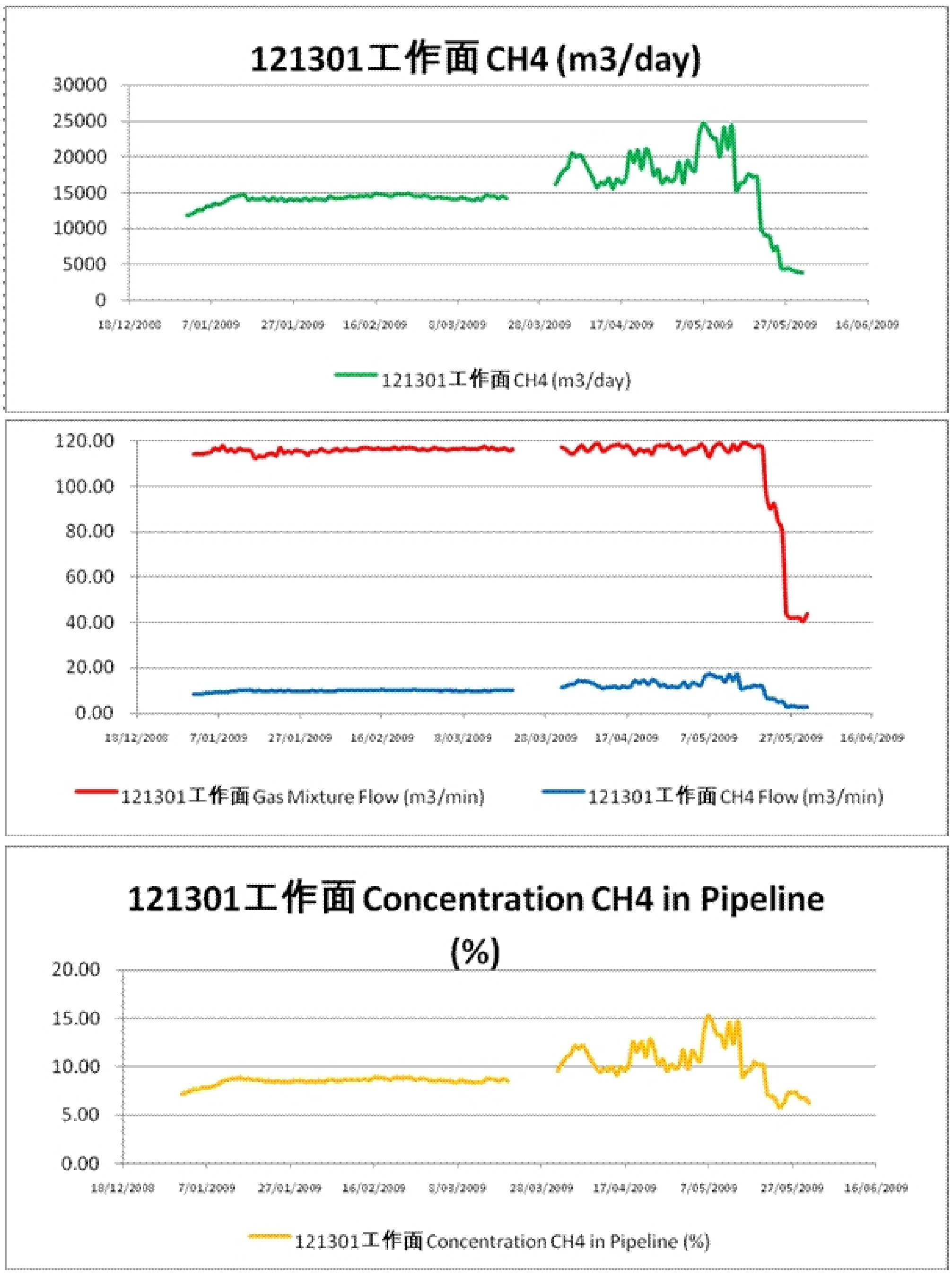


Figure 4-8: Detailed Hourly Methane Flow Rate and Concentration
Seam 13-1 – Working Face 121301 – Dec 2008 to May 2009 (Source: SDIC)

4.4 Reservoir Simulation Modeling of the Liuzhuang Mine

Reservoir simulation is a rigorous quantitative approach that can be used to model, understand, and optimize CMM drainage at coal mines. Using measured and inferred reservoir parameters, modeling is a powerful tool for determining the most efficient borehole spacing, length, and timing.

For this analysis, a base-case model was developed based on current reservoir conditions and borehole placement. Two alternate scenarios were then evaluated, with different borehole spacing and lengths using directional horizontal drilling. Both of the alternate scenarios were configured to meet the Chinese government safety requirement to reduce the initial gas content by 30% prior to mining. The current study is believed to be the first application of reservoir simulation at the Liuzhuang mine.

The reservoir simulation of the main coal seam reservoirs in Liuzhuang mine was conducted to better understand and optimize borehole length, spacing, and placement. Using Advanced Resources International, Inc.'s COMET3 reservoir simulator, a simulation model was constructed that represents the current Liuzhuang mine degasification boreholes. The model employs two layers to enable simulation of horizontal in-seam directional drilling. Details of the base case and alternate scenarios modeled are described below.

4.4.1 Base Case - Cross Panel In-Seam Drainage Borehole Model

For the base case simulation, the current degasification method using short horizontal boreholes into Seam 13-1 was simulated (Figure 4-9).

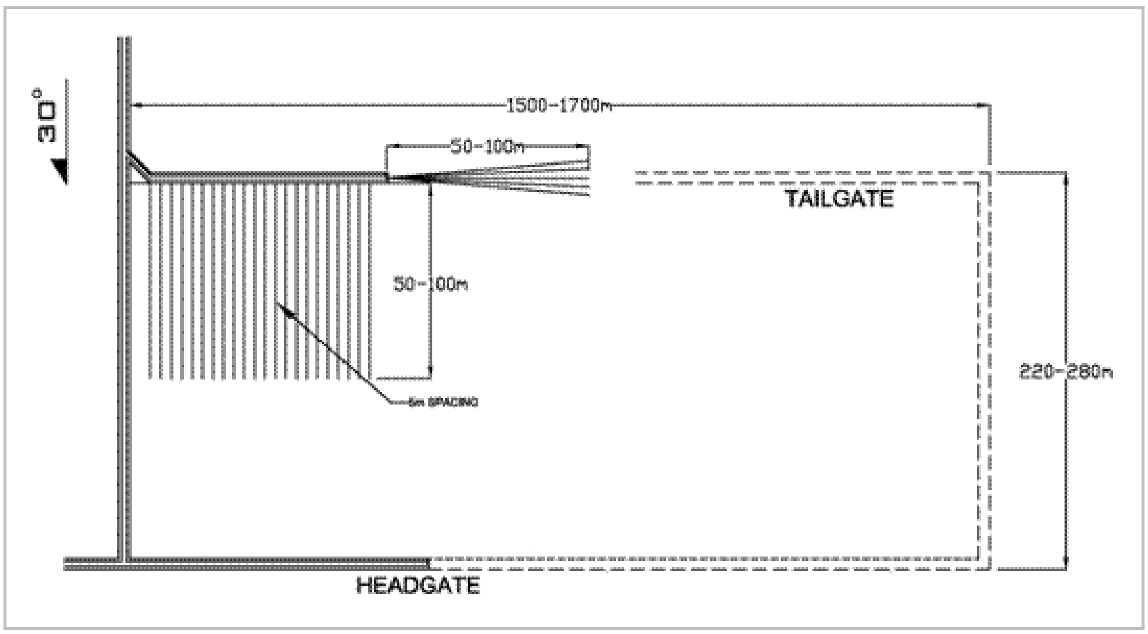


Figure 4-9: Schematic of Current CMM Drainage Practice at Liuzhuang Mine
(Source: ARI)

Permeability was assumed to be 0.05 mD in the XY (lateral) direction and 0.005 mD in the vertical (Z) direction, based on measured and estimated permeability values in the Huainan coal field and site-specific measurements at the Liuzhuang mine. While permeability is difficult to measure in coal seams, the low permeability used in the simulation model is consistent with drainage experience at the Liuzhuang mine, as well as well test permeability measurements elsewhere in the Huainan Coal Field. No changes in permeability as a function of pressure are included in this model.

The COMET3 reservoir simulation model comprises 22 * 1 * 2 grid blocks (225 m * 5 m * 4.5 m). The 225-m dimension represents the distance from the tailgate to the headgate of the mine. The 5-m dimension is the current borehole spacing (adjusted later for the different model alternatives), and the 4.5-m scale is the total average coal seam thickness.

Figure 4-10 shows a map view of the top layer for the base-case model, as well as a north-south trending cross-sectional slice through the model. The base-case scenario that was modeled represents a 100-m long in-seam borehole drilled into Seam 13-1 with an assumed 5-m drainage width (the current borehole spacing). Just as currently practiced, the borehole was drilled in a cross-panel direction into the 225-m wide longwall from the gate road. The cross-sectional view shows Seam 13-1 dipping at a 30° angle. The color represents gas pressure, which remains close to original levels due to the low coal seam permeability.

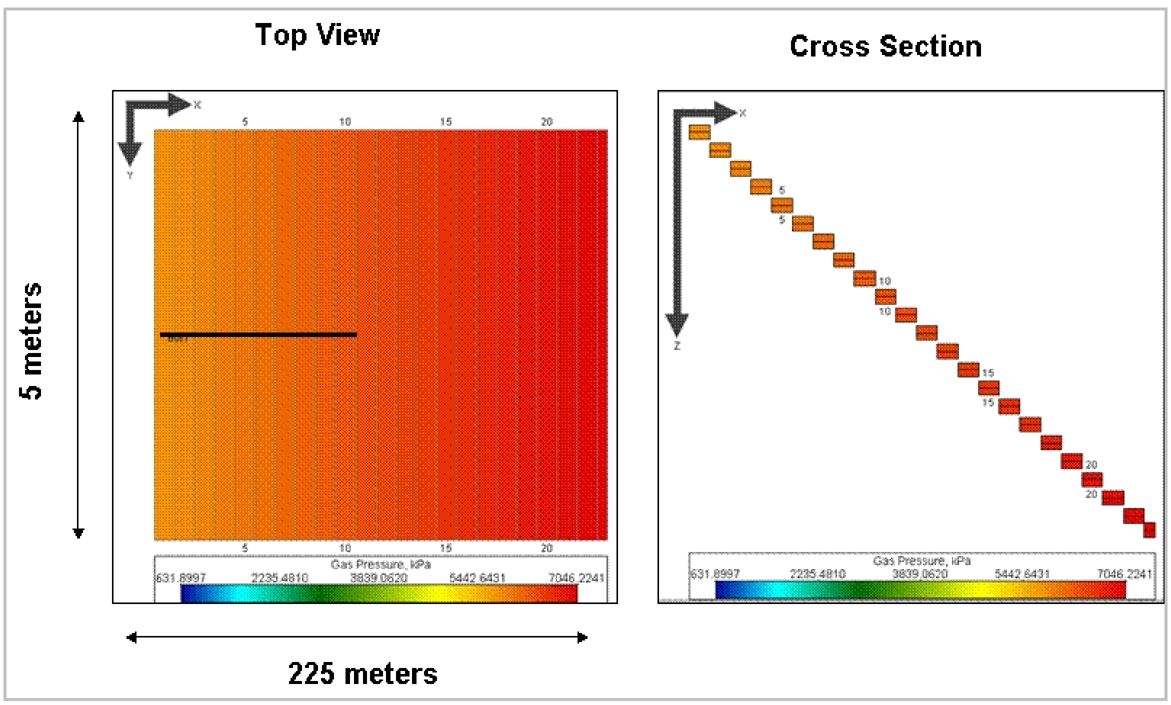


Figure 4-10: Reservoir Simulation Model of the Current Liuzhuang mine degasification borehole
(Source: ARI)

The sorption isotherm (pressure vs gas content) curve used in the model (Figure 4-11) was generated based on known dry, ash-free Langmuir parameters (Langmuir Volume and Langmuir Pressure). Those parameters were converted to in-situ conditions using an average ash content of 20% and an average moisture content of 1.7%. An average coal density of 1.4 grams per cubic centimeter (g/cc) was used to convert m3/t to m3/m3 for input into the reservoir simulator. The average initial gas content used was 7 m3/t, representing the moderately undersaturated initial reservoir condition. This initial saturation was assumed to be constant in all gridblocks. Other key reservoir parameters used in the modeling are presented in Table 4-2.

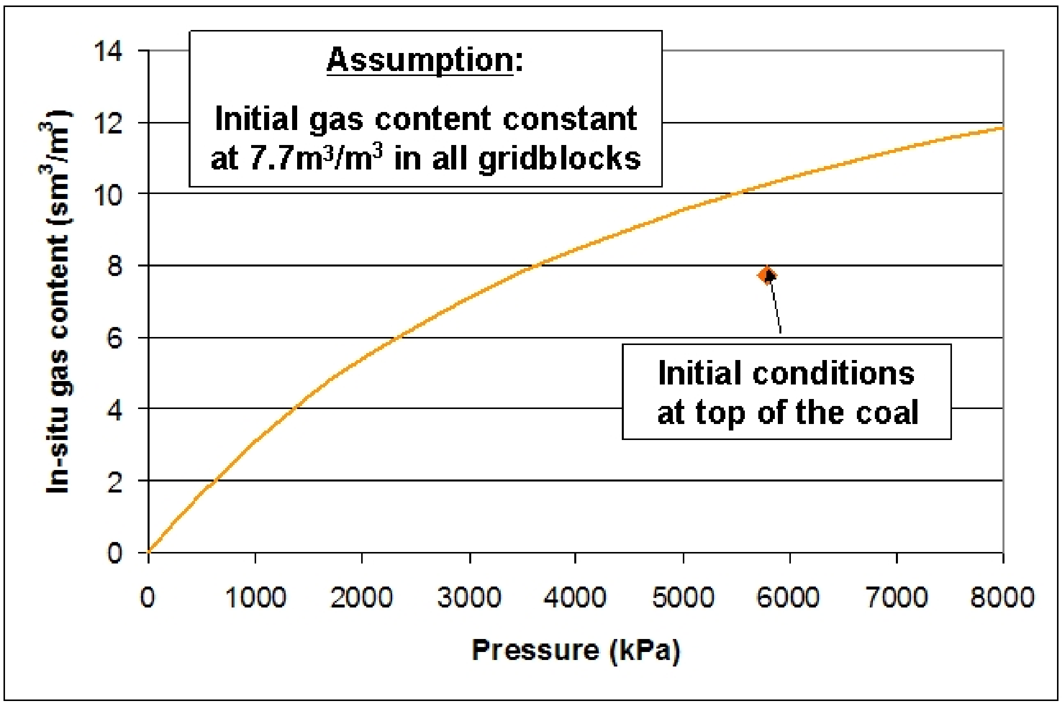


Figure 4-11: Sorption Isotherm for Coal Seam 13-1
(Source: ARI)

Figure 4-12 (cross-sectional view) and Figure 4-13 (plan view) show the simulated reduction in gas content after 9 months of production from the 100-m long horizontal borehole drilled into Seam 13-1 at Liuzhuang mine. Gas content remains close to virgin levels even after 9 months of drainage from the borehole, reaching 5.3 and 6.2 m3/m3 in Layers 1 and 2, respectively, down slightly from the original 7.7 m3/m3. The model predicts that methane production from horizontal in-seam boreholes at Liuzhuang mine peak early at over 100 m3/day, followed by a hyperbolic decline to about 20 m3/d by month 9 (Figure 4-14).

Parameter	Value	Units	Comments
Coal Depth	725	m	Base of seam (590.5 meters top of coal)
Coal Thickness	4.50	m	
Pressure Gradient	0.433	psi/ft	Hydrostatic (9.79 kPa/m)
Dip	30	degrees	To the south
Initial water saturation	100	%	
Horizontal Permeability	0.1	mD	Estimated
Vertical Permeability	0.01	mD	Assumed
Porosity	2	%	Assumed
Sorption Time	1	day	
Fracture spacing	1	cm	
Langmuir Volume	580	scf/ton	d.a.f. (19.8 sm^3/m^3 in situ)
Langmuir Pressure	780	psia	
Initial Gas Content	7	m3/t	d.a.f. (7.7 sm^3/m^3 in situ)
Moisture content	1.7	%	Average for 13-1 seam
Ash content	20	%	Average for 13-1 seam
Coal density	1.4	g/cc	Average for 13-1 seam
Pore Compressibility	4.30E-05	1/kPa	Assumed (300e-6 1/psi)
Permeability Exponent	3	-	
Matrix Compressiblity	1.45E-07	1/kPa	Assumed (1e-6 1/psi)
Water density	1	g/cc	
Water Viscosity	0.8	cp	
Temperature	28	C	
Gas Composition			95% CH4; 1% CO2; 4% N2
Borehole Length	100	meters	
Borehole Radius	48	mm	
Borehole BHP	103	kPa	15 psi

Table 4-2: Simulation Inputs to the Reservoir Simulation Borehole Drainage Model
(Source: ARI)

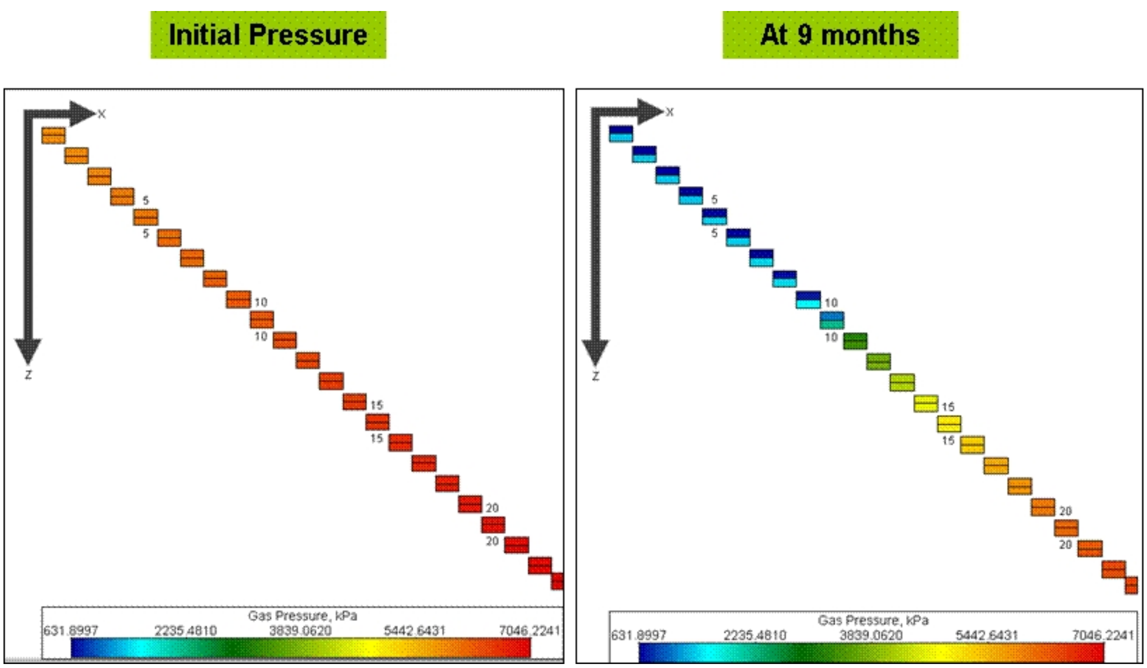


Figure 4-12: Simulated Reduction in Pressure
Current case – cross-sectional view (Source: ARI)

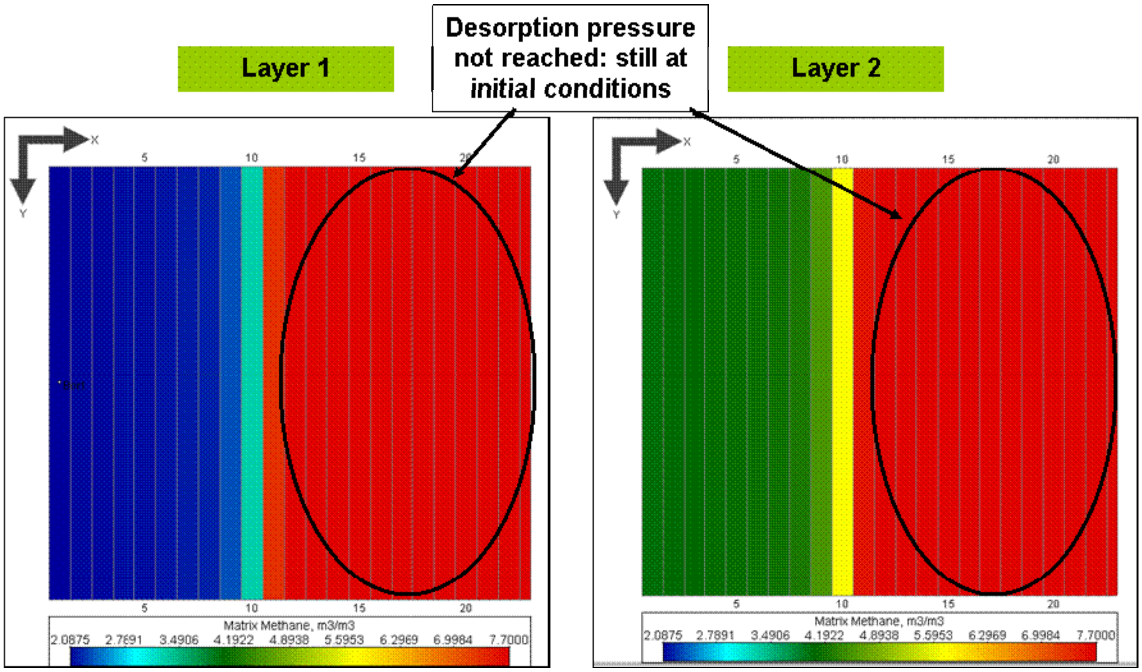


Figure 4-13: Simulated Reduction in Gas Content
Current case – plan view (Source: ARI)

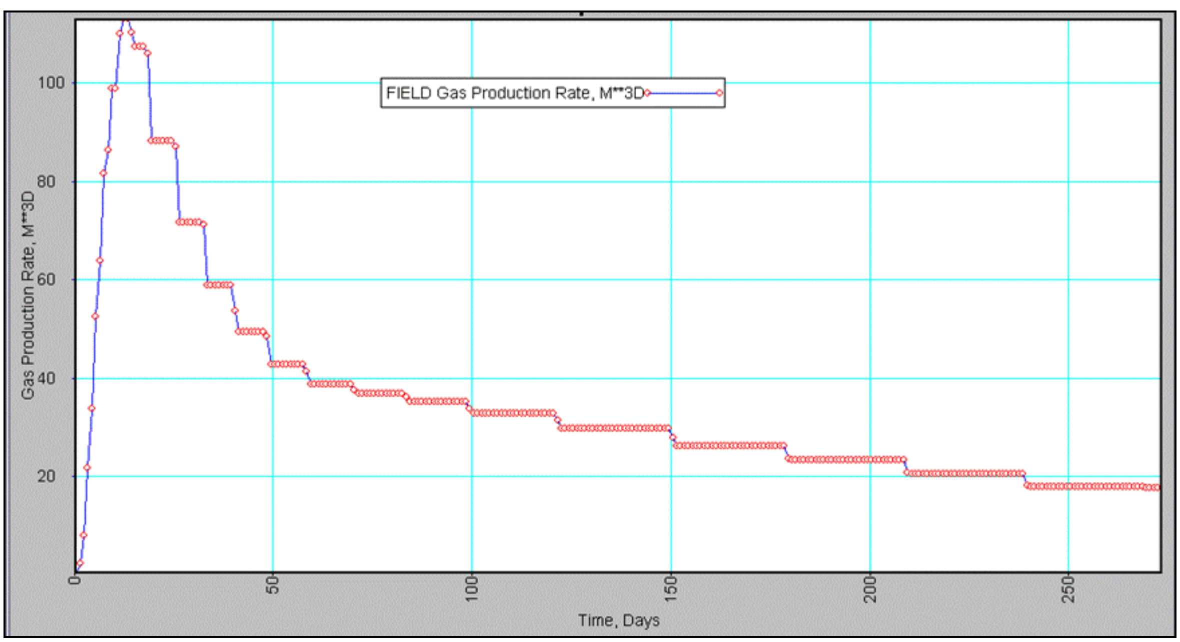


Figure 4-14: Simulated Methane Production from a Horizontal In-Seam Borehole at Liuzhuang
Current case (Source: ARI)

4.4.2 Simulation Alternative No. 1

For the first alternative simulation scenario, the borehole was more than doubled in length to 220 m (Figure 4-15), compared with the original base-case length of 100 m (still only in layer 1). In addition, the spacing was modified in order to reach the same residual gas content as for the base case after 9 months of production. It was determined that boreholes needed to be spaced approximately 10 m apart to reach the same residual gas content as in the base case. Gas production rate and matrix methane maps are provided in Figure 4-16 and Figure 4-17, respectively.

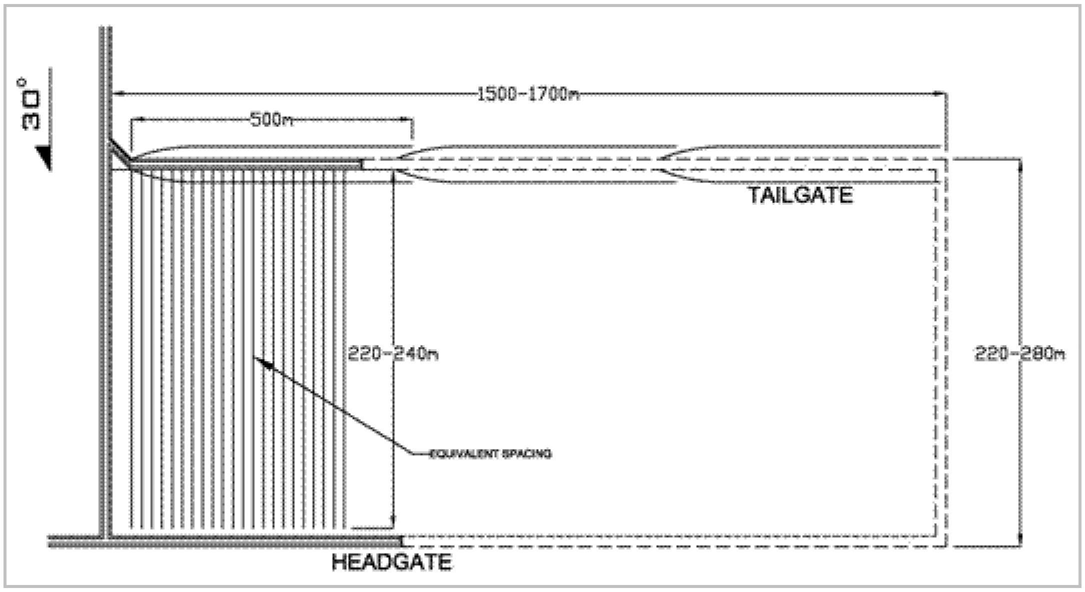


Figure 4-15: Alternative Drainage Drilling Scenario No.1
(Source: ARI)

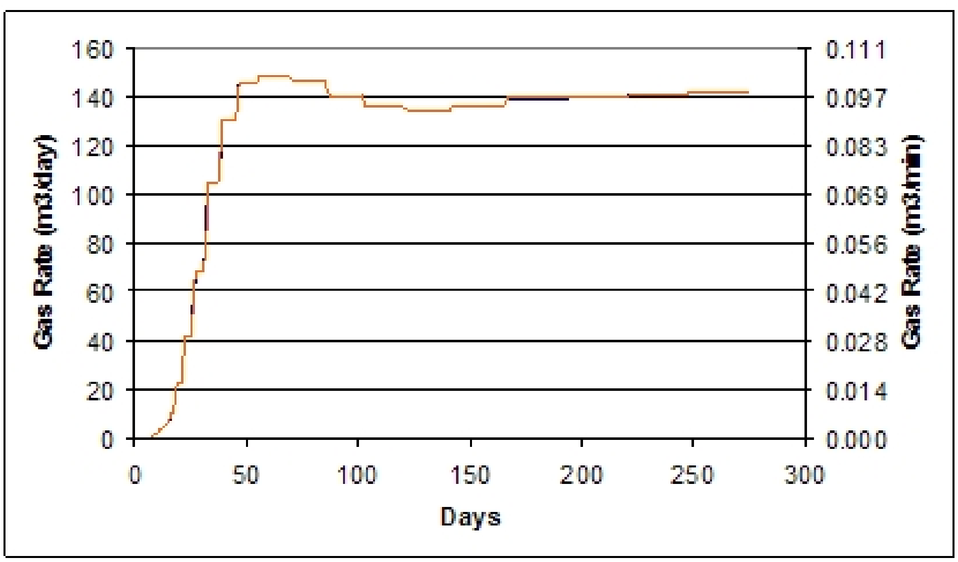


Figure 4-16: Gas Production Rate for Scenario No.1
Horizontal boreholes drilled every 10m and produced for 9 months (Source: ARI)

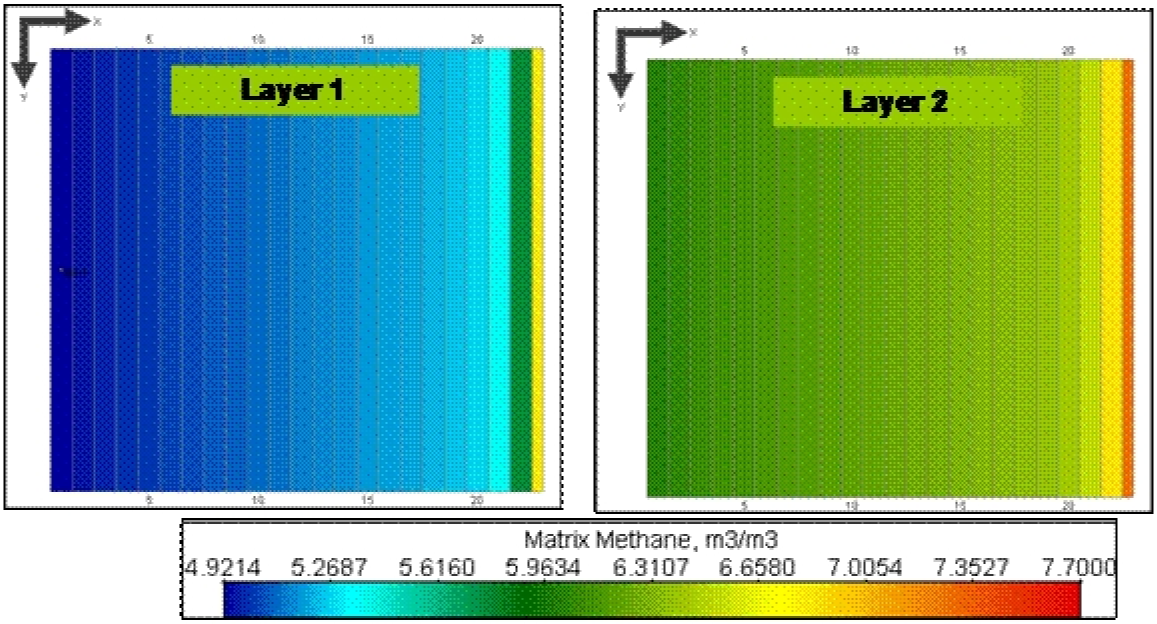


Figure 4-17: Scenario 1 – Simulated Reduction in Gas Content
220 m horizontal boreholes drilled in Seam 13-1 only (Source: ARI)

4.4.3 Simulation Alternative No. 2

For the second scenario, directional drilling was investigated by assuming 220-m long boreholes are drilled, one in each layer. As for alternative 1, the spacing was modified in order to reach the same residual gas content as for the base case after 9 months of production. It was found that boreholes spaced every 20 m were required to reach the same residual gas content as for Scenario 1 (5.3 and 6.2 m3/t in Layers 1 and 2, respectively, down slightly from the original 7.7 m3/m3). Gas production rate and matrix methane maps are provided in Figure 4-18 and Figure 4-19, respectively.

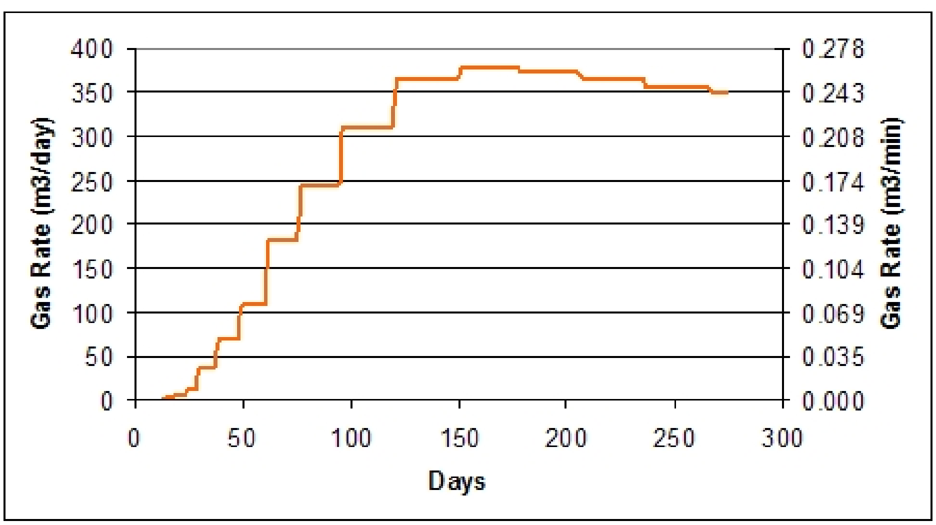


Figure 4-18: Gas Production Rate for Scenario No.2
Horizontal boreholes drilled every 41m and produced for 9 months (Source: ARI)

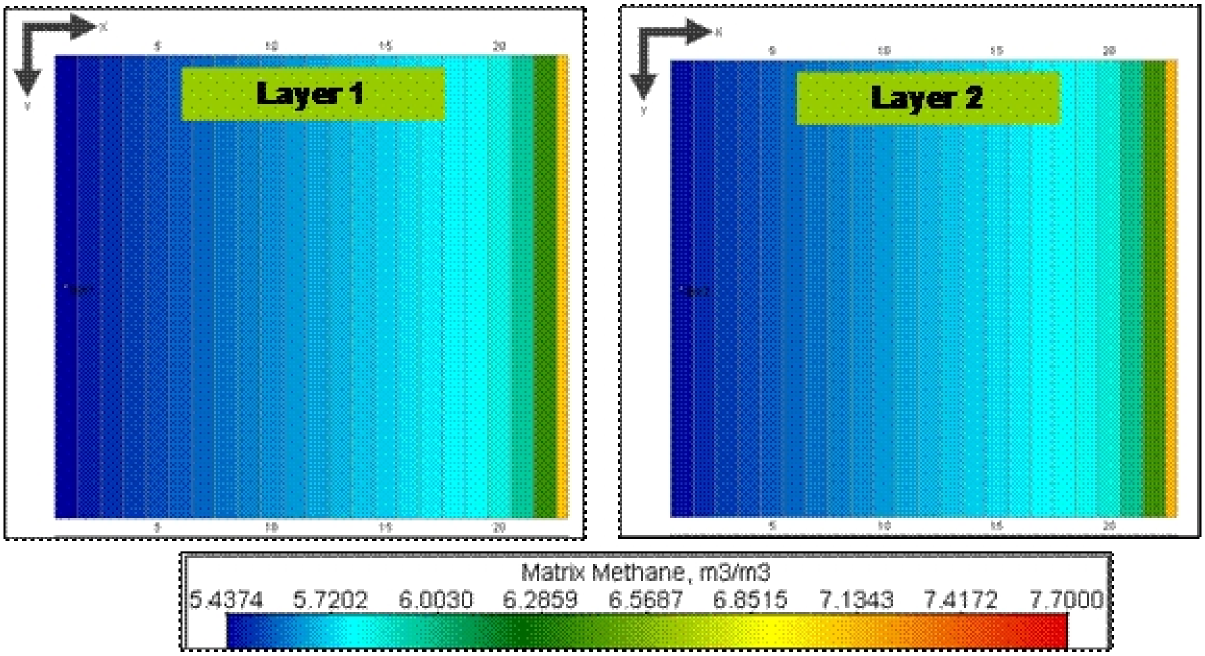


Figure 4-19: Scenario 2 – Simulated Reduction in Gas Content
220 m horizontal boreholes drilled in Seams 13-1 and 11-2 (Source: ARI)

4.5 Surface CMM/CBM Well Potential

4.5.1 Introduction

Currently, in-mine borehole drilling is the only technology employed for CMM drainage and production at Liuzhuang mine. However, there also is potential for drilling surface CBM/CMM wells near the mine to pre-drain the coal ahead of mining. Unfortunately, surface wells in China generally have a much higher risk of failure and are more expensive than in-mine horizontal boreholes. Also, surface wells have not been proven to be commercially successful to date elsewhere in the Huainan Coal Field region. At the Liuzhuang mine specifically, a relatively advanced surface-to-horizontal gob well was attempted several years ago, but with poor results. No vertical or horizontal CBM (i.e., completed directly in coal seams) pre-drainage wells have been drilled at Liuzhuang, nor does the mine currently plan to attempt any.

Surface CBM/CMM well designs include vertical frac and horizontal multi-lateral wells (Figure 4-20). CBM wells of these types are widely employed in the U.S., Canada, and Australia, with a total of more than 50,000 production wells currently in commercial operation, contributing substantially to national gas production in these countries.

Another surface drilling technique with potential for enhancing CMM drainage at Liuzhuang is the use of vertical gob wells to drain during and after mining and longwall collapse. Gob wells are discussed in Section 4.5.5.

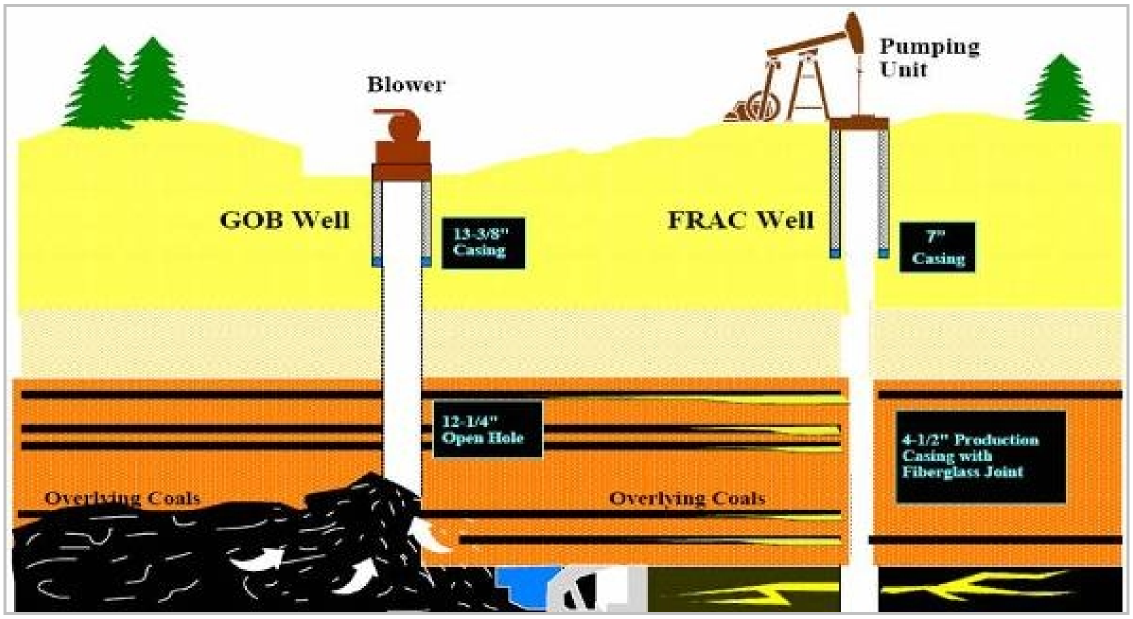


Figure 4-20: Vertical Frac Well Schematic
(Source: ARI)

After two decades of mostly disappointing trials, surface wells for CMM drainage are starting to be implemented on a large scale in several Chinese mining regions. As of 2008, roughly 1,800 to 3,400 vertical (data sources vary) and 25 horizontal multi-lateral CBM wells reportedly have been drilled in China. By far the greatest concentration of surface CBM well development has been in the geologically favorable southeastern portion of the Qinshui basin, Shanxi Province.[3],[4]

Surface drilling techniques, when effective, have major advantages that can augment the in-mine CMM drainage boreholes. CBM/CMM wells produce gas from areas not yet affected by mining and ventilation activities, thus producing high-methane CMM (typically 95% CH_4), much higher than the low (7-10%) methane concentration currently being drained at Liuzhuang. Gob wells typically produce CMM at a moderate (50% CH_4) methane concentration. If positioned close to planned mining, surface wells can capture methane that otherwise would be released during initial mine excavation and development, long before any in-mine drilling can be applied.

Ultimately, surface wells reduce the need for in-mine drainage, saving cost and improving the mine's productivity, and increasing the overall effectiveness of methane capture. Modern coal mining companies in the U.S. and Australia (such as Consol Energy, BHP Billiton, and Jim Walters Resources) typically apply an integrated program of both surface CBM and in-mine CMM drilling to maximize the efficiency of CMM drainage and coal mining.

[3] Qiu, Haijun, "Coalbed Methane Exploration in China," American Association of Petroleum Geologists, AAPG Annual Convention, San Antonio, TX, April 20-23, 2008.
[4] Huang, Shengchu, 2009. "Current Status of Methane Emissions Reductions in 4 Sectors, China." Methane to Markets, Steering Committee Meeting, September 30, 40 p.

However, during the near term at least, the potential for surface CBM/CMM wells at Liuzhuang mine appears to be rather limited and risky. Vertical well exploration drilling in the Huainan Coal Field, amounting to only a dozen or so wells drilled since 1992, has been mostly disappointing. This is thought to be due to the relatively low coal-seam gas content and permeability, as well as the physically weak and sheared mechanical properties of the coal seams.

China's largest and most successful surface CBM/CMM field is the southeastern Qinshui basin, Shanxi Province, where more than 1,000 vertical hydraulically fractured wells currently are in operation. These surface wells are capturing methane that otherwise would be emitted to the atmosphere during subsequent coal mining. Drilling continues in the Qinshui basin, with operators PetroChina, CUCBM, Lanyan (Jincheng Coal Group), and Green Dragon Energy adding several hundred new wells each year. There have been more than a dozen advanced horizontal multi-lateral wells, which are proving to be highly effective at pre-draining the Daning and Sihe mines.

To place China's experience with surface CBM/CMM development in context, it should be noted that other countries experienced a high initial failure rate for CBM/CMM development, even in the currently successful areas. Surface CBM/CMM and gob wells are now extensively employed on a large scale in the U.S. and Australia, but 10 out of the 13 currently successful CMM/CBM fields in the U.S. and Canada failed during initial testing and were abandoned, only to be commercialized years later once operators developed more effective well designs. For this reason, the capital risk profile for drilling vertical CBM/CMM wells is generally more suited for risk-diversified natural gas exploration and production companies rather than for coal mining firms, where the geologic risk is concentrated on a single locality (the mine).

Despite early setbacks, vertical CMM/CBM testing continues in the Huainan Coal Field. It is possible that new techniques will succeed, but this cannot currently be predicted. This evaluation does not recommend that SDIC-Xinji pursue surface drilling at the Liuzhuang mine at this time, because it appears that improving in-mine borehole drilling offers a more effective and low-risk near-term strategy. The following sections of the report provide more detailed analysis of the performance and potential for surface drilling in the Huainan Coal Field.

4.5.2 Previous Surface Well CBM/CMM Testing at Huainan

During the period 1992 to 2000, a total of at least eleven vertical surface CBM test wells were drilled in the Huainan Coal Field.[5],[6] These wells were not successful in establishing production,

[5] Zhang, Hong; Li, Guihong; Cui, Yongjun; and Jing, Xianglan, 2004, "The Evolution of CBM Reservoir-forming Dynamic System in the Huainan Coalfield, Eastern China." International Coalbed Methane Symposium, University of Alabama, Tuscaloosa, May 5-6.
[6] Yuan and Li, 2003.

although one well achieved a peak gas production rate of 5,000 m^3/day. If sustainable, this level of production would be economic. However, it appears that this rate was a short-term unsustained peak.

In 1995, the Huainan Coal Administration drilled and hydraulically fractured three vertical wells to degasify coal seams in advance of mining. Two of the wells were considered successful, producing about 1,000 m^3/day per well for 3 years. The gas reportedly was used to drive a generator set. In addition, a directional surface gob well also tried at the Liuzhuang mine which successfully produced gas as well. The local land owners/farmers would occasionally restrict access to the wellhead and demand compensation. No further information was available on these early surface drilling programs.

4.5.3 Current CBM/CMM Testing at Huainan

Surface CMM/CBM exploration and appraisal drilling continues in the Huainan Coal Field. Currently, the only vertical well CBM/CMM testing underway in the Huainan Coal Field is being conducted by Green Dragon Gas Ltd. (GDG), which holds a Production Sharing Contract (PSC) to explore for and produce CBM/CMM. GDG is a relatively small operator based in Hong Kong and listed on the London Alternative Investment Market. While most of GDG's activity has been focused on its Qinshui basin blocks, the company also operates the 584-km2 Panxie East PSC license in the eastern half of the Huainan Coal Field.[7]) This area has higher gas content than in the Liuzhuang mine area, located about 150 km to the west.

At the Panxie block in eastern Huainan Coal Field, GDG is targeting Seam 13-1 which, together with Seams 16 and 17, average 600-700 m deep and 6.5 m thick. (Note that Seam 13-1 is being mined at a similar depth at Liuzhuang mine.) An independent reserve study estimated 1.123 Tcf of total gas in place was present at Panxie East, of which 472 Bcf is considered prospective CBM/CMM resources.[8] Through 2008 GDG had drilled six vertical wells at Panjie East, of which five were completed open hole and dewatering on pump starting March 2008. The wells were not initially fracture stimulated.[9] No production results have been released.[10]

4.5.4 Advanced Horizontal Multi-Lateral Drilling Potential

Advanced horizontal CBM/CMM wells drilled from the surface and using multiple horizontal laterals can be highly effective for pre-draining CMM from the virgin coals near mines. Also known as "pinnate" wells, this technology was first developed by CDX Gas for coal mine degasification

[7] Green Dragon Gas Ltd., corporate press release, August 24, 2009.
[8] Green Dragon Gas Ltd., corporate presentation, March 2008.
[9] Green Dragon Gas Ltd., corporate annual report, 2007.
[10] Green Dragon Gas Ltd., corporate interim results, June 2009.

purposes at the U.S. Steel Pinnacle mine in West Virginia, U.S..[11] Horizontal multi-lateral CBM/CMM wells are now quite widely employed in certain geologically favorable basins, with a total of more than 1,000 wells producing in the Central and Northern Appalachian basins (U.S.), the Alberta basin (Canada), and eastern Australia. In addition, about 20 pinnate wells have been drilled in China to date.

Each pinnate well system actually comprises of a pair of wells: a vertical cavity-completed, cased-hole dewatering well that is penetrated by a separate multi-lateral open-hole, horizontal gas production well (Figure 4-21). Pinnate wells typically are drilled underbalanced with an air-mist mixture to minimize formation damage.

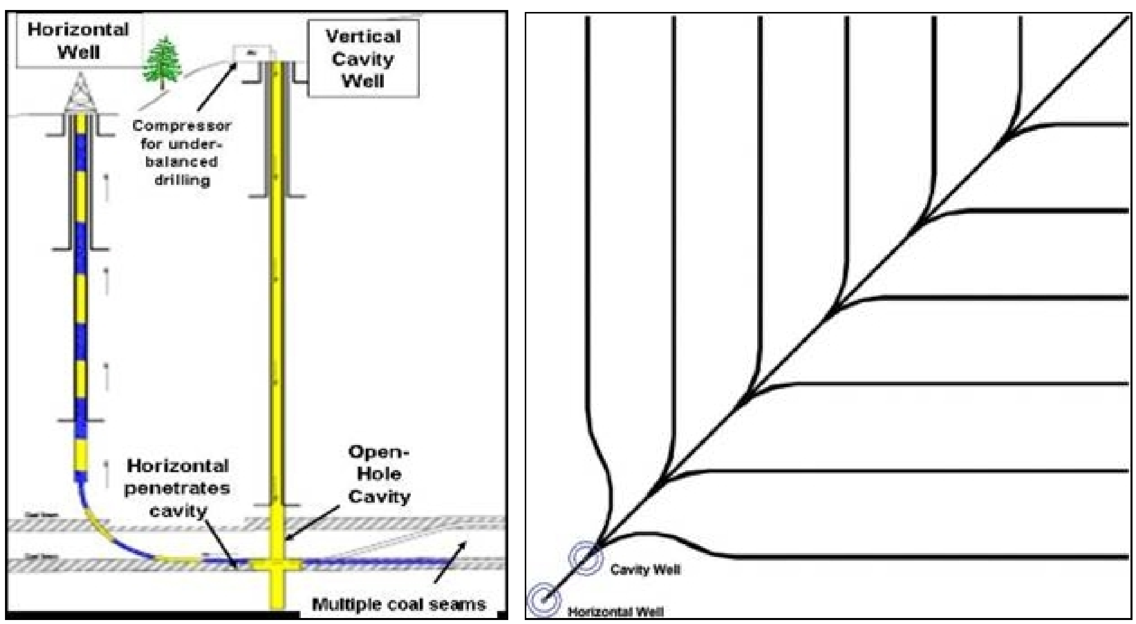
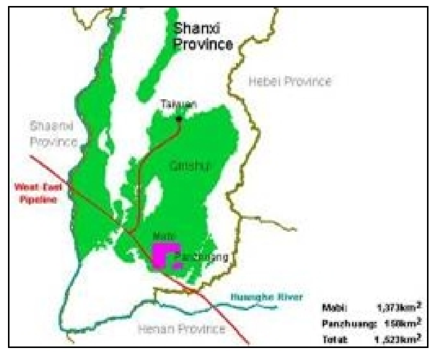


Figure 4-21: Horizontal Pinnate Well Schematic
(Side and plan views) (Source: von Shoenfeldt et al., 2004)

Starting about 2005, pinnate (or as they are more commonly known in China, horizontal multi-lateral "MLD") wells were successfully adapted to Chinese coal mine degasification by the Chinese company Beijing Orion Energy ("Orion"). Orion's most successful area has been in the southern Qinshui basin, especially the Daning and Panzhuang mine areas, where they have drilled at least six MLD wells in each area (**Figure 4-22**). The Orion MLD wells are located close to planned future coal mining and thus can be considered primarily CMM (rather than CBM) wells. In fact, one of the Daning MLD wells was on line less than five years degassing coal seam #3 before it was mined through.

[11] von Shoenfeldt, H., Zupanik, J., Wight, D., and Stevens, S.H., "Unconventional Drilling Methods for Unconventional Reservoirs in the US and Overseas." 2004 International Coalbed Methane Symposium, University of Alabama, Tuscaloosa, Alabama, May 3-7, 2004.

(by Aug 30, 2009)			
Block	Well	Starting Time	Cum. Gas Production (Mcf)
Panzhuang Block	PZP01-1	22 Oct 06	509,724.72
	PZP01-2	10 Nov 06	1,310,307.00
	PZP03-1	13 Nov 06	707,104.34
	PZP03-2	19 Dec 06	262,970.76
	PZP02-1	17 Jan 07	705,824.61
	PZP02-2	26 Jan 07	403,440.37



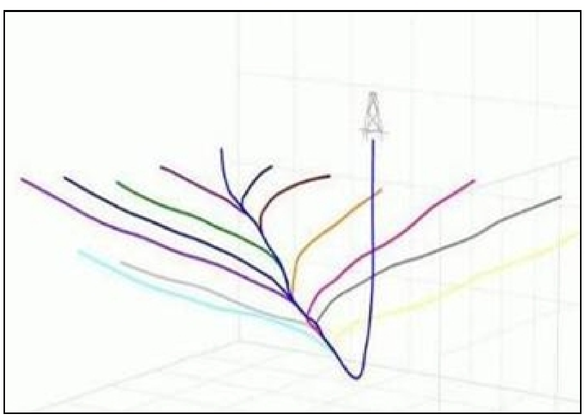


Figure 4-22: Horizontal Multi-Lateral Well Drilling
(Source: Beijing Orion Energy, ARI)

One of the Orion's Panzhuang wells (PZP01-2), which was drilled on a Production Sharing Contract controlled by Asian American Gas, Inc. (AAGI), is by far is the best performing CBM/CMM well of any type drilled in China to date. This well, including the laterals, required only 8 days to complete from spud (start of drilling) to total depth. Orion's MLD wells typically employ one main lateral and six side laterals using a 6-inch diameter hole. Hole length within the coal totals about 5 km in each well (much longer than the typically 100-m long in-seam boreholes drilled at Liuzhuang mine). The MLD wells are completed open-hole (not cased) and are not fracture-stimulated.

The Orion/AAGI Panzhuang well produced a maximum confirmed rate of 50,124 m^3/d (1.77 MMcfd) with casing pressure choke of 0.8 MPa,[12] reportedly peaking some months later at approximately 3 MMcfd. First placed on production in November 2006, the well has produced a remarkable total of 37 million m3 (1.31 Bcf) of high-purity CMM in less than three years.[13] MLD technology has proved extremely effective in pre-draining high gas content anthracite coals near the Daning and Sihe mines in the southern Qinshui basin.

Unfortunately, MLD technology does not appear to be feasible for application at the Liuzhuang mine. Unusual for China, the coal seams in the southern Qinshui basin are mechanically hard and stable anthracites, but still have some modest levels of permeability (~0.5 mD). These coals are highly suited to being drilled, completed and produced in an open-hole environment. Faulting is rare in the southern Qinshui basin and the dip angle is quite gentle (~5°).

In contrast, Liuzhuang and the other mines in the Huainan Coal Field are lower in rank (high-volatile Bituminous A), faulted and tectonically sheared, and mechanically weak and unstable. Powder coal in particular would be difficult to drill horizontally while maintaining an open hole. Faulting, fairly prevalent at Liuzhuang, would cause drilling problems as well as difficulty remaining in seam. Also, the dip angle is probably too steep (30°) for horizontal drilling. In summary, horizontal MLD drilling technology is not recommended for Liuzhuang mine.

4.5.5 Surface Gob Well Potential

Vertical wells drilled from the surface into the gob zone of longwall mines are commonly used for methane drainage in the U.S., particularly in the Warrior and Appalachian basins, but they generally have not been successful in China. This probably is due to the frequently soft nature of the coal seams ("powder coal") and the low permeability of the coal seams and interbedded clastic rocks.

Longwall mining of Seams 13-1 and 11-2 at Liuzhuang unavoidably releases methane from four overlying coal seams (14, 15, 16, and 17). Anticipating more serious methane influx and coal outburst hazards in the future as mining of Seam 13-1 moves to deeper areas, in 2007 the Liuzhuang mine conducted an experimental trial of vertical and horizontal directional boring into the gob zone. Vertical boring was conducted from the surface above the mining face. The well served a dual purpose: first, to pre-drain methane in the coal seams stratigraphically above Seam 13-1 (Seams 14, 15, 16 & 17) and, second, to discharge gas from the gob area once the mining face passed the vertical well location.

[12] China United Coalbed Methane Corporation Ltd., press release, February 14, 2007.
[13] Asian American Gas, Inc., website, August 31, 2009.

Rather than a simple vertical gob well, the design was an experimental vertical-to-horizontal surface well, making it one of the first such deviated gob wells attempted in any country.[14] The well was intended to evaluate methods for augmenting the relatively poor level of drainage achieved by in-mine horizontal boreholes at the mine.

Equipment installed for the gob drainage experiment consisted of surface vertical and horizontal directional boring, two units of 2BE1-303-series, with 560-kW power rating, as well as two 2BEY67-series mobile blowers powered by a 200-kW mobile diesel generator. The mine's monitoring system, a KJ90 series installed in May 2005, is considered very stable and capable of detecting power failure.

For the discharge pipe network, steel pipe of varying sizes was installed:

- Above ground section : diameter (ø) 820 mm, total length 80 m.
- Shaft section : twin main, ø426 mm, total length 1600 m.
- Ventilation discharge cross-cut : ø630 mm, total length 650 m.
- Mining face : ø325 mm, total length 2200 m.

Figure 4-23 shows a plan view of the layout for the surface-to-horizontal gob borehole that was drilled at Liuzhuang mine in 2007. The vertical borehole was located about 140 m from the initial mining position (in the direction of mining) and about 30 m from the return airway (in the direction of seam slope).

Figure 4-24 shows a cross-sectional view of the gob well hole, while Figure 4-25 details the well's casing string design. First, a large-diameter (311 mm) hole was drilled to about 20 m below the base of the unconsolidated Quaternary alluvium and then cased and cemented with 244.5-mm pipe to a depth of 390 m. Next, a smaller diameter (216 mm) hole was drilled to near the top of Seams 17 and 16. This was then cased with 177.8-mm diameter pipe to a depth of 581 m. Then, a 190-mm hole was drilled to total depth of 668 mm, through the section containing Seams 14 through 17, but remaining about 15 m above Seam 13-1. Finally, a 140-mm diameter perforated liner was hung across the future gob zone.

[14] Anhui Guotou Xinji Group Liuzhuang Mine Company Ltd. And Anhui Polytechnic University, "Coalbed Methane Gas Drainage Via Surface Horizontal Boring Research Report," 2007, 116 p. (in Chinese).

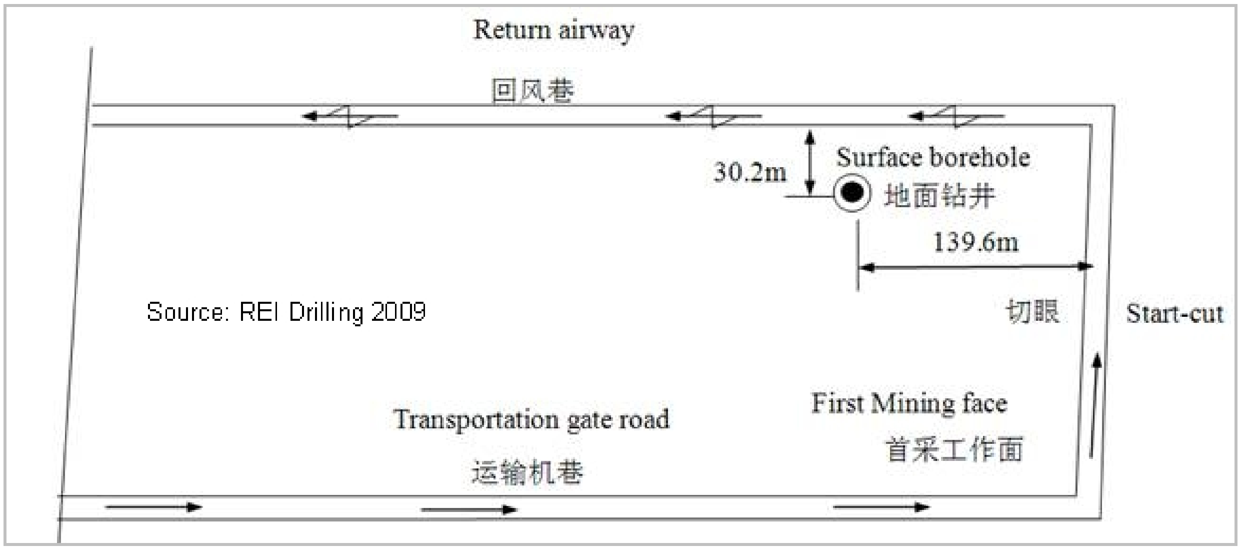


Figure 4-23: Surface to Horizontal Gob Borehole Drilled at Liuzhuang mine
Plan view

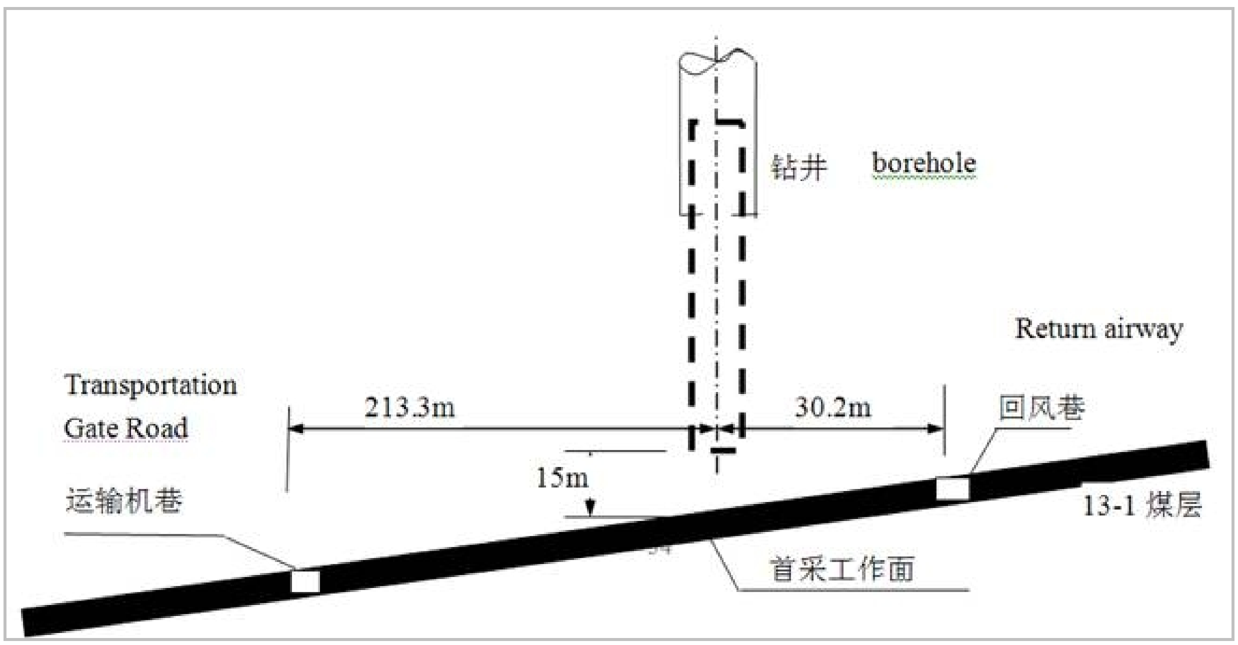


Figure 4-24: Surface to Horizontal Gob Borehole
Cross-section view (Source: SDIC-Xinji Energy)

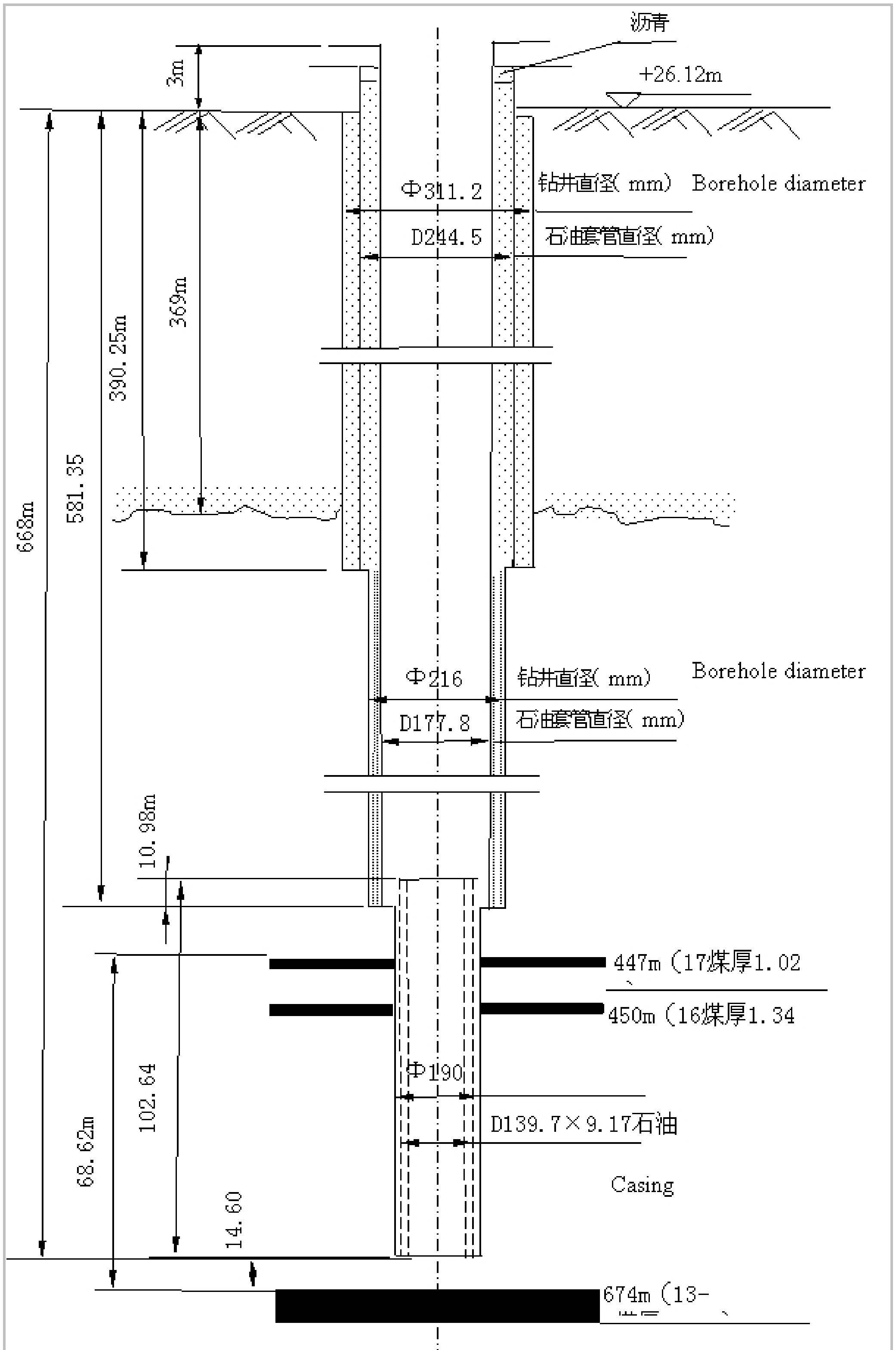


图3-3　垂直钻井结构示意图

Figure 4-25: Gob Well Casing String Design at Liuzhuang mine

Cross-section (Source: SDIC)

A surface gas control and measurement system was installed for testing the gob well. Pipe joints used flange connections or were welded. Gas rate was measured using an orifice plate meter, based on monitoring pressure and flow velocity.

Prior to drilling, the gob well was estimated to reach peak gas production of approximately 18,500 m^3/day (650 Mcfd) on Day 11 of production. This would be typical of vertical gob wells in the Warrior basin and Appalachian basin.

However, actual production from the gob well turned out to be only about one-fifth of the predicted flow rate. The combined methane drainage rate mostly ranged from 10 to 15 m^3/min, with a maximum stable rate of only 2.55 m^3/min (3,672 m^3/day). During the 332-m advance of the working face, the cumulative methane drained during the test totaled about 45,501 m^3.

In retrospect, it appeared that the base of the gob well was too close to the gob zone and may have been outside the zone of maximum cracking. This resulted in several negative results:

Production was probably negatively impacted by extreme subsidence and blockage by soft coal as the gob developed. For example, in the horizontal plane the borehole terminus was only 17 to 18 m away from Seam 13-1, whereas the model recommended a safe distance of at least 19.25 m.

In addition, the methane content was much lower than predicted. This indicates the gob well terminus was positioned too deep into the gob mixing zone and thus did not benefit from gravity stratification which tends to concentrate buoyant methane near the top of the gob.

In summary, surface gob well drilling technology is not recommended for Liuzhuang mine due to poor past performance in the Huainan Coal Field and high risk of future failure.

SECTION 5

Evaluation of CMM Utilization Technologies

SECTION 5 CONTENTS

SECTION 5 FIGURES

SECTION 5 TABLES

5.1 Section Overview

This study evaluated a number of potential options for utilizing coal mine methane produced at the Liuzhuang mine. A few options (such as gas turbines) were considered to be technically infeasible, while others (such as pipeline construction) were not currently cost effective at Liuzhuang.

In the end, the option of on-site power generation using 1- to 2-MW size internal combustion (IC) reciprocating engines stood out as the most feasible and economically viable option for utilizing CMM at Liuzhuang. Given the relatively small CMM volume produced at this mine and its low methane concentration, as well as the mine's considerable distance from urban and industrial users, the IC engine approach seems the most practical and cost-effective approach to utilize CMM at Liuzhuang. Increasingly, the IC power generation approach is being viewed in many parts of China as a preferred option for utilizing CMM supplies with low-moderate methane concentration.

There have been several recent studies of CMM drainage and utilization in China, at both the national level as well as for individual mines.[1,2,3] None of the previous mines evaluated closely resemble the specific geologic and mining situation at Liuzhuang mine, particularly the extremely low current methane concentrations. For this study, an optimal CMM recovery and utilization plan (presented in Section 6) was developed based on the analysis of the most appropriate technologies in this Section, the local market characteristics discussed in Section 3, and the CMM drainage system improvement program outlined in Section 4.

This section of the report discusses the technical and practical aspects of a wide range of utilization options, including power generation, LNG/CNG, pipeline construction, and gas processing to upgrade its quality. Ventilation air methane (VAM) mitigation also is discussed. Finally, the option of flaring the drained gas for greenhouse gas mitigation is presented.

5.2 Introduction

CMM utilization is a significant challenge at Liuzhuang mine because of the very low methane concentration (currently 7-10%), the relatively low to moderate flow rate (up to 37.5 m^3/min, recalculated at 100% CH_4), and the mine's significant distance from large urban or industrial gas markets (a rural setting some 70 km from the nearest metropolis, Huainan city).

[1] International Energy Agency, 2009. "Coal Mine Methane in China: A Budding Asset with the Potential to Bloom: An Assessment of Technology, Policy and Financial Issues Relating to CMM in China, Based on Interviews Conducted at Coal Mines in Guizhou and Sichuan Provinces." IEA Information Paper, February, 36 p.
[2] Raven Ridge Resources, 2009. "Feasibility Study of CMM Utilization for Songzao Coal and Electricity Company Coal Mines." USEPA Contract No. EPW05063 to 13, May, 150 p.
[3] Shi Su, Ting Ren, Rao Balusu, Andrew Beath, Hua Guo, Cliff Mallett, 2006. "Development of Two Case Studies on Mine Methane Capture and Utilisation in China." CSIRO Exploration and Mining, January, 48 p.

Additional utilization challenges include the high degree of variability in both CMM flow rates and methane concentrations, which may occur over time scales that range from short-term (minutes to hours) to medium-term (days to weeks). This variability distinguishes CMM fuel supplies from other, generally more stable, fuel sources (such as pipelined natural gas, LPG, etc.) and makes certain potential utilization processes impractical (notably, gas turbines).

Typically in underground coal mines, the CMM drainage flow rates will vary by 30-50% over the medium-term (months). Flow depends on which seams (some high gas, others lower gas) and which mine areas (with similar variation in gas content) are being mined. In addition, there may be short-term mining events affecting CMM drainage, which can be planned (machinery maintenance, repositioning of the longwall, etc.) or unplanned (accidental mining into an unmapped fault, sudden rock or gas outbursts, etc.).

This section of the evaluation considers various alternative CMM utilization technologies for the Liuzhuang mine including the following:

- Power generation using reciprocating engines
- Power generation using gas turbines
- Ventilation air methane (VAM) oxidation
- Transport via pipeline to urban, industrial, or village users
- Compressed natural gas (CNG)
- Catalytic oxygen removal
- Other methane upgrading technologies
- Liquified natural gas (LNG)
- Retrofitting boilers to CMM fuel
- Flaring CMM for greenhouse gas mitigation

5.3 China Government Policy Toward CMM Utilization

Early in 2006, China's State Council enacted policies to accelerate CMM and CBM utilization, requiring power grid companies to prioritize the on-grid sales of electricity generated by CBM. The State Grid currently guarantees that all surplus electricity generated by CMM/CBM plants can be sold on the grid.

One important step taken by the government in 2008 was the new regulation that coal mines must utilize CMM with CH_4 concentrations higher than 30%.

As a result of these policies, as of July 2009 China reportedly had 570 individual coal mine methane and coalbed methane power generators in operation and hooked into the state power grid in 10 provinces.[4] Installed capacity currently totals 484 MW, up from only 154 MW in 2007. According to State Grid statistics, CMM/CBM power plants generated 1.122 billion kilowatt hours of electricity during the first half of 2009. Some 42 percent of this electricity generated (473 million kilowatt hours) was consumed by the mine companies, with the remaining 58 percent (649 million kilowatt hours) sold into the power grid.

Most CMM/CBM power generators in China are fairly small capacity and locally made, but recently larger imported units with up to 3 MW capacity are being installed. The average generating unit size in China has increased to 784 kilowatts/unit, up from only 546 kilowatts in 2007.

5.4 Power Generation Using Reciprocating Engines

5.4.1 Introduction

First applied on a large scale in Australia, the use of CMM-fueled reciprocating engines equipped with generating sets to generate electric power has become a preferred option for CMM utilization in China. Today, this approach is being used successfully at numerous mines in China, where both medium- (30-50% CH_4) and low-quality (~6 to 30% CH_4) CMM is being utilized for power generation.

The power generation process typically works off of drained CMM stored in an above-ground storage tank (typically 30,000 m3 capacity), which is then pretreated for use in the reciprocating gas engines (Figure 5-1). The stored CMM is filtered for dust and particles through 10- and then 1-micron filters, dried to below 80% relative humidity, and then sent through a fuel train, where the pressure is regulated at 5 to 35 kPa. Following pretreatment, the CMM is sent through to the generator sets that are built close to the mining site and managed with switchgear to provide synchronization, voltage checks, loading and unloading of the engines and overall system protection.

[4] Huang, 2009.

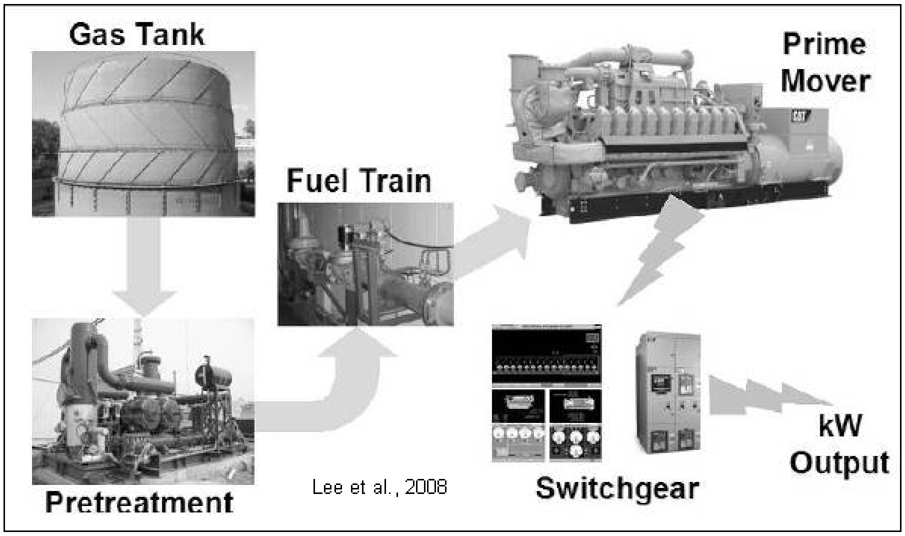


Figure 5-1: Stages of the CMM to Power Generation Process

Figure 5-2 shows the location of CMM projects in China that currently utilize Caterpillar reciprocating engines. (Other engine manufacturers also have installations in China but no map is available for them.) Caterpillar's largest project (108-MW) is at the Sihe mine near Jincheng, Shanxi, while much smaller installations of Caterpillar engines also are in operation at nearby Chengzhuang and Meiganshi mines. Further northeast in Shanxi Province, the Yangquan Coal Group has installed three Caterpillar engines totaling 5.4 MW installed capacity. Finally, Huainan Coal Group has installed two Caterpillar engines with 3.6 MW total capacity in the Huainan Coal Field in Anhui Province, approximately 50 km from the Liuzhuang mine.

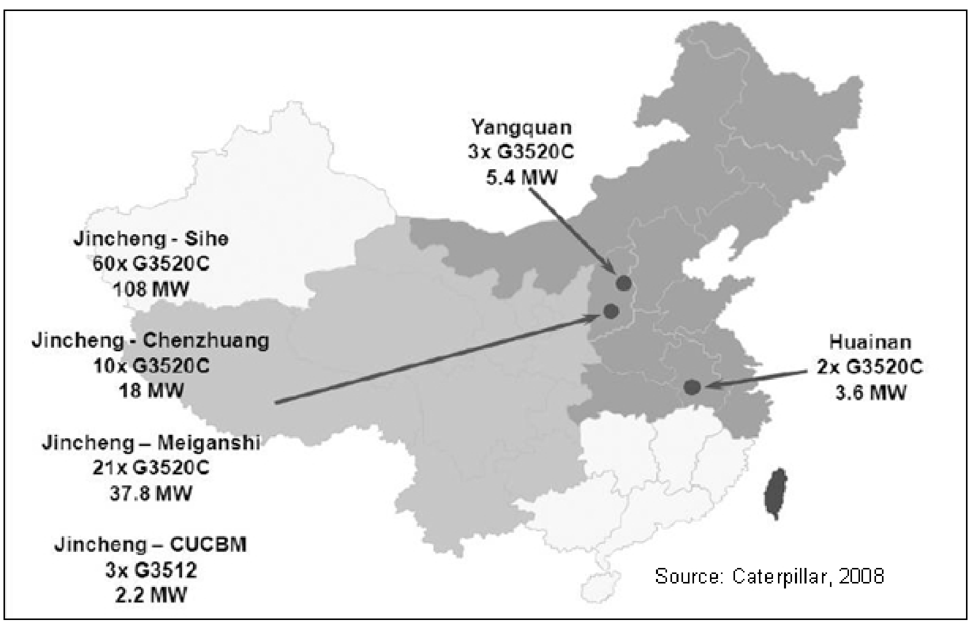


Figure 5-2: Location of China CMM Power Projects Using Caterpillar Reciprocating Engines

5.4.2 Medium-Quality CMM-Fueled Power Generation Projects

The overall operating efficiency of IC engines improves significantly within the 1- to 2-MW unit size range compared with smaller units, which have lower reliability and thermal efficiency. Furthermore, IC units larger than about 2 MW lack the flexibility to handle the variability in fuel concentration and volume that are characteristic of CMM projects. For these reason, IC units in the 1- to 2-MW size range are considered to have the optimal scale for power generation at coal mines in China and other countries.

As discussed in Section 4, although methane concentration at Liuzhuang mine currently is low (7-10% CH_4), it may be possible to boost fuel quality at Liuzhuang mine to a level of approximately 40% CH_4 through the implementation of improved borehole drilling and drainage practices. The higher methane concentration would enable the application of these more reliable and efficient 1- to 2-MW scale reciprocating engines for power generation.

Caterpillar, Deutz, and Jenbacher are three of the leading manufacturers of internal combustion engines that have been used to convert medium-quality (approximately 40% or higher CH_4 concentration) CMM to electricity in China and other countries. Below, the operating experience and equipment utilized at three significant projects employing these types of medium-quality IC engines for power generation is briefly summarized. These three locations are the Tower/Appin, Sihe, and Yangquan mines.

Tower/Appin. One of the first and largest CMM-to-power generation projects, as well as one of the largest installations of reciprocating engine-generators of any kind, was the 94-MW CMM-fired power station at BHP's Tower and Appin mines near Sydney, Australia (Figure 5-3).[5] Commissioned in 1996, this project consists of 94 individual 1-MW reciprocating engines.

Figure 5-3: Tower-Appin CMM-to-Power Station

[5] Lee, John, C.Y., Teo, Thomas, and Tnay, Choon Hwa, 2008. "Sustainable Application of Reciprocating Gas Engines Operating on Coal Mine Methane Gas." October, 11 p.

The Tower/Appin project consumes 600,000 m3/day of CMM (average 71% CH_4) drained from two separate mines. The fuel supply is supplemented with natural gas when necessary, such as during periods of reduced mining or CMM drainage activity. The Tower/Appin project employs 94 Caterpillar G3516 lean-burn generator sets, each of which produces 1,030 kW of continuous power. As of mid-2008, most of the units had completed 80,000 running operating hours.

The G3516 engine is a 16-cylinder bulldozer engine that is connected to a Caterpillar SR4 brushless generator. Housed in soundproof sheds, the 94 generator sets installed at the Tower/Appin mine complex convert about 280 m3/min (>20 MMcfd) of coal mine methane at 50-85% methane concentrations to generate 94 MW of electricity. That equates to a fuel-to-power conversion rate of approximately about 3 m3/min/MW (calculated at 100% CH_4). (A similar conversion rate was assumed for the proposed Liuzhuang mine project.)

The CAT3516 model also is the most widely used engine for moderate-concentration biogas projects, such as landfill gas utilization, which tend to have similar operating characteristics and challenges compared with CMM projects.

Sihe Mine Project. Modeled after the Tower/Appin power project, the recently constructed 120-MW project at Sihe mine located near Jincheng, southeastern Shanxi Province is the largest CMM-to-power project commissioned to date (Figure 5-4).[6] The Sihe mine project utilizes a total of 60 Caterpillar G3520C generator sets running on moderate-quality (~50% CH_4) CMM. The generator sets themselves produce over 108 MW of electric power. In additional, exhaust heat is recovered off the engines and used to drive steam turbines to produce an additional 12 MW of electric power. With jacket water heat recovery for hot water production, the total production target is a combined 120 MW.

Figure 5-4: 120 MW CMM-Fired Power Station, Sihe Mine, Shanxi Province
(Source: Lee et al.,2008)

[6] Lee et al., 2008.

The Caterpillar CAT3520 generator set also could be a suitable candidate for application at Liuzhuang mine. The CAT3520 is a 20-cylinder development of the original 16-cylinder CAT3516 design, which significantly increases its output. Its 1.8-MW size represents the largest and most efficient engine rating currently available for CMM or similar-fuel biogas projects, including those from other manufacturers. The CAT3520 uses over 90% of the CAT3516 moving parts, as well as 100% of the critical parts that are in direct contact with the combustion chamber.

The latest and most advanced version of this model (CAT G3520C; Table 5-1 and Figure 5-5) operates at 1,500 rpm with a continuous rating of 1,966 ekW under standard operating conditions. An open combustion chamber design allows it to operate using low-pressure gas supplies of just 5 to 35 kPa (0.7 psi to 5 psi). The low-boost pressure requirement reduces the installation cost of fuel treatment systems often found in low-energy fuel environments.

G3520C — CMM Fuel Specification				
Parameters		**Unit**	**Min**	**Max**
Concentration		volume %	25*	100
Supply Pressure at Engine Inlet		kPag	5	35
Supply Pressure at Fuel Train Entry		kPag	40	60
Rate of Change of Supply Pressure	Steady-State	kPad / second		0.69
	Transient	kPad / second		4.83
Particulates (Beta 200)		µm		5
Relative Humidity		%		80

Table 5-1: Caterpillar CAT3520 Generator CMM Fuel Specifications
(Source: Caterpillar)

This G3520C can utilize a wide range of CMM fuel concentration and so can remain useful throughout the life of a coal mining project. With special modifications, the CAT3520C can be adapted to utilize methane concentrations downs to about 25%. Also, with special pre-treatment it can utilize VAM as combustion air with up to 3% CH_4 concentration.

To compensate for the pressure drop across the gas train, the generator set would require a gas supply pressure of 40 to 60 kPa, with less than 0.69 kPa for steady-state or 4.83 kPa for transient per second of fuel pressure rate of change at the entry of the fuel train system.

Equipped with the ADEM™ III electronic control module, the generator set allows for full engine control from a single source. Its advanced air/fuel ratio control is designed for use without an oxygen sensor, allowing as high as a 19.2 bar BMEP rating while supplying high power density and meeting NOx emission levels of 500 mg/NM3. An optional NOx level of 250 mg/NM3 also is available through a 54°C separate circuit after-cooler system, providing greater emissions control for projects that must meet stricter local regulations or for project owners interested in pursuing carbon trading opportunities.

Source: Caterpillar, 2009

CAT GAS ENGINE

G3520C SCAC 4-stroke-cycle watercooled gas engine

Number of Cylinders	V20
Bore --- mm (in)	170 (6.7)
Stroke --- mm (in)	190 (7.5)
Displacement --- L (cu in)	86 (5248)
Compression Ratio	11.3:1
Aspiration	Turbocharged Separate Circuit Aftercooled
Cooling Type	Two-stage aftercooler, JW + O/C + A/C 1 combined
Fuel System	Low Pressure
Governor Type	Electronic (ADEM™ III)

CAT SR4B GENERATOR

Frame size	828
Excitation	Permanent Magnet
Pitch	0.7777
Number of poles	4
Number of bearings	2
Number of leads	6
Insulation	Class H
IP rating	Drip proof IP22
Alignment	Pilot shaft
Overspeed capability -- % of synchronous speed	125%
Waveform deviation line to line, no load	less than 3.0%
Paralleling kit droop transformer	Standard
Voltage regulator	CDVR
Voltage regulation with 3% speed change	+/- 0.5%
Telephone Influence Factor (TIF)	less than 50

Figure 5-5: Caterpillar Cat3520 Reciprocating Engine

Yangquan Project. Another significant CMM-to-power project utilizing reciprocating engines was recently initiated at the Yangquan coal mine complex in east-central Shanxi Province.[7] The project covers three mines operated by Yangquan Coal Group (YCG): Mine No. 5, Mine Nos. 2 and 3, and the Xinjing Mine. Separately, as discussed in Section 5.9, YCG also is evaluating the feasibility of a CMM-to-LNG plant at a different mine site.

First commissioned in May 2007, the Yangquan CMM-to-power project currently comprises three Caterpillar G3520C-CMM gas engines generating 1.8 MW each (5.4 MW total). CMM fuel is delivered at average methane concentration of approximately 40%, with significant short-term variations lasting several days to as low as 30% and as high as 48%. The generator sets are grid parallel, operate continuously, and have overall electrical efficiency of about 40%. Power generated from the project is used in the mine or sold back to the grid during times of low internal demand. Ultimately, YCG envisions the installation of as much as 90 MW capacity using CMM-fueled IC gas engines for power generation.

5.4.3 Low-Quality CMM-Fueled Power Generation Projects

The commercial utilization of low-concentration CMM (generally less than about 30% methane concentration) for power generation is unique to China. Coal mines and national safety regulatory agencies in other countries have placed priority on avoiding or minimizing contamination with ventilation air, through the use of improved in-mine and surface drilling, as well as drainage and pipeline systems that are less prone to air leakage. These steps, plus the commonly more favorable geologic drainage conditions, have resulted in coal mines in the U.S. and Australia capturing a more concentrated CMM stream, typically with 50-95% CH_4 levels.

However, many Chinese coal mines have been utilizing low-concentration methane. These projects generally employ Chinese-made Shengli engines that have been specifically designed to utilize this challenging fuel source. These engines utilize a computer-controlled carburetor device to control and optimize methane concentration of the input fuel gas to utilize low-quality CMM in the range of 6-30% methane concentration. In addition, water is injected during gas transmission to reduce the risk of explosion. A dehydration device later separates the water vapor from the gas, allowing the gas to be used for power generation.

[7] Yangquan Coal Mine Methane (CMM) Utilization for Power Generation Project, Shanxi Province, China: Monitoring Report. UNFCCC Project Number 0892, August 10, 2009.

For example, two Shengli low-concentration engines (500 kW each) already have been installed by SDIC-Xinji at the company's Xinji No. 2 mine (Figure 5-6). As of report time, SDIC-Xinji was still considering the installation of 8 x 500 kW Shengli low-concentration power plants at the Liuzhuang mine (no final decision had been made).

Figure 5-6: 500 kW Shengli Reciprocating Engine and Generator

5.5 Power Generation Using Gas Turbines

Gas turbines appear to be impractical for power generation at Liuzhuang mine. Gas turbines require a minimum methane concentration of approximately 50% CH_4. They also require quite stable CMM fuel supply and concentration over time, with only small fluctuations permitted during efficient operation.

However, owing to routine mining operations and typical geologic variations within the mine, the quantity and quality of methane tends to vary significantly and unpredictably at coal mines in China, far outside the practical range for operating gas turbines. For example, at Liuzhuang mine both the quantity and quality of CMM fuel commonly vary by +/- 30% over short (hourly) and medium (daily to weekly) time scales (Figures 4-7 and 4-8 in Section 4). To some extent, the use of surface gas storage tanks can help moderate these short-term volume and quality fluctuations. Nevertheless, the effective variability remains far outside the range for efficient turbine usage, which can only handle concentration variability of approximately several percent.

In one early but unsuccessful case study, during the mid-1990's the Songzao Coal Administration mine attempted to adapt a gas turbine for utilizing coal mine methane at one of their mines in

Sichuan under a UNDP-sponsored coalbed methane support project.[8] Following this disappointing trial application, turbines have widely been considered to be inappropriate for use under most China CMM utilization conditions.

Similarly, early application of gas turbines at coal mines in Australia were not considered successful. During the period 1984 to 1999, the West Cliff coal mine in New South Wales operated a 15-MW gas turbine fueled by CMM. Similarly, the Appin coal mine ran a 15-MW gas turbine during 1986 to 1995. Both of these mines had high methane concentration (>50%). Ultimately, excessively high maintenance costs and operating inefficiencies caused by variations in CMM concentration led to the decommissioning of these turbine units. They were replaced by IC engines.[9]

A more recent application of gas turbines has taken place since 2000 at the relatively small Akabira coal mine in Japan, where mining activity had ceased following cumulative production of about 40 million t of coal.[10] The abandoned workings of this mine produce approximately 3 m^3/minute of CMM with relatively high and stable methane concentration (80% CH_4).

The Japanese firm Kanamoto Company engineered and installed an array of five micro-turbines each with 6-kW capacity (total 30 kW). These micro-turbines, which were manufactured by Capstone Turbines (California, U.S.), are more commonly used for critical-needs, small-scale power generation applications, such as urban hospitals. The project, which has been funded by the research organization Japan Coal Energy Center (JCOAL), is not considered to be commercially viable but is run as a R&D demonstration.

In contrast, experience gained from over ten years of commercial operation at the Appin Mine in Australia, the past two years at Sihe mine near Jincheng, Shanxi, as well as other coal mines have demonstrated that internal combustion (IC) engines have much greater tolerance for the wide variations in methane concentration and supply that are typical of CMM production.

Based on site-specific conditions at Liuzhuang mine, notably the low absolute methane concentration and the temporal fluctuations in CMM quantity and quality, gas turbines are considered to be technically impractical for application at the Liuzhuang mine.

[8] Siegel, J.S., Liu, Huanjie, and Ancell, K.L., 1998. "Development of Coalbed Methane Resources in China: Report of the Evaluation Mission." United Nations Development Programme, Project Number CPR/92/G31/A/IG, November, 53 p.
[9] Black, D. and Aziz, N., 2009. "Reducing Coal Mine GHG Emissions through Effective Gas Drainage and Utilisation." Coal Operators' Conference, University of Wollongong & the Australasian Institute of Mining and Metallurgy, p. 217-224.
[10] Hirasawa, Hiroaki, 2003. "Coal Mine Methane Project Conducted by JCOAL."

5.6 Ventilation Air Methane (VAM) Oxidation

Ventilation air methane (VAM) is a significant component of overall methane emissions from coal mines and a number of technical applications for VAM utilization or mitigation are under development. These applications include direct use as a principal energy source in oxidation units, lean-burn turbines, and kilns, where it is mixed with coal fines or other combustible materials. In addition to direct greenhouse gas abatement, it is also possible to recover and transfer the heat produced from this oxidation to generate electricity.

Currently, there is only one VAM power generation project in commercial operation, a 6-MW MEGTEK Vocsidizer application in Australia that was commissioned in 2007. This technology employs a reverse-flow oxidization reactor along with a steam turbine to utilize 250,000 m^3/hour of VAM. Other pre-commercial VAM projects are currently underway in the U.S., Canada, and U.K.[11]

Unfortunately, the methane concentration in the ventilation air at Liuzhuang mine is extremely low, averaging only about 0.02% by volume. Currently, commercially available technologies to mitigate VAM (via thermal oxidation) require CH_4 concentration to be at least 0.2% (Table 5-2**)**. Thus, Liuzhuang mine VAM is far too dilute and does not appear to be a viable candidate for VAM mitigation.[12,13]

Parameter	MEGTEC TFRR	CANMET CFRR	CSIRO CMR	EDL Turbine	CSIRO Turbine	Ingersol Rand Turbine
Minimum CH4 Concentration	0.2%	0.1%	0.4%	1.6%	1.0%	1.0%
Minimum Plant Size	Huge	Large	Small	Small	Small	Small
Application to date	Field	Bench	Bench	Pilot	Bench	Field

Table 5-2: Minimum Methane Concentrations Required for various VAM Technologies

Elsewhere at high-gas mines in the Huainan Coal Field, the Huainan Coal Mining Group, China Coal Information Institute, and MEGTEC Systems have jointly evaluated a VAM power generation project to utilize Vocsidizer technology for power generation using low-concentration VAM. A pre-feasibility report supported by USEPA has been completed for that site.[14]

[11] Black and Aziz, 2009.
[12] Mattus, R., 2006. "VAM to Electricity – 1st Large-Scale Installation." Proceedings of the International Coalbed Methane Symposium, University of Alabama, Tuscaloosa, May 22-25.
[13] Mallett, C., 2004. "Developing a Diverse CMM Industry including VAM Utilisation." Methane to Markets Ministerial Meeting, 15-17 November 2004, CSIRO, Australia.

[14] Huang, Shengchu, Liu, Wenge, Sun, Qinggang, Liu, Xin, Zhao, Guoquan, and Dou, Xiaodong, 2006. "Analysis of Potentials and Prospects of CMM Project in China Through Methane to Markets Partnership" (sic). Proceedings of the International Coalbed Methane Symposium, University of Alabama, Tuscaloosa, May 22-25.

5.7 Transport via Pipeline to Urban, Industrial, or Village Users

Liuzhuang mine is located about 70 km west of Huainan city in a rural, mostly agricultural area. Upgrading the methane concentration to approximately 40% may be achievable with the drilling improvements recommended in this report. That would enable Liuzhuang to utilize more reliable and more efficient larger reciprocating engines (1- to 2-MW unit size). Shengli, Caterpillar, Deutz, and Jenbacher have installed these types of units in numerous Chinese coal mines, with the largest array featured at the 120-MW Jincheng power plant in Shanxi Province that was commissioned in 2007.

Given the small volume of CMM supply from the mine and its relatively low concentration, as well as the mine's distance from sizeable cities and industrial users, it would be far too costly to build and operate a gas pipeline. SDIC-Xinji also considers the local village markets to be too small and unable to afford the market price for CMM at Liuzhuang mine. As discussed in Section 9, the alternative use of CMM as fuel for power generation provides it with a value that is considerably more expensive than the current village practice of obtaining energy form low-quality, locally mined coal as well as from agricultural waste.

Pipeline costs are fairly well established in China, compared with the other technologies discussed in this chapter. Thus, it is worth considering the capital costs for a low-pressure 40.6-cm diameter, 70-km long pipeline to Huainan city. Based on typical unit costs of $7,600 per cm-km ($30,000 per inch-mile), total capital costs would be approximately $21 million. By comparison the 5-year gross revenues from gas sales would total only about $18 million, assuming 105 million m^3 is produced at a drainage rate of 40 m^3/min and then sold at the current price of 1.2 RBM/m^3 ($5.00/Mcf). This would not even cover return of the initial capital, much less operating and maintenance costs of the pipeline or return on capital.

5.8 Catalytic Oxygen Removal

Another potential commercial method to enable utilization of CMM supplies at Liuzhuang mine would be to remove the oxygen using a catalysis. This process is occasionally use to treat natural gas that is slightly below pipeline specification, specifically to remove all of the oxygen from the CMM stream, which mostly originated from contamination with mine ventilation air.

Unfortunately, catalytic oxygen removal does not reduce nitrogen levels. In fact, applying this method at Liuzhuang mine actually would concentrate the remaining N2 from approximately 68% in the initial raw CMM stream (assuming 10% CH_4 initial concentration) to nearly 88% following oxygen removal. Methane levels would increase commensurately to about 12%, still a very low concentration. The resulting methane/ nitrogen mixture would remain difficult to utilize.

Catalytic oxygen removal is not a particularly widely used technology, but it has been used at selected coal mines in the U.S. to treat CMM that already is relatively high in methane content (70-90%), though still slightly below pipeline specifications. After treatment, the CMM is then sold to a pipeline as high-quality natural gas.

In one recent coal mine application, catalytic oxygen removal has been used since 2006 to treat gob gas at the Tower mine in Carbon County, Utah, U.S.[15] This longwall mine generates a large gob zone that extends an estimated 110 m above and 15 m below the main seam, fracturing the surrounding coal and tight sandstone formations and releasing extensive CMM volumes. After mining the longwall panels are sealed to isolate and concentrate the gob gas. In certain mining aspects the Tower mine resembles Liuzhuang.

The Tower mine utilizes unstimulated vertical surface gob wells to produce CMM. Methane concentration is about 75% in the unsealed gob areas during mining, increasing to 94% in the post-mining sealed gob (both of which are far higher than at Liuzhuang currently). A skid-mounted catalytic combustor is used to reduce oxygen levels from about 2% by volume at gas inlet to under 10 ppm after processing. Heat generated by the combustor is simply dissipated, though in other applications the heat might be recovered and utilized if practical. Gas flows of up to 127,000 m^3/day (4.5 MMcfd) have been treated at this plant.

After treatment with a nickel platinum catalyst, the CMM gas is transported about 8 km via a 10-inch diameter pipeline to a gas processing plant for further CO2 and water removal. Finally, the gas is sold through an interstate pipeline.

Gas sales from Tower mine reached 56,000 m^3/day (2 MMcfd) in 2007 and were expected eventually to reach the unit's capacity of 227,000 m^3/day (8 MMcfd). Despite operating in a harsh climate at 2,300 m (7500 ft) elevation, with wide temperature swings, run time has been high (99%). Five-year, full-cycle treatment costs for the Tower mine plant were estimated to be about \$0.59/m^3 (\$0.021/Mcf), which is considered to be economically viable for this particular application.

5.9 Other Methane Upgrading Technologies

Several other technologies exist for potentially boosting the methane content of CMM at Liuzhuang mine. These include cryogenics, pressure-swing adsorption, and molecular gate techniques.[16]

[15] Rhodes, Q. Zane II, 2008. "O_2 Removal Key to Tower Mine Project." American Oil and Gas Reporter, May, p. 132-139.

[16] Carothers, F.P. and Schultz, H.L., 2008. "Upgrading Drained Coal Mine Methane to Pipeline Quality: A Report on the Commercial Status of System Suppliers." United States Environmental Protection Agency, EPA-430-RO8-004, January, 26 p.

However, the main problem for these methods is that Liuzhuang mine is starting with very low methane concentration (7-10% CH_4), whereas these technologies normally are practical only at much higher methane purity (>50% CH_4) as well as larger plant scale.

Cryogenic Upgrading. The upgrading method with most experience of upgrading CMM gas quality is the use of cryogenic technology to separate nitrogen and other unwanted gases from methane in the CMM stream, resulting in pipeline-quality natural gas.

Jim Walters Resources (JWR), one of the earliest CMM and CBM operators in the U.S., operates a cryogenic methane upgrading process for gob gas produced at three deep longwall mines in the Black Warrior basin, Alabama (Figure 5-7).[17] During the initial decade of CMM drainage at these mines, JWR's gob well production was simply mixed with a larger volume of pure CBM production from vertical frac wells to generate a blended pipeline-quality gas. However, when mining ceased in the older gob areas, the methane concentration in the gob wells gradually deteriorated to unacceptably low levels, so that blending no longer was feasible.

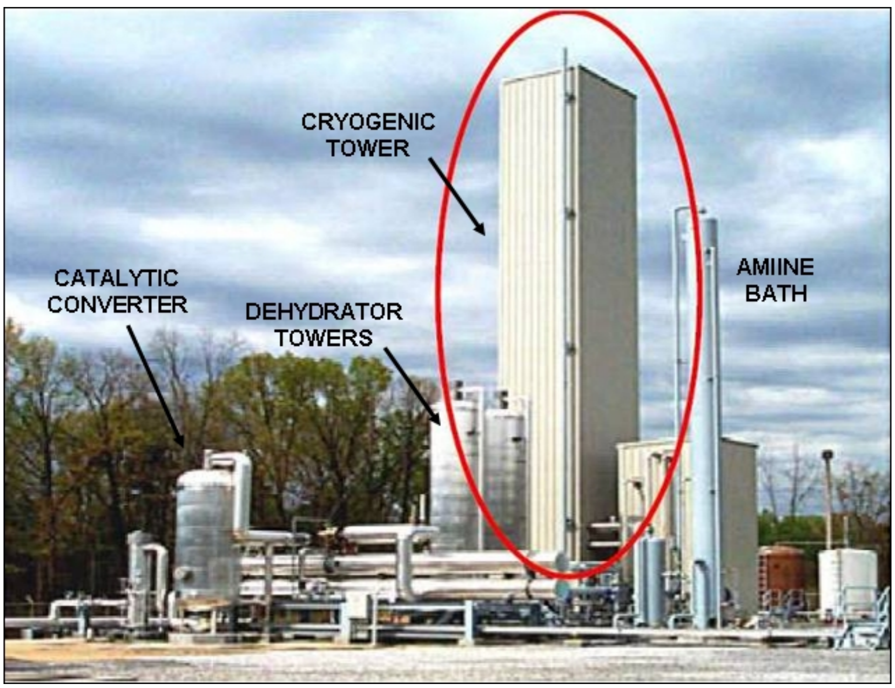


Figure 5-7: Cryogenic Gas Processing Plant
(Jim Walters Resources mine in Alabama, U.S.) (Source: Katz, 2006)

JWR considered utilizing their low-quality CMM as fuel for power generation using turbine or reciprocating engines, or perhaps upgrading it to pipeline quality gas using pressure-swing

[17] Katz, Richard, 2006. "Cryogenic Methane Extraction in the Alabama Coal Fields." International Coalbed Methane Symposium, University of Alabama, Tuscaloosa, May 22-25.

absorption. However, these methods were rejected as not practical or economic for their particular application, probably because the initial methane concentration was already quite high (65-70% CH_4). In 2000, JWR hired contractor BCCK Engineering, Inc., which also operates its technology at two other U.S. coal mines, to develop a cryogenic process that would boost methane concentration of the gob gas to pipeline quality.

The JWR-BCCK cryogenic plant was designed with throughput capacity of about 340,000 m^3/day (12 MMcfd). On average, the gas produced from the inactive mine gob areas consists of methane (65 to 70%), nitrogen (28%), CO2 (3%), ethane (1%), and O2 (1%), as well as varying amounts of water. After processing the upgraded gas stream consists of at least 96% methane, which is considered pipeline quality.

The first process used in JWR's cryogenic plant employs two stages of compression to boost the produced gob gas pressure from the initial 15-psi inlet to about 300-psi outlet. Small amounts of hydrogen sulfide are then removed using carbon absorption. Oxygen (1%) is removed using catalytic combustion (Ni-Pt catalyst). A heat exchanger cools the gas and is used again to dry the gas later in the process. The minor (initial 3%) carbon dioxide is dissolved in a recirculating amine bath and then boiled away with CO2 emitted to the atmosphere. Water is removed using a dual-chamber molecular sieve dehydrator.

The final stage of the process is nitrogen removal. Nitrogen, by far the largest contaminant, is removed by cryogenically liquefying the other gas components at -215° F. This leave nitrogen is the gas phase and separation is a simple step. The concentrated liquid methane is then moved across the heat exchanger off the catalytic combustor and regasified.

Plant maintenance is significant, requiring about 25 hours of down time per month, mainly to service valves and filters. Otherwise the plant performs reliably and runs fairly continuously (24 hours per day, 7 days per week). BCCK considers their cryogenic process to be economic at this Black Warrior basin application at a minimum natural gas price of about $3.50/Mcf.

However, cryogenic processing is not economically feasible for Liuzhuang mine. It should be noted that pipeline and surface infrastructure already was in place at this mine site, which saved significant cost compared with constructing a plant at Liuzhuang. Also, JWR's surface gob wells which provide the CMM input are highly productive, thanks to favorable geologic conditions, whereas gob wells have not worked effectively and are not economically viable at Liuzhuang. Furthermore, the minimum plant scale is about 10 times larger than Liuzhuang's current CMM drainage. Undoubtedly, the principal reason arguing against the use of cryogenics at Liuzhuang is the low CH_4 concentration (7-10% vs 65-70% at the JWR plant), and the resulting high energy costs to compress and chill the much larger input gas volumes.

In summary, the use of cryogenic separation technology to boost methane concentration does not appear to be a viable technical option for the CMM at Liuzhuang mine. Again, the main problem is that methane concentrations are far too low at Liuzhuang and the energy requirement needed to chill and process the CMM are far too high. A second drawback is that high-productivity surface gob wells may be needed to produce sufficient gas for the minimum feasible plant scale, which is about 10 times the size of current drainage at Liuzhuang mine.

5.10 Cryogenic Technology to Convert CMM to LNG

A variant of the cryogenic process discussed above is to maintain concentrated methane in the liquid state for sale directly as liquefied natural gas (LNG), which is methane chilled to a liquid state, rather than heating and re-gasifying the LNG for use in a pipeline, turbine, or engine. China now has world-class small-scale LNG production and distribution capabilities, at least for high-purity natural gas input streams.

For example, in 2002 the Henan Zhongyuan Green Energy Hi-Tech Co. Ltd. (based in Puyang, Henan Province) -- a spinoff of Sinopec -- constructed China's first commercial LNG production facility at the Zhongyuan oil field. The plant has a design capacity of 55 million m^3/year. LNG produced at the plant is delivered by a fleet of 18 specialized road tankers to LNG storage tanks at end users in cities such as Beijing.[18] Separately, the Jincheng Coal Group operates a CBM-to-LNG plant in Shanxi Province, but this project utilizes high-purity methane (95% CH_4) as its input.

Converting lower quality CMM to LNG also may be practical, albeit more energy intensive than using high-purity natural gas feedstock. At least two small-scale CMM-to-LNG projects have been proposed or are undergoing pilot testing in China, one in at the Yangquan coal mine in Shanxi Province and a second at the Songzao coal mine in Sichuan Province.

Yangquan, Shanxi. Yangquan Coal Group Ltd. (YCG), China's largest CMM producer, is evaluating the construction of a small-scale CMM-to-LNG project at its Shigang coal mine in Shanxi Province.[19] The Shigang mine started production in 2004. Coal rank is anthracite, with moderately high gas content (13 m^3/t) and low-moderate permeability (0.5 mD). Current coal output is approximately 800,000 t/year and scheduled to increase to about 900,000 t in 2010.

[18] Fortune Oil PLC, Annual Report, 2008, 106 p.

[19] Yangquan Coal Group, Methane to Markets Poster, 2009.

CMM drained at Shigang mine has methane concentration ranging from 30% to 50% (average 40%). The current CMM drainage rate is about 10 m^3/min, nearly all of which is vented. An additional 7.6 m^3/min of CMM is released by the ventilation system as very low quality methane (0.5%).

As currently envisioned the project would concentrate CMM that is currently being emitted to the atmosphere to generate town gas quality product. The $7.5-million plant would use cryogenic liquefaction and separation technology. It would utilize about 4,300 m^3/day (6 m^3/min) of CMM feedstock to produce approximately 20,000 t/year of LNG, generating annual emission reductions estimated by Yangquan to be up to 400,000 t CO2e.

As a preliminary test, YCG constructed a small-scale CMM-to-LNG plant with 4,300 m^3/day capacity that produces 1.22 t/day of LNG (Figure 5-8). (For comparison, the capacity of Yangquan's test plant is about 3 m^3/min, less than 10% of Liuzhuang's current CMM drainage rate.) If successful, the $7.5-million plant would handle up to 60 m^3/min CMM input and generate 20,000 t/year of LNG, which would be re-gasified and used in the local town gas system.

Figure 5-8: Test-Scale CMM-to-LNG Plant, Shigang mine, Shanxi Province
(Source: Yangquan Coal Group, 2009)

Songzao, Sichuan. A second small-scale CMM-to-LNG is under consideration at Songzao in Sichuan Province.[20] As of late 2007, the mine was producing about 400,000 t/year. Methane drainage was about 32 m^3/min, which is comparable in size to the Liuzhuang mine. However, the methane concentration of the drained gas was much higher, averaging about 45%.

[20] Raven Ridge Resources, 2009.

In summary, cryogenic conversion of CMM to LNG does not appear to be the most practical option for utilizing CMM at Liuzhuang mine, particularly compared with the proven technology and plant-scale flexibility of power generation using IC engines.

5.11 Retrofitting Boilers to CMM Fuel

CMM is often used as a boiler fuel in China for residential and commercial hot water and space heating purposes. For example, during 2004-2007, the Huainan Coal Group reportedly retrofitted a total of 14 boilers with capacity of 4 tons each at seven coal mines located near urban areas in the Huainan Coal Field. Formerly fueled with coal, these boilers were converted to utilize CMM. In total, the boilers combust 65.8 million m^3/year of CMM, equivalent to estimated emission reductions of 1.67 MtCO2eq per year.[21]

Unfortunately, unlike the relatively urban eastern portion of the Huainan Coal Field, the Liuzhuang mine is located in the rural western region and opportunities for use of CMM in boilers is very limited. The residential blocks adjacent to the mine are equipped with small boilers. However, these boilers are capable of using low-quality (high-ash) coal, which is not readily marketable, in abundant supply, and essentially a free fuel for the mine. Therefore, CMM-fired boilers do not appear to offer a cost-effective option for utilizing the drained methane compared with power generation. In addition, the current methane concentration (7-10%) in the drained CMM is much too low to be used in a standard gas-fired hot water boiler, which much like the flaring mitigation technology discussed below requires at least 25% CH_4 concentrations.[22]

Alternatively, CMM could be co-fired along with coal in boilers at Liuzhuang mine. However, disadvantages include the fact that mine boilers are not used continuously, output has wide seasonal fluctuations (weather, climate), as well as the very limited local demand for boilers. SDIC-Xinji estimates that converting its boilers entirely to CMM (not feasible given current low CH_4 concentrations) would only utilize about 10 m^3/minute of the 37.5 m^3/minute CMM supply it expects by 2011. Overall, CMM utilization in boilers is a less attractive option compared with IC power generation.

[21] Yuan, Liang, Zhang, Bingguang, Zhang, Ping and Zhou, Deyong, 2007. “New Progress Made in Huainan Mining Area CMM Extraction Technologies and Options of Emission Reduction and Utilization.” Huainan Coal Group, 8 p.
[22] Alternative Energy Development, Inc., 1998. “Technical and Economic Assessment of Coal Mine Methane in Coal-Fired Utility and Industrial Boilers in Northern Appalachia and Alabama.” United States Environmental Protection Agency, 430-R-98-007, April, 46 p.

5.12 Compressed Natural Gas (CNG)

Compressed Natural Gas (CNG) is methane that has been compressed to less than 1% of its volume at standard temperature and pressure conditions, enabling it to be stored and transported in strengthened containers at pressures approximately 200-220 bar (2900-3200 psi). Currently in China, CNG is widely used as a gas source for residential and industrial users and, increasingly, as a vehicle fuel.

Although macro conditions in China certainly favor the use of CNG, the current low concentration of methane at Liuzhuang mine (7-10%) makes it costly to compress CMM for CNG use. Even if methane concentration is improved to around 40%, as anticipated with the recommended borehole drilling improvements, vehicles and other potential CNG end users in China are unlikely to be equipped to utilize such low-purity fuel.

5.13 Flaring CMM for GHG Mitigation

5.13.1 Introduction

Should direct or indirect utilization somehow prove to be impractical at Liuzhuang mine, a final option to consider would be the feasibility of flaring the captured CMM stream. Although less efficient or desirable than utilization, flaring could be an option for remote CMM facilities where utilization is more challenging, and at least could reduce the overall GHG potential of emitted CMM.

One of the positive factors of flaring CMM is the potential for significant GHG reduction. In addition, it is a simple technology with low capital and operating costs, is generally reliable to operate, and requires a short manufacture and installation lead time. Installation requirements include a methane flow rate of at least 80 liters/second of pure methane flow, with methane concentration of at least 20%.

Apart from costs and feasibility, an important consideration is safety. Specifically there needs to be suitable flame arrestor technology installed to prevent flame propagation back into the mine. Although European mine safety regulators have permitted flaring projects to take place at coal mines, this particular safety issue is of great concern for both US and China mine safety regulators. It is not clear whether flaring would be permitted at all under current regulations in those countries.

Conventional open flares actually have low combustion efficiency, as little as 60%. Advanced flaring technology, such as that developed by the German engineering company Haase Energietechnik AG, can increase the efficiency of gas combustion to as high as 99.9%.[23]

Modern flaring projects are skid mounted for ease of installation, and are automatic and/or remotely controlled via internet connection. To protect against lightening as an unintended ignition source, multiple failsafe concentration transducers are employed to automatically interrupt the supply of gas to the extraction pumps and the flare.

5.13.2 Flaring Projects.

Since 2004 Harworth Power (UK) has been operating a CMM flaring project at the suspended Harworth coal mine, which employs one enclosed flare combusting 2,000 m^3/hour (33 m^3/minute) of CMM with 45-55% CH_4 concentration.[24] Similar sized flaring projects also are underway at Harworth's Kellingley (40-50% CH_4), Thoresby (30-40% CH_4), and Welbeck (35-45% CH_4) coal mines. By comparison, the flow rates at these individual projects are approximately one-third higher than the current CMM drainage rate from boreholes at Liuzhuang mine, thus on a scale basis alone have at least some applicability.

5.13.3 Applicability to Liuzhuang

Harworth's experience in the UK indicates that sustained flaring requires CH_4 concentrations of at least 25% (27% for a reliable flare start). However, current methane concentration in CMM drained at Liuzhuang mine is only 7 to 10%, which is much too low for flaring. Assuming the recommended borehole upgrades are able to boost methane concentrations to about 40%, the IC power generation option would have an overall positive rate of return (Section 9), making it demonstrably a better approach than simple flaring. In addition, it is unlikely that Chinese coal mine regulators would permit flaring projects under current regulations. Therefore, flaring is not recommended as a mitigating technology for Liuzhuang mine.

[23] Clarke Energy, 2007. "The Modern High Temperature Flare." U.S. Coal Mine Methane Conference, St. Louis, Missouri, U.S., September 26.
[24] Harworth Power Ltd., 2007. "CMM Flaring." U.S. Coal Mine Methane Conference, St. Louis, Missouri, U.S., September 26.

SECTION 6

Technical Analysis and Preliminary Engineering Design

SECTION 6 CONTENTS

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SECTION 6 TABLES

6.1 Introduction

This section presents the technical analysis and preliminary engineering design for a proposed coal mine methane drainage and utilization improvement project at SDIC-Xinji Energy's Liuzhuang mine, located in the Huainan Coal Field, Anhui Province, China. The design is based on the mine-specific data and evaluation discussed in detail in previous sections of this report. It also draws upon experience gained from other, often larger-scale CMM drainage and power generation projects that have been operating for the past several years at coal mines in China, Australia, and the U.S..

In summary, the proposed Liuzhuang CMM utilization project has two principal engineering components (Table 6-1): a) Equipment and technical process improvements for the borehole drilling and drainage systems, comprising three sub-areas (drilling, borehole grouting, and pipeline upgrades); and b) Installation of small-scale power generation at the mine using reciprocating internal combustion (IC) engines, which has been configured to use the moderate-quality CMM fuel (40%) that is projected to be produced as a result of the borehole and drainage upgrades.

Component	Technology	Number of Units	Anticipated Benefit
Borehole Drilling	Directional Drills	2	Longer, precise borehole placement, higher methane concentration
Borehole Wellhead	Improved Grouting	-	Reduced air leakage, higher methane concentration
CMM Pipeline	Fused HDPE Pipeline	2	Reduced air leakage, higher methane concentration
Power Generation	IC Engine Generators	10 x 1.255 MW	CMM utilization, high efficiency & reliability

Table 6-1: Summary of CMM Drainage and Utilization Improvements Recommended for Liuzhuang Mine

6.2 Proposed Design and Use of CMM Drilling and Drainage Component

6.2.1 Borehole Drilling Improvements

The preliminary engineering strategy for borehole drilling at the Liuzhuang mine is shown schematically in Figure 6-1 (oblique view from top of panel). As previously discussed more fully in Section 4, advanced directionally controlled borehole drills employing downhole steer-able motors would be used to place longer and more precisely positioned bore-holes to more effectively drain CMM at the mine.

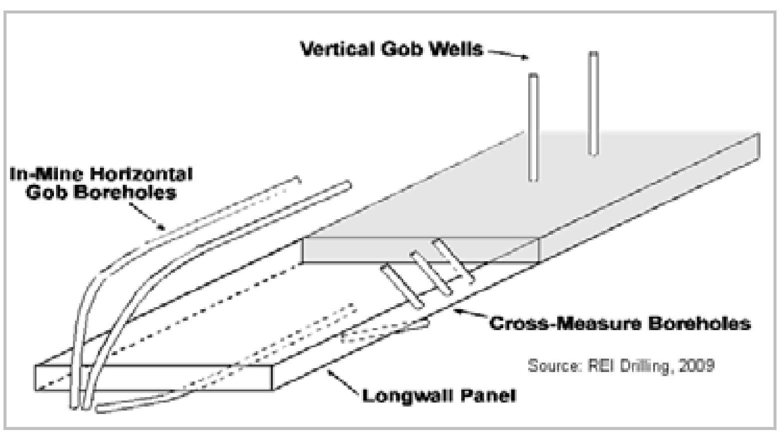

Figure 6-1: Preliminary Engineering Strategy for Borehole Drilling at Liuzhuang mine

Specifically, a two-phase drilling strategy is envisioned. First, fewer but longer (225-m long) and more precisely positioned horizontal boreholes would be drilled into the coal seams in a cross-panel direction. Second, very long (1000-m) boreholes would be drilled in a longitudinal direction down the length of the panel, not in the coal seam itself but rather arced upwards over the seam and then drilled horizontally and precisely positioned within the overlying fractured gob zone.

These longer proposed boreholes would replace the short, un-steered, cross-measure boreholes and relatively high-cost rock galleries that currently are being used at the mine for methane drainage. Surface gob wells, while frequently effective in the U.S., have not been successful at Liuzhuang mine or elsewhere in the Huainan Coal Field and thus are not recommended.

As shown in Figure 6-2 (top view), the in-seam boreholes would be approximately 225 m long and spaced 10 m apart, which is expected to improve CMM drainage and methane concentration. Note that the boreholes would be directionally drilled essentially straight across the panel, whereas the current unsteered and unsurveyed boreholes very likely arc in various directions with unpredictable trajectories. Current practice almost certainly results in a less efficient placement for drainage, with some portions of the seam undrained, while other parts of the seam have many boreholes that are too closely spaced and possibly even intersecting.

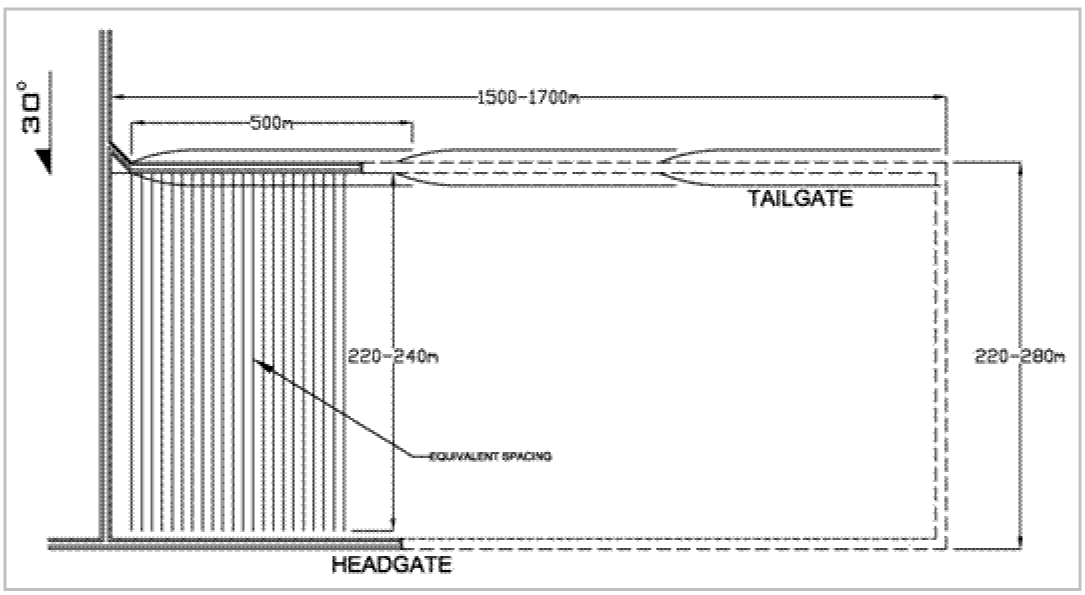

Figure 6-2: Preliminary Engineering Design for In-Seam Directional Drilling
(Source: ARI)

The proposed borehole drilling equipment and procedures for Liuzhuang mine are schematically shown in Figure 6-3. Key components of the proposed drilling system include the truck-mounted drill itself, high-quality drill rods, downhole surveying equipment, blow-out preventer, stuffing box, and diversion valves. Figure 6-4 shows an actual drilling setup similar to the one recommended for use at the Liuzhuang mine. This drilling arrangement is capable of routinely drilling long (1000-m) boreholes in coal seams or adjoining rock strate in areas with suitable geologic conditions (i.e., few faults and limited natural fracturing). Figure 6-5 shows details of the drill configuration similar to what could be employed at Liuzhuang mine.

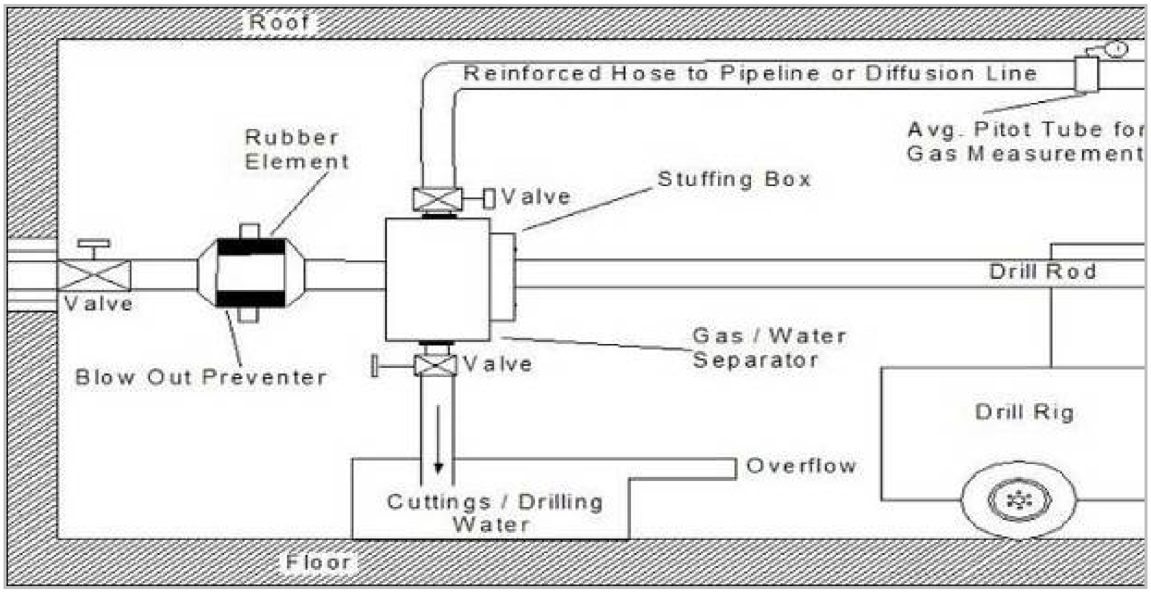

Figure 6-3: Proposed Borehole Drilling Equipment and Procedures
(Source: REI Drilling)

Figure 6-4: Directional Drill Capable of Drilling Long 1000 m Boreholes

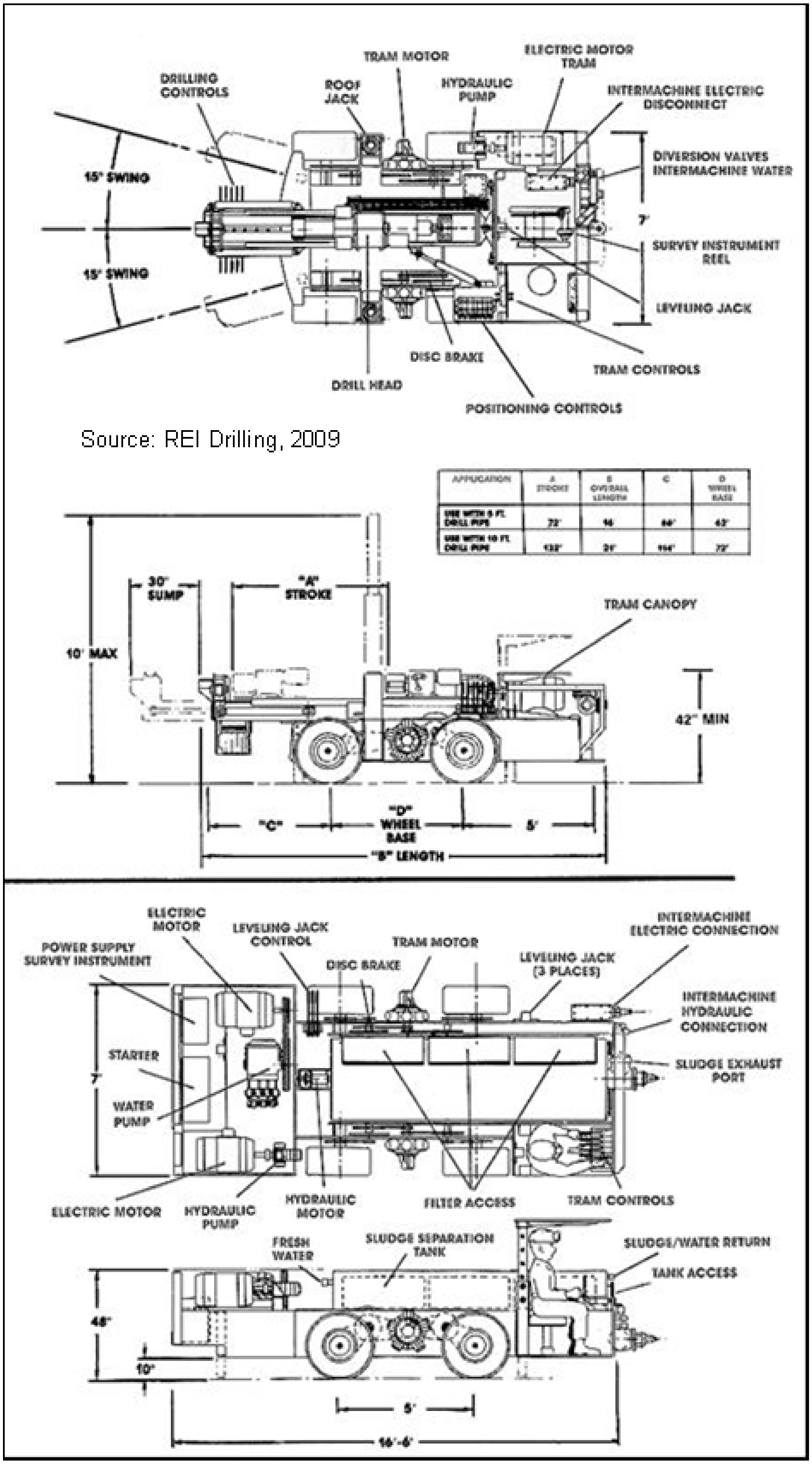

Figure 6-5: Schematic of Drilling Setup for Drilling Long (1000 m) Boreholes

One significant recommended operational improvement would be to produce CMM simultaneously while the boreholes are being drilled. Typically, borehole gas pressure builds up during drilling and can limit penetration due to equipment, borehole condition, and safety concerns. However, as demonstrated at Sihe mine in Shanxi as well as in numerous mines in Australia and the U.S., CMM production while drilling relieves excess gas pressure down the hole and enables much longer boreholes to be drilled (e.g., 1,000 m or longer). The gas and cuttings generated during the drilling process would be diverted using a gas/water separator in the stuffing box. A blow-out preventer would be used to control borehole pressure and fluid production in case of sudden gas outbursts (kicks).

The current method for gob drainage at Liuzhuang mine employs cross-measure boreholes that are drilled toward the retreating longwall face (Figure 6-6, top). Drill stations are spaced approximately 80 m apart along tailgate entry and ramped up 10 m or so into the overlying strata. From these drilling stations, boreholes up to 110 m long and 50-90 mm diameter are angled 15-30° up into the overlying rock strata. After drilling is complete, the stations are sealed and connected to a vacuum. CMM is released as the panel is mined through and the fractured gob forms, liberating the methane gas trapped the coal seam and adjoining strata. The gob zone is later isolated to limit ventilation air contamination.

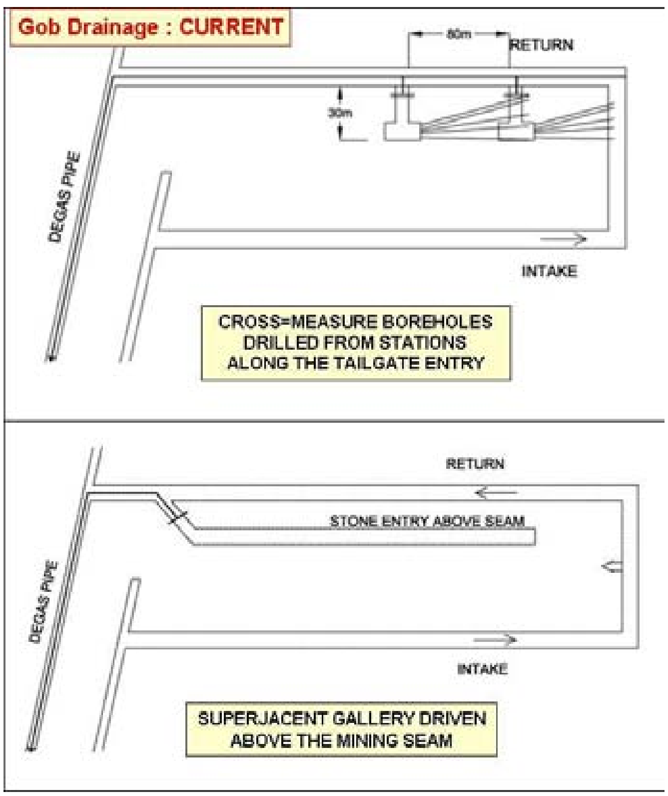

Figure 6-6: Current Gob Drainage Methods at Liuzhuang Mine (Source: ARI)

The current method for gob drainage also employs rock tunnels (galleries) drilled from a gallery developed in rock about 18-25 m above seam, located along tailgate side of panel (Figure 6-6, bottom). The galleries are sealed to limit air influx and then connected to the vacuum system. This approach is costly yet still leads to considerable unintended influx of ventilation air into the CMM stream, because it is extremely difficult to effectively seal off the gallery from the ventilation system.

The proposed preliminary engineering design for borehole drilling at Liuzhuang mine is based on U.S. and Australian borehole drilling technologies that have been successfully implemented in other Chinese coal mines which have geologic conditions comparable to those at Liuzhuang mine

(Figure 6-7**)**. The most notable recommended change is that the current short gob boreholes and rock galleries would be replaced by fewer long (1000-m) directionally drilled horizontal boreholes drilled from the ends of the panel. The boreholes are placed at different vertical levels within the gob zone, because the gob gas is likely to be stratified depending on the distribution of mining-induced fractures.

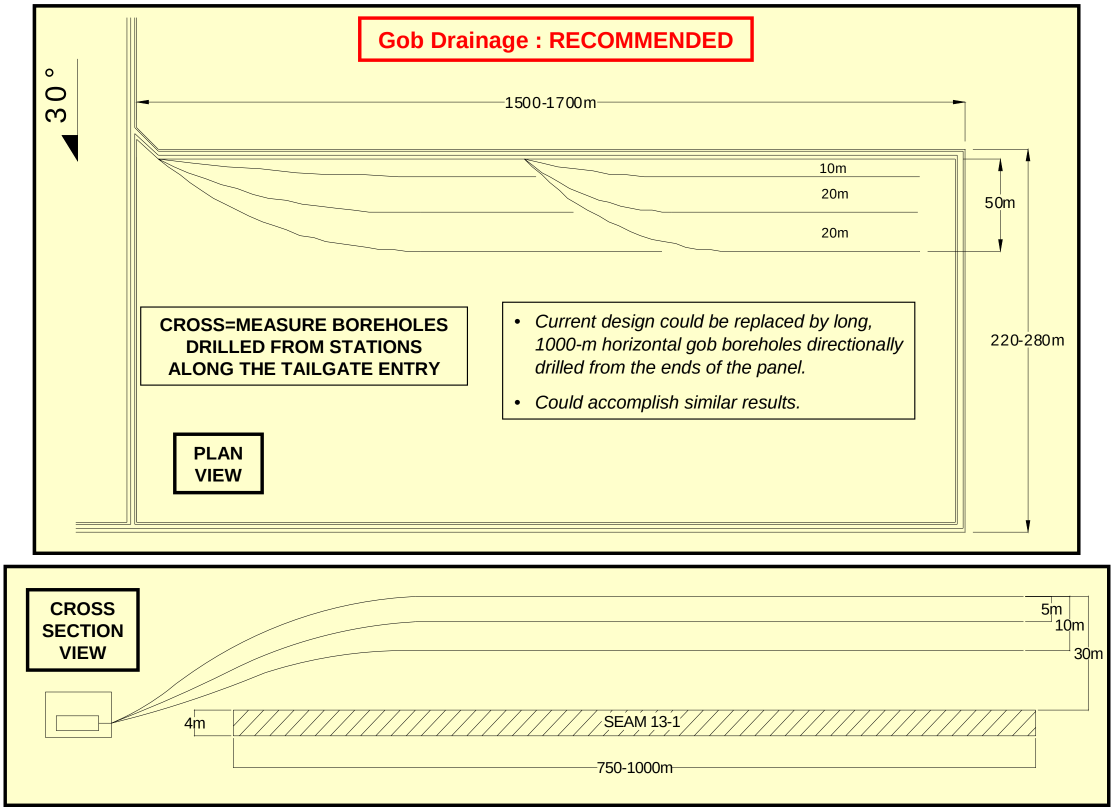

Figure 6-7: Proposed Preliminary Engineering Design for Gob Borehole Drilling
(Source: ARI)

The proposed changes could have numerous benefits for mine safety, cost of CMM containment, and coal mining productivity at Liuzhuang. An estimated 75% fewer boreholes would be drilled (counting the tangential boreholes individually). The proposed changes also could reduce the number of drill setups, borehole collars, standpipes, and wellheads by about 88%, dramatically increasing the efficiency of borehole drilling. Despite the reduced drilling, the reservoir simulation model indicates that the same volume of methane would be recovered.

The reduced number of wellheads also is likely to minimize the potential for air intrusion into the gathering system, thereby improving recovered gas quality. Fewer boreholes also reduce the time required for drilling as well as methane drainage costs. There is potential for further reduction in drainage time by reducing borehole spacing. The targeted reduced residual gas content should improve mine safety. Finally, the reduced residual gas contents should enable an increased coal production rate.

However, prior to adopting these recommended drilling changes, a small-scale test would need to be conducted at Liuzhuang mine, for example, involving the drilling of one or several long boreholes into the gob zone. This would help demonstrate the feasibility of the improved drainage and verify the achievement of the projected higher methane concentration.

6.2.2 CMM Drainage System Improvements

In addition to upgrades in borehole drilling, improvements are recommended to other components of the CMM drainage system, including more effective borehole sealing as well as the construction of less leak-prone CMM pipelines.

Borehole Grouting. As discussed in Section 4, very likely one of the significant causes of the low-methane concentration in the drained CMM at Liuzhuang mine is leakage of ventilation air around the borehole wellhead. A preliminary design for improved borehole completion at Liuzhuang mine is shown in Figure 6-8. After boring out a short, large-diameter hole, an approximately 20-m length of steel casing would be inserted to protect the hole from collapse. Grout would then be injected down the casing, diverted by the rock at the end of the hole to flow around the outside of the casing. The grout would be kept within the hole by a foam plug at the well head, while a relief tube is provided to allow excess grout to escape. This method would help ensure a secure bond between the casing and the coal seam or rock, minimizing the entry of ventilation air into the CMM stream.

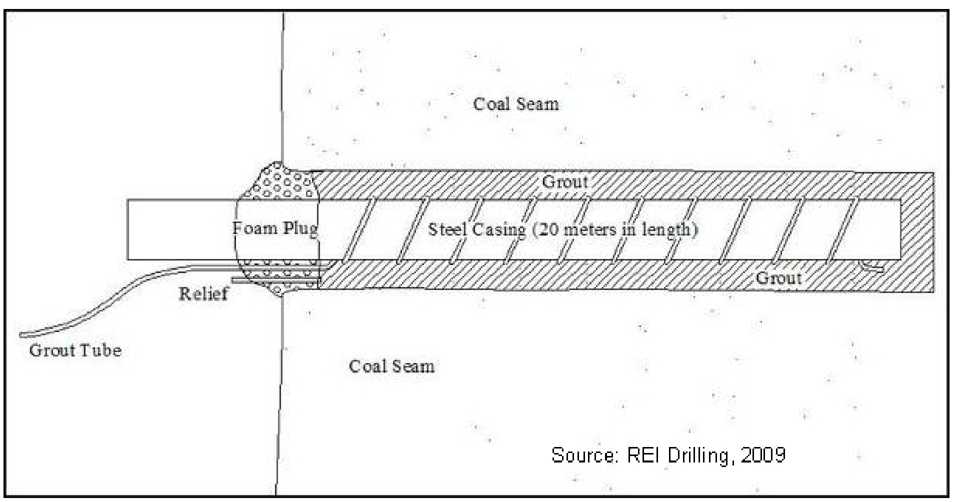

Figure 6-8: Preliminary Design for Improved Borehole Completion

Details of the grout injection process for borehole casing completion are shown in Figure 6-9. A tightly fitted “pig” (piston) is used to force grout down the inside of the casing. The grout would be then diverted around the outside of the casing. The borehole would then be pressure tested to confirm a tight seal with the host coal seam or rock. Such a “pressure leakoff” test is performed by first increasing pressure in the borehole, then verifying that no significant pressure leak off occurs over a fixed time period. After the pressure leak-off test, the now-hardened grout and remaining length of the borehole would be drilled out to its total length.

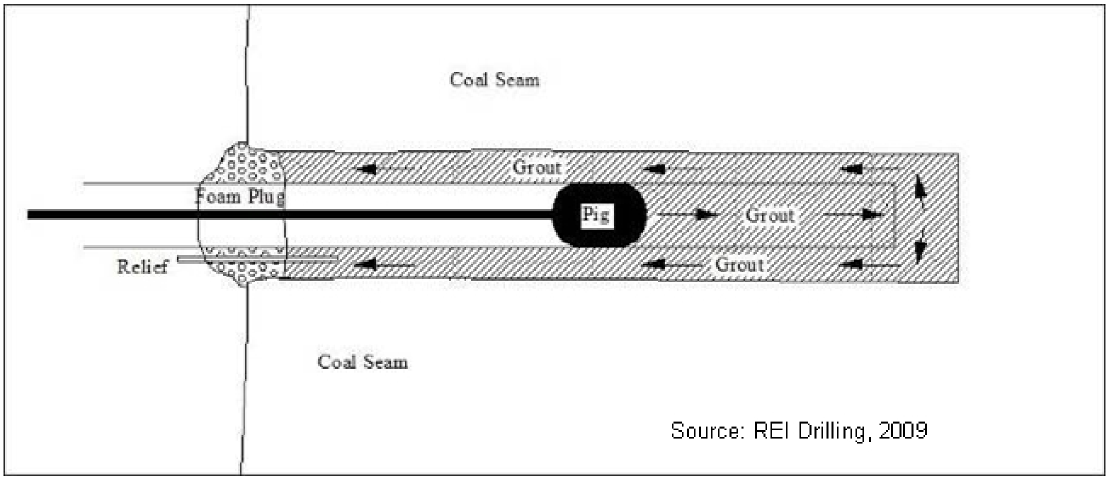

Figure 6-9: Grout Injection Process for Borehole Casing Completion

High-Density Polyethylene (HDPE) Pipeline. Also as discussed in Section 4, another significant cause of the low methane concentration at Liuzhuang mine could be unintended leakage of ventilation air into the steel pipeline system, which transports drained CMM to the surface under vacuum. The current pipeline system utilizes lengths of steel pipe that are temporarily connected using flanges, O-rings, and bolts. This approach can result in corrosion and air leakage at the joints.

Instead, seamless high-density polyethylene (HDPE) pipe, the standard pipeline material used in U.S. and Australian underground coal mines, could be used to replace steel pipe in an upgraded CMM pipeline network at Liuzhuang mine (**Figure 6-10**). HDPE is light, slightly flexible, non-sparking, and has the advantage of being much more corrosion resistant than steel. Thermal fusers would be used to heat and soften the ends of the HDPE pipe, enabling long lengths of HDPE pipe to be permanently joined together. This provides a much more secure seal than the conventional and currently employed flanged steel pipe.

Figure 6-10: Seamless High-Density Polyethylene Pipe

In addition, to further improve mine safety and reduce the likelihood of sudden air intake into the pipeline drainage network, a pipeline integrity system should be installed. This is a fairly simple and low-cost arrangement whereby small-diameter "impact" vacuum tubing is wrapped around the HDPE pipeline. Generally the first component to be broken in the event of pipeline disruption, the impact tubing would serve as an early warning system in case of pipeline disruption or actual rupture. An additional step would be to install actuator valves at regular intervals which would then automatically shut down the affected section of pipeline. This would further minimize unintended air intake and maintain high methane concentration within the CMM pipeline system. Today, pipeline integrity systems are considered standard operating practice in underground gas-prone mines in the U.S. and Australia.

Costs for the HDPE fusing system are provided in Section 8. Overall, the costs for the recommended changes to the borehole completion and pipeline system are expected to be comparable to those of current practices at Liuzhuang mine.

6.3 Proposed Design and Layout of Power Generation Component

6.3.1 Introduction

This section discusses the overall handling and utilization of moderate-quality (40% CH_4) CMM for power generation at the Liuzhuang mine, including the equipment and its placement at the mine.

Following CMM drainage and transport to the surface, the fuel cycle continues with storage of the drained CMM in an above-ground gas storage tank (typically 30,000 m^3 capacity). The storage tank provides a more stable flow and concentration for efficient utilization by the reciprocating gas engines, which otherwise could experience deleterious swings in fuel quality or quantity.

The stored CMM is filtered for dust and solid particles first through 10-micron and then 1-micron filters. Then the filtered CMM is dried to below 80% relative humidity and sent through a fuel train, where the inlet pressure is regulated in the range of 5 to 35 kPa. Following this pretreatment cycle, the processed CMM is sent through to the generator sets, which are installed close to the mining site and managed with switchgear to provide synchronization, voltage checks, loading and unloading of the engines and overall system protection (Figure 5-1, Section 5).

6.3.2 Engine Type and Size

The basic concept for power generation at the Liuzhuang mine is to install an array of approximately 10 reciprocating engines that are equipped with generator sets for power production. As discussed in Section 5, a variety of individual engine sizes is commercially available in the range of approximately 0.5 to 3.0 MW of designed output, but the most efficient unit scale is considered to be the 1- to 2-MW range. Manufacturers of IC engine and generator sets appropriate for CMM applications include GE Jenbacher, Caterpillar, Deutz, Shengli as well as other companies.

For the illustrative purposes of this feasibility study and report, an intermediate-size engine and generator set pair was selected with mid-range output of approximately 1.255 MW, comparable to a particular mid-sized Deutz reciprocating engine model. This engine model benefits from the operating efficiencies of minimum size (about 1-MW), but yet is not too large (>2 MW) to compromise flexibility should CMM fuel supplies fluctuate as anticipated. It should be noted that other engine types and sizes may prove to be equally or more appropriate and cost effective for application at Liuzhuang mine. As well, offered prices from IC manufacturers can vary widely depending on the particular application. It is recommended that the specific engine size and manufacturer most appropriate for the Liuzhuang project be determined by competitive bidding.

Assuming the borehole drilling improvements (Section 6.1) are able to achieve the targeted 37.5 m^3/min CMM drainage rate with 40% CH4 concentration, and that 100% of the drained CMM is available for power generation, it is estimated that Liuzhuang mine could provide a stable fuel supply adequate for approximately ten engines of the selected size (10 x 1.255 MW = 12.55 MW total; Table 6-2).

Number of Generators	10	units
Engine Size - Electrical Output	1255	kWe
Maximum Generating Capacity	12.55	MW
Fuel Utilized	2250	m3/hr CH4
Fuel Utilized	37.5	m3/min
Energy Export (net)	69.45	GWhr

Table 6-2: Preliminary Power Generation Design and Specifications

The use of gas engines of even greater rating (>2 MW) would be marginally more efficient and the capital cost would be slightly lower. However, larger engines have not yet been adapted to moderate-quality CMM or comparable biogas fuel and thus would require modification and a period of development. Without development and operating experience the risk of failure likely would be too high for this application.

Based on evaluations of successful CMM-to-power projects, it is recommended that that only engines that have been fully developed and are proven to work reliably with CMM or biogas should be considered for Liuzhuang mine. Caterpillar, Deutz, and GE Jenbacher all manufacture engines and generating sets that meet these criteria for the development of the Liuzhuang mine power plant layout and power house designs.

6.3.3 Power House layout, Backup and Redundancy of Generators & Boilers

The Power Station layout consists of one workshop containing the 10 gas engine generators as well as one waste heat boiler. There is probably not enough generating capacity or fuel to warrant the use of a steam turbine driven generator.

Fortunately, the CMM produced at Liuzhuang mine does not contain high levels of sulfur. However, should sulfur prove to be a problem as mining moves into other fault blocks (unlikely in Huainan Coal Field), the engines would require more frequent oil changes as well as major overhauls after less than 10,000 hours of operation. As part of the bidding process the accurate maintenance and down time of the offered engine needs to be determined and considered, because this could reduce engine availability for power generation to as low as 80%.

Maintaining a backup generator for redundancy appears to be too costly for the relatively small proposed power plant at Liuzhuang. The boiler plant is considered secondary; when shut down for maintenance, the excess heat can be vented to the atmosphere with an exhaust bypass at the waste heat boiler of each engine.

6.3.4 Layout of Gas Generators

The proposed layout of the generators is based on that which is common for diesel-driven generators, with the sets laid out in an open hall and covered by a common overhead crane. The generators are arranged in parallel on 3.5-m centers with space at one end for crane drop off and a working area. The dimensions of the building would need to be large enough to accommodate these requirements.

The open hall arrangement is typical of heavier medium-speed diesel engines that require substantial cranes to install the engines and facilitate their major overhaul. Overhead cranes have the serious disadvantage of preventing any use of the space over the generating sets for ancillary plant. In additional, the proposed engines are of relatively light weight and high speed, thus not necessarily requiring an overhead crane for maintenance or overhaul. For the infrequent installation and removal of the generating set, its light weight permits it to be skidded (dragged). The normal practice with this size and type of generator is no longer to have an overhead crane.

Consideration must be given to the far higher risk and ramifications of a fuel leak and fire with gas. A diesel oil leak is not an immediate or serious risk and a diesel engine fire can be relatively easily controlled and terminated. A gas leak on the other hand is a serious problem and would necessitate complete shut down of all engines to avoid explosion. Reciprocating engines by nature vibrate excessively, leading to very high risk of failure of their ancillary plant, including the gas train, thus gas leakage is a significant risk.

6.3.5 Procurement Schedule

A project of the type and size of the proposed Liuzhuang 12.55-MW CMM power plant project normally would be contracted as a single 'turn key' contract, leaving design co-ordination between the distinct packages of work to the main contractor. SDIC-Xinji is likely to coordinate overall design and execution in house.

The overall project comprises five distinct work packages:

1. **Gas Generator Plant**, comprising:

- Generator sets.
- Cooling system including roof mounted radiators, circulating pumps, combined heat and power (CHP) heat exchangers, accumulators, and interconnecting piping.
- Generator enclosure including ventilation and internal lighting.
- Oil day tank and waste oil pump, piping and storage tank.
- Exhaust system up to and including the exhaust isolating valve.
- Fuel gas system up to but excluding the gas isolating valve on the gas bus main. Plant to include emergency shut off valves, condensation traps, flame arresters, filtration, and pressure regulation.
- Generator local control and cable termination panel including interconnecting flexible cable between the generator and panel, and all generator cabling.
- Engine management panel and interconnecting cable with generator.
- Generator enclosure instrumentation and monitoring.
- Cooling water make up tank, mixing system and piping.
- Generator fire fighting equipment.

2. **CHP and Building Heating**, comprising:

- CHP primary circuit including circulating pumps, control valves, and piping up to but excluding the generator heat exchanger.
- Main hall ventilation / heater units, including circulating pumps, control valves, piping, and instrumentation and control.
- Hot water export system comprising: circulating pumps, temperature control valve, and piping up to connection with district heating piping.

3. **Waste Heat Boilers Plant,** comprising:

- Waste heat boiler, complete with water treatment plant, exhaust stacks, filters, etc. necessary for complete working system.
- Exhaust collection manifold and transfer piping to boiler plant, including insulation.
- Steam delivery piping and return up to and including the steam turbine room isolating valves.
- Waste heat cooling system including circulating pumps, water supply, cooling towers, and all interconnecting piping and control.

4. **Steam Turbine Generators**, comprising:

- Steam generator sets.
- Steam piping within generator room including all lagging.
- Steam turbine control and instrumentation.
- Turbine ancillary plant including oil cooling, treatment, storage, etc.

5. **Gas Treatment and Distribution.** Possibly as an extension to the contract for off site gas abstraction, storage, and transfer, and comprising:

- Gas filters, water separation, and where necessary gas scrubbing plant.
- Gas boosting plant including; flame traps, gas blowers, coolers, pressure relief, and recirculation system.
- All interconnecting piping and power house bus main including valved branches for each generator and lagging.

6.4 VAM Mitigation

As discussed in Section 5, VAM mitigation is not considered feasible at Liuzhuang mine given the current very low CH4 concentration in the ventilation air stream (average 0.02%). All of the currently available and developing VAM oxidation technologies require CH4 concentrations of at least 0.2% to be self-sustaining and technically feasible (Table 5-1, Section 5).

SECTION 7

Emissions Reductions from Project Implementation

SECTION 7 CONTENTS

SECTION 7 TABLES

7.1 Introduction

Methane (CH_4) is a greenhouse gas (GHG) with a global warming potential (GWP) over 20 times greater than carbon dioxide (CO_2). Because of this, projects that capture and utilize or destroy methane that is otherwise vented into the atmosphere will reduce project-related emissions and potentially generate a considerable amount of carbon offsets in the process. Ultimately, the monetization of any emissions reductions begins with the selection of an appropriate methodology developed under one of the many certification regimes.

The objective of this chapter is to estimate emissions reductions from the proposed project activity. The proposed project would reduce the amount of coal mine methane liberated by capturing and combusting (oxidizing) methane that would otherwise be emitted to the atmosphere. If done according to the systems and procedures of a specific certification regime, the proposed project could generate carbon offsets. Numerous certification standards exist with approved methodologies for coal mine methane projects. Many of these methodologies are based on existing methodologies approved under the UNFCCC-accredited clean development mechanism (CDM), which is the most well-known of the international certification regimes.

Currently, there are some 4,823 active projects in the CDM pipeline.[1] Another 865 projects have been withdrawn or rejected by either the Executive Board (EB) or by Designated Operational Entities (DOEs). Of the active projects in the CDM pipeline, 1,985 have been registered, 236 projects are in the process of registration, and 2,602 are at validation. Nearly 40% of the projects (1,916) active in the CDM pipeline are hosted by China. Currently, China is the number one country by issued certified emission reductions (CERs), accounting for 48% or 174 million CERs. China also accounts for over half of CERs expected by 2012 and 2020 (55% and 57%, respectively).

Due to methane's high global warming potential, CMM projects can generate significant carbon offsets and have become one of the leading types of CDM projects. Currently, there are 68 CBM/CMM projects in the CDM pipeline with total planned power generation capacity of more than 1000 MW. Fully 66 of these are located in China (the other two projects are in Mexico and India). To date 26 of the projects submitted have been registered by the CDM EB, and only six CBM.CMM projects have been issued CERs, all of which are categorized in the coal mine methane project sub-type.

This analysis examines the GHG reduction potential for the proposed CMM drainage and utilization improvement project at Liuzhuang mine. The analysis considers emissions directly avoided by power generation using CMM fuel, as well as indirect emissions avoided by displacing coal-fired

[1] Fenhann, J., 2010. "CDM/JI Pipeline Analysis and Database." UNEP Riso Centre, Denmark, 1 January 2010.

power. Key assumptions regarding project timing, coal mining, CMM production, and power generation are summarized in Table 7-1.

Topic	Key Project Parameters	Value	Unit
Timing	Project Initiated	2010	mid-year
	Project Fully Implemented	2012	January
	Project End	2034	December
Coal Production	Coal Production (2010)	3.00	million t/year
	Coal Production (2011 on)	7.85	million t/year
CMM Drainage	CMM Drainage Rate	37.50	m^3/minute
	CMM Utilized / CMM Drained	100%	percent
	CMM Concentration Expected	30-40	percent
Power Generation	Power Generation Capacity	12.55	MW
	Operating Efficiency	90%	percent
	Cumulative Project Power Production	2,448	GWh
GHG Reduction	Global Warming Potential of Methane	21	tCO2e/tCH4
	Total Emissions Avoided by Power Generation	9.18	million t CO2e
	Total Project Emissions	0.92	million t CO2e
	Net Total Emissions Avoided	8.26	million t CO2e

Table 7-1: GHG Emission Reduction Evaluation - Key Assumptions and Results

Because the proposed project is largely contingent upon the successful upgrading of CMM drainage equipment and procedures at Liuzhuang, there is considerable uncertainty regarding the actual emissions reductions that would be achieved. This analysis utilizes a streamlined emissions calculation methodology that was developed by the World Bank for the 120-MW CMM-to-power project at Sihe mine, near Jincheng, Shanxi Province.

7.2 Baseline Emissions

Defined as “the scenario that reasonably represents the anthropogenic emissions by sources of greenhouse gases that would occur in the absence of the proposed project activity,”[2] the baseline emissions for the Liuzhuang project enable the emissions reductions expected by the proposed project to be estimated. The baseline covers all gases, which in the case of Liuzhuang mine is principally the coal mine methane captured and the CO_2 exhaust from the reciprocating engines used for power generation; other greenhouse gases are minimal.

[2] CDM Rulebook, 3/CMP.1, Annex, paragraph 44.

The basic methodology used for developing an approved consolidated baseline and monitoring methodology was CDM document ACM0008.[3]

$$PE_{ME} = CONS_{ELEC,PJ} \times CEF_{ELEC} + CONS_{HEAT,PJ} \times CEF_{HEAT} + CONS_{Foss\ Fuel,PJ} \times CEF_{Foss\ Fuel} \quad \textbf{(2)}$$

Where:

PE_{ME} = Project emissions from energy use to capture and use or destroy methane (tCO2e)

$CONS_{ELEC,PJ}$ = Additional electricity consumption for capture and use or destruction of methane (MWh)

CEF_{ELEC} = Carbon emissions factor of electricity used by coal mine (tCO2/MWh)

$CONS_{HEAT,PJ}$ = Additional heat consumption for capture and use or destruction of methane, if any (GJ)

CEF_{HEAT} = Carbon emissions factor of heat used by coal mine (tCO2e/GJ)

$CONS_{FossFuel,PJ}$ = Additional fossil fuel consumption for capture and use or destruction of methane (GJ)

$CEF_{FossFuel}$ = Carbon emissions factor of fossil fuel used by coal mine (tCO2/GJ)

Baseline emissions at Liuzhuang mine are fairly straightforward to calculate because the mine has been in operation for several years and has established a reasonably stable CMM drainage performance record. In addition, currently the mine is venting all of the captured CMM, with no utilization projects.

Table 7-2 shows the estimated baseline emissions for Liuzhuang mine, which is connected to the North China power grid. By 2011, once the mine is under full-scale expanded operation producing the planned 7.85 Mt/year coal, and assuming a CDM project is approved and in place by that time, its annual baseline greenhouse gas emissions related to coal mine methane production are estimated to be approximately 374,733 tCO_2eq (note : uncertainty range is estimated to be approximately +/- 10%).

[3] CDM Executive Board, "Approved consolidated baseline and monitoring methodology ACM0008. Consolidated methodology for coal bed methane, coal mine methane and ventilation air methane capture and use for power electrical or motive) and heat and/or destruction through flaring or flameless oxidation."

Parameters	Description	Liuzhuang	Sihe	Unit
$CONS_{ELEC,PJ}$	Additional electricity consumption for use of methane	0	0	MWh
CEF_{ELEC}	Carbon emissions factor of electricity used by coal mine	0.98255	0.98255	tCO2e/tCH4
$PE_{ME,y}$	Project emissions from energy use to capture and use methane	0	0	tCO2e
GWP_{CH4}	GWP of CH4	21	21	ratio
ρ	density of CH4 under normal condition	0.00067	0.00067	t/m3
MM_{ELEC}	Methane measured sent to power plant	19.72	181.474	Mm3
Eff_{ELEC}	Efficiency of methane destruction/oxidation in power plant	0.995	0.995	percent
CEF_{CH4}	Carbon emission factor for combusted methane	2.75	2.75	tCO2e/tCH4
CEF_{NMHC}	Carbon emission factor for combusted non-methane hydrocarbo	2.75	2.75	tCO2e/tNMHC
PC_{CH4}	Concentration (in mass) of methane in extracted gas	0.40	0.55	percent
PC_{NMHC}	NMHC concentration (in mass) in extracted gas	0	0	percent
r	Relative proportion of NMHC compared to methane	0	0	percent
PE_y	**Project emissions**	**37,540**	**345,461**	**tCO2e**
$BE_{MD,y}$	Baseline emissions from destruction of methane	0	0	
GEN_y	Electricity generated by project activity in year y	99000	823200	MWh
$EF_{OM,y}$	OM emission factor for North China Grid	1.0585	1.0585	tCO2e/tCH4
$EF_{BM,y}$	BM emission factor for North China Grid	0.9066	0.90660	tCO2e/tCH4
EF_{ELEC}	Emission factor for North China Grid	0.98255	0.98255	tCO2e/tCH4
BE_y	**baseline emissions**	**374,733**	**3,362,175**	**tCO2e**
Ly	**Leakage**	0	**0**	**tCO2e**
ERy	**Emission reduction**	**337,193**	**3,016,714**	**tCO2e**

Table 7-2: Estimated Annual Emissions Reductions for Liuzhuang Mine

7.3 Emissions Reductions

The reductions in greenhouse gases attributed to the proposed project are two-fold : a) direct combustion of CMM at the mine by the power plant engines; and b) indirect reduction of power consumption purchased by the mine from more GHG-intensive (dominantly coal-fired) energy sources off the North China grid.

Table 7-2 also shows the estimated project emissions reductions at Liuzhuang mine. 2010 would represent a partial year of emissions reductions, as project installation and ramp up proceeds. By 2011, under full-scale coal production and CMM-fueled power generation, the annual emissions reductions for the proposed project are estimated to be approximately 337,193 tCO_2eq, representing a 90% utilization rate for the IC engines and a 100% utilization rate for drained CMM supply.

The CMM power project itself would generate sustained annual emissions of about 37,540 tCO_2eq, which was estimated based on the CMM fuel consumption and thermal efficiency of the engines. This is subtracted from the baseline to yield the overall 337,193 tCO_2eq annual emission reduction.

Table 7-3 shows the total estimated emissions reductions that would occur over the entire 25-year project life of the CMM project at Liuzhuang mine. Emissions from the power project itself are subtracted from baseline emissions to yield the total net emission reduction estimate of approximately 8.26 MtCO_2eq.

Year	Estimed Project Emission (t CO_2eq)	Estimated Baseline Emissions (t CO_2 eq)	Estimated Leakage (t CO2eq)	Estimated Net Emission Reductions (t CO_2 eq)
2010	18,770	187,367	0	168,597
2011	37,540	374,733	0	337,193
2012	37,540	374,733	0	337,193
2013	37,540	374,733	0	337,193
2014	37,540	374,733	0	337,193
2015	37,540	374,733	0	337,193
2016	37,540	374,733	0	337,193
2017	37,540	374,733	0	337,193
2018	37,540	374,733	0	337,193
2019	37,540	374,733	0	337,193
2020	37,540	374,733	0	337,193
2021	37,540	374,733	0	337,193
2022	37,540	374,733	0	337,193
2023	37,540	374,733	0	337,193
2024	37,540	374,733	0	337,193
2025	37,540	374,733	0	337,193
2026	37,540	374,733	0	337,193
2027	37,540	374,733	0	337,193
2028	37,540	374,733	0	337,193
2029	37,540	374,733	0	337,193
2030	37,540	374,733	0	337,193
2031	37,540	374,733	0	337,193
2032	37,540	374,733	0	337,193
2033	37,540	374,733	0	337,193
2034	37,540	374,733	0	337,193
Total (t CO_2eq)	**919,723**	**9,180,959**	**0**	**8,261,235**

Table 7-3: Estimated Total GHG Emissions Reductions
(Over the 25 year life of the project)

SECTION 8

Capital and Operating Costs

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SECTION 8 TABLES

8.1 Introduction

A previous study prepared by the Huainan Coal Group in cooperation with USEPA estimated capital and operating costs for various CMM utilization projects in the Huainan Coal Field.[1] However, these costs date back to the late 1990's and, furthermore, the Liuzhuang mine did not exist at the time this study was performed.

The natural gas price in Huainan at the time of the study was assumed to be 0.20 RMB/m^3. That is about one-sixth of the current gas price, reflecting both subsequent price inflation and partial freeing of government controls on natural gas prices. Current costs and prices were used in this analysis for the Liuzhuang mine, dating from about the first half of 2009. Fortunately, today's costs and prices are much more economically favorable for CMM utilization.

8.2 Drilling Improvements

The estimated costs for the proposed upgrades to the CMM borehole and drainage system at Liuzhuang mine are shown in Table 8-1. The preliminary design specifies two longhole directional borehole drills, one for each mining district at Liuzhuang (the second longwall at the mine is planned to start operation in 2010). Also included are special non-magnetic and MECCA drill rods, downhole motors, directional survey tools, as well as other items. The total capital costs for the drilling package are estimated to be approximately $3.5 million, which includes contingencies and engineering costs.

Two sets of HDPE fusion equipment also are recommended for Liuzhuang mine, one for each mining district. The fusion machines handle large and small-diameter pipe. The total estimated capital costs for the pipeline upgrade components are approximately $0.7 million (Table 8-2).

Based on discussions with SDIC-Xinji, the labor costs for operating the proposed CMM drilling and pipeline equipment are assumed to be comparable to costs currently incurred for the existing drilling and drainage practices at Liuzhuang mine. Thus, there are no incremental operating costs associated with the drilling and drainage operations.

[1] China Coalbed Methane Clearinghouse and USEPA, 2001. "Investment Opportunities in Coal Mine Methane Projects in Huainan Mining Area." April, 20 p.

Description		Unit Price	Unit	Quantity	Total Cost
1. Longhole Directional Drill					
	a. Drill and Power and Control Unit	$650,000	package	2	$1,300,000
	b. Spare Parts	$80,000	package	2	$160,000
2. Drill Rods					
	a. Non-Magnetic Drill Rods	$7,000	Rod	4	$28,000
	b. Drill Rods MECCA, 3m	$500	Rod	800	$400,000
3. Downhole Motor					
	a. 5/6 Stage "N" Motor	$30,000	package	4	$120,000
	b. Subs / Swivel, etc.	$10,000	package	4	$40,000
	c. Spare U-Joints and Bearings	$10,000	package	3	$30,000
	d. Fishing Tools	$10,000	package	2	$20,000
	e. Over-core Rods	$250	package	400	$100,000
4. Survey Tools					
	a. MWD Downhole Survey Tool	$350,000	package	2	$700,000
	b. Ancillary Equipment and Spare Parts	$50,000	package	2	$100,000
5. Miscellaneous Items					
	a. Drill Bits	$3,000	pc	20	$60,000
	b. Hole Openers	$6,000	pc	6	$36,000
	c. Miscellaneous Tools and Equipment	$30,000	package	2	$60,000
	d. Wellhead Equipment (Initial Boreholes)	$3,000	package	6	$18,000
7. Other					
	a. Shipping	$50,000	est.	1	$50,000
	b. Training and Technical Support	$10,000	week	26	$260,000
				TOTAL (USD):	**$3,482,000**

Table 8-1: Estimated Costs to Upgrade CMM Boreholes and Drainage System

Description		Unit Price	Unit	Quantity	Total Cost
1. Fusion Equipment					
	a. Fusion Machine (100 mm - 150 mm)	$40,000	package	2	$80,000
	b. Fusion Machine (200 mm - 400 mm)	$50,000	package	2	$100,000
2. HDPE pipe for Training					
	a. 200 mm SDR 17	$25	meter	2000	$50,000
	b. 300 mm SDR 17	$60	meter	2000	$120,000
	c. assorted fittings	$5,000	lot	10	$50,000
3. Pipeline Equipment					
	a. Integrity System	$6	meter	4000	$24,000
	b. Pneumatic Valves	$5,000	Unit	25	$125,000
	c. Gas/Water Separators	$3,600	Unit	5	$18,000
	d. Monitoring Meter Runs	$6,000	Unit	4	$24,000
	e. Assorted fittings	$5,000	lot	10	$50,000
4. Other					
	a. Shipping	$30,000	est.	1	$30,000
	b. Technical Support and Training	$10,000	week	4	$40,000
				TOTAL (USD):	**$711,000**

Table 8-2: Estimtated costs for fusion equipment and training

8.3 Power Generation

The proposed power generation sub-component envisions an array of ten 1.255 MW reciprocating engines with related power generation equipment. Estimated capital costs for the proposed 10 x 1.255 MW power station at Liuzhuang mine are summarized in Table 8-3.

Capital Costs	Liuzhuang million USD
Power Station (incl foundation, electrical mechanical & gas connections, control cabling, and commissioning)	16.67
Electrical Connection	0.25
Gas Interconnection	0.17
Land Acquisition	0.00
Permitting (electric, gas, environmental)	0.08
Emergency Spares	0.17
Total Capital Costs	**17.33**

Table 8-3: Estimated Capital Costs for Proposed Power Station

The proposed design assumes that the in-mine borehole drilling and pipeline upgrades are able to achieve a CMM supply of about 37.5 m^3/min at a 40% methane concentration, although some engine manufacturers (e.g, Caterpiller) rate their equipment as useable down to about 25% CH_4 concentration.

The capital costs for the power station are estimated to total approximately $17.33 million, mainly for the engines and generator sets, building foundation, electrical work, control cabling, and commissioning. Other capital costs include electrical and gas connections, permitting, and emergency spares. These figures already build in a 10% engineering contingency. Given that Liuzhuang mine controls the land surface already assigned for a power generation project at the mine, no land costs are included.

Operating costs for the proposed 10 x 1.255 MW power station at Liuzhuang mine are estimated to be approximately $1.7 million per year (Table 8-4). Operating costs for the power station include management & administration, daily operation costs including consumables, and life-cycle preventive maintenance.

Annual Operating Costs	million USD/yr
Management & Administration	0.54
Daily Operation Including Consumables	0.43
Life Cycle Preventive Maintenance	0.72
Total Annual Operating Costs	**1.70**

Table 8-4: Estimated Operating Costs for Proposed Power Station

In the course of a typical year, the operating efficiency for the power station is assumed to be approximately 90%, with the engines out of commission for 10% of the year due to routine maintenance or repair. This is a slightly lower and more conservative utilization rate than the experience at the BHP Tower/Appin mine project near Sydney, Australia, which has experienced a long-term average 8,000 hours in operation out of an average total 8,766 hours/year (including leap years), for a 91.3% utilization rate.

SECTION 9

Economic and Financial Evaluation

SECTION 9 CONTENTS

SECTION 9 TABLES

9.1 Introduction

The economic and financial performance of the Liuzhuang mine CMM drainage and utilization project were evaluated using key inputs discussed in the previous sections of this report. A simple cash-flow model of CMM drainage and power sales was constructed to evaluate project economics and sensitivities. Key performance measures that were used for evaluating the project included net present value (NPV), internal rate of return (IRR), and pay-back period (years).

Monte Carlo analysis is frequently used in evaluating resource exploration projects, where the uncertainties are extremely high. However, the key characteristics of the Liuzhuang mine project are considerably better constrained. Thus, a conventional +/- 25% engineering sensitivity analysis was conducted to show project variability in a transparent manner.

Key assumptions for the project are summarized in Table 9-1 and then discussed below.

Topic	Key Project Parameters	Value	Unit
Timing	Project Initiated	2010	mid-year
	Project Fully Implemented	2012	January
	Project End	2034	December
Coal Production	Coal Production (2010)	3.00	million t/year
	Coal Production (2011 on)	7.85	million t/year
CMM Drainage	CMM Drainage Rate	37.50	m^3/minute
	CMM Utilized / CMM Drained	100%	percent
	CMM Concentration Expected	30-40	percent
Power Generation	Power Generation Capacity	12.55	MW
	Operating Efficiency	90%	percent
	Cumulative Project Power Production	2,448	GWh
Power Price	Power Price (base)	0.05	USD/kWh
	Power Price (escalation)	1%	per year
Investment Costs	Borehole Drainage Investment	3.42	million USD
	CMM Pipeline Investment	0.71	million USD
	Power Generation Investment	17.33	million USD
	Total Capital Investment	21.46	million USD
Operating Costs	CMM Drainage System Opex	same	as current
	Power Generation Opex	1.70	million USD
Financial Performance	Net Present Value (r = 10%; base case; pre-tax)	11.51	million USD
	Internal Rate of Return (base case; pre-tax)	17.6%	percent

Table 9-1: Financial Analysis Key Assumptions

9.2 Project Timing

The Liuzhuang mine CMM improvement project was assumed to begin early during 2010 and require two years to implement. This schedule is consistent with other large CMM-to-power projects in China and also corresponds with SDIC-Xinji's overall plan to boost coal production at Liuzhuang mine to 7.85 Mt/year. For purposes of the cash flow evaluation, the capital costs for the drilling and power generation components were split evenly over the 2010-11 period. No further expansion was assumed after 2011, although it could well be possible to boost CMM production further by additional borehole drilling into non-mined coal panels.

9.3 Capital and Operating Costs

As discussed in Section 8, the estimated capital and operating costs for the drilling and drainage portion of the project are provided in Tables 8-1 and 8-2, respectively. Power generation capital and operating costs are provided in Tables 8-3 and 8-4, respectively. As discussed below, sensitivity analysis was performed by varying these parameters by +/- 25%.

Note that, once a short training period has been completed, the labor costs for operating the new borehole drilling system are assumed to equivalent to current practices at the mine. These costs are currently borne by the mine as part of the methane drainage and safety function. Therefore, no incremental labor costs were assumed to be charged to the power generation project.

9.4 Power Sales or Savings

Electricity generated by coal enterprises from CMM can be used by the enterprises themselves. Surplus electricity must be sold to the grid, which must accommodate such sales. The price of electricity fed to the grid is fixed by the State or established by the posted price of electricity generated by local thermal power plants equipped with desulfurization cleanup devices.

Most of the power generated by the Liuzhuang mine project is assumed to be consumed internally by the mine, with the potential to export power to the grid. Power sales were computed based on volume and price, which was estimated at $0.05/kWhr for the Liuzhuang mine region. A real (inflation-adjusted) increase in power prices amounting to 1%/year was assumed under the base case scenario.

9.5 Fiscal Parameters

Coal enterprises conducting CMM recovery and utilization projects with approved mining licenses receive preferential state policies on the resources tax, value added tax (VAT), income tax of enterprises, and the tariff tax, as well as other benefits. On October 25, 2006, the Ministry of Finance, the State Administration of Taxation, and China Customs exempted import tariffs and VAT for CMM equipment. Since January 1, 2007 the same bodies have implemented a "levy-first-refund-later" policy on CMM drainage and sales.[1]

CMM recovery and utilization technical transformation projects can enjoy import tariffs and preferential policies when importing necessary equipment, instruments, spare parts and components as well as special tools. Depreciation of equipment for recovery of CBM (CMM) can be accelerated on the basis of baseline year and the depreciation capital can be included in enterprise cost.

According to China's latest (11th) 5-year plan, the VAT on products (such as electricity) which use recovered CMM as their main input is reimbursed simultaneously with the levy up to 2020. Projects utilizing recovered CMM also are exempt from income tax for a five-year period starting from the first year profitability is attained. The enterprises are allowed to deduct 150% of expenditures for technical development in that year from taxable income of that year.

9.6 Financial Performance

The project as modeled has reasonably good financial performance (Table 9-2). On a pre-tax basis, it achieves an internal rate of return of 17.8%, with a NPV estimated at approximately 78.6 million RMB ($11.5 million). The pay-back period on a discounted basis is projected to be during the year 2020 or about 10 years from project inception.

Project risks are considered relatively small and manageable. Due to strong economic growth, the risk of declining natural gas and electricity prices in China is considered low. Likewise, the Chinese RMB is widely viewed to be strengthening in a controlled manner relative to the USD, thus capital costs for the project may actually decline in the future. Fuel supply at the mine is related to footage drilled and appears to be fairly secure. Financing risks appear manageable, as the capital required for the power project is small relative to SDIC's overall size.

[1] Huang, Shengchu, 2007. "Progress and Project Opportunities of the CMM Development and Utilization in China." Presented at the Methane to Markets Partnership Expo, Beijing, China, October 30 - November 1.

Item	Factor	Unit	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	TOTAL
Borehole Drill Capex	1	(million USD)	1.74	1.74																								**3.48**
	6.83	(million RMB)	11.89	11.89																								**23.78**
Borehole Drill Opex	1	(million USD)	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	**8.71**
	6.83	(million RMB)	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38	**59.46**
CMM Production	100% CH4	(m3/min)	24.7	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	
	100% CH4	(million m3/yr)	12.99	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	**486.36**
Power Generation Capex	17.33	(million USD)	8.67	8.67																								**17.33**
	6.83	(million RMB)	59.19	59.19																								**118.39**
Power Generation Opex	1.70	(million USD)	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	**42.42**
	6.83	(million RMB)	11.59	11.59	11.59	11.59	11.59	11.59	11.59	11.59	11.59	11.59	11.59	11.59	11.59	11.59	11.59	11.59	11.59	11.59	11.59	11.59	11.59	11.59	11.59	11.59	11.59	**289.71**
Annual Operation Efficiency	90%		0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	
Power Conversion Factor	2.98	(m3/min/MW)	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	
Net Power Capacity		(MW)	7.5	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	
Net Power Production		(GWhr/yr)	65	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	**2,448**
Power Price	$0.050	(USD/kWhr)	$0.050	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	
Escalation (above inflation)	1%	(per year)	1.00	1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.08	1.09	1.10	1.12	1.13	1.14	1.15	1.16	1.17	1.18	1.20	1.21	1.22	1.23	1.24	1.26	1.27	
Escalated Power Price		(USD/kWhr)	$0.050	$0.051	$0.051	$0.052	$0.052	$0.053	$0.053	$0.054	$0.054	$0.055	$0.055	$0.056	$0.056	$0.057	$0.057	$0.058	$0.059	$0.059	$0.060	$0.060	$0.061	$0.062	$0.062	$0.063	$0.063	
Power Sales or Savings		(million USD)	3.27	5.01	5.06	5.11	5.17	5.22	5.27	5.32	5.38	5.43	5.48	5.54	5.59	5.65	5.71	5.76	5.82	5.88	5.94	6.00	6.06	6.12	6.18	6.24	6.30	**138.50**
	6.83	(million RMB)	22.33	34.24	34.59	34.93	35.28	35.63	35.99	36.35	36.71	37.08	37.45	37.83	38.20	38.59	38.97	39.36	39.75	40.15	40.55	40.96	41.37	41.78	42.20	42.62	43.05	**945.98**
Net Revenues		(million USD)	-9.18	-7.44	3.02	3.07	3.12	3.17	3.22	3.28	3.33	3.38	3.44	3.49	3.55	3.60	3.66	3.72	3.78	3.83	3.89	3.95	4.01	4.07	4.13	4.20	4.26	**66.57**
	6.83	(million RMB)	-62.72	-50.81	20.62	20.96	21.31	21.67	22.02	22.38	22.75	23.11	23.48	23.86	24.24	24.62	25.01	25.39	25.79	26.19	26.59	26.99	27.40	27.82	28.23	28.66	29.08	**454.65**
Discount Factor	10%	Capital Return	1.00	0.91	0.83	0.75	0.68	0.62	0.56	0.51	0.47	0.42	0.39	0.35	0.32	0.29	0.26	0.24	0.22	0.20	0.18	0.16	0.15	0.14	0.12	0.11	0.10	
Discounted Net Revenues		(million USD)	-9.18	-6.76	2.49	2.31	2.13	1.97	1.82	1.68	1.55	1.44	1.33	1.22	1.13	1.04	0.96	0.89	0.82	0.76	0.70	0.65	0.60	0.55	0.51	0.47	0.43	**11.51**
	6.83	(million RMB)	-62.72	-46.19	17.04	15.75	14.56	13.45	12.43	11.49	10.61	9.80	9.05	8.36	7.72	7.13	6.58	6.08	5.61	5.18	4.78	4.41	4.07	3.76	3.47	3.20	2.95	**78.60**
Cumulative Net Disc Rev		(million USD)	-9.18	-15.95	-13.45	-11.14	-9.01	-7.04	-5.22	-3.54	-1.99	-0.55	0.77	2.00	3.13	4.17	5.14	6.03	6.85	7.61	8.31	8.95	9.55	10.10	10.61	11.08	11.51	
	6.83	(million RMB)	-62.72	-108.91	-91.87	-76.12	-61.56	-48.11	-35.67	-24.19	-13.58	-3.77	5.28	13.64	21.37	28.50	35.08	41.16	46.77	51.95	56.74	61.15	65.22	68.98	72.45	75.65	78.60	
Net Present Value	**11.51**	**(million USD)**																										
	78.60	**(million RMB)**																										
Internal Rate of Return	**17.6%**																											

Table 9-2: Cash Flow Analysis of Combined CMM Borehole Drainage and Power Generation Project at Liuzhuang Mine

Even under the worst-case scenario, should CMM fuel supplies at Liuzhuang mine somehow prove to be lacking in quantify or quality, the engine gen sets could readily be sold or repositioned to other mines in the Huainan Coal Field, with a high salvage value (estimated 80% of the original installed cost).

9.7 Sensitivity Analysis

Sensitivity analysis was performed on the CMM drainage and power generation project at Liuzhuang mine by varying key base-case parameters to analyze their impact on pre-tax project economics (Table 9-3). Four key factors were varied by ± 25%: electricity price growth, capital and operating costs, and utilization efficiency.

Variable	-25%		Base Case		25%	
	IRR	NPV	IRR	NPV	IRR	NPV
Power Price Escalation	17.1%	71.60	17.6%	78.60	18.1%	85.82
Drilling/Power Capex	25.5%	118.47	17.6%	78.60	13.0%	38.74
Drilling/Power Opex	21.3%	113.47	17.6%	78.60	14.1%	43.74
Operating Efficiency	16.6%	68.78	17.6%	78.60	18.6%	88.43

Table 9-3: Sensitivity Analysis

The largest impacts came from varying the capital and operating costs for the drilling and power components, with project NPV declining by about one-half should capital or operating costs increase by 25% over the base case levels. On the other hand, the power price escalation and operating efficiency changes had relatively smaller impacts on project economics. All sensitivity cases yielded pre-tax returns of over 10%, and thus could be considered economically viable.

9.8 Conclusions

The Liuzhuang mine CMM drainage and utilization project appears to have favorable economic performance, including good IRR (17.6%), robust NPV (78.6 million RMB), and a reasonable real pay-back period (10 years). Changes in capital and operating cost would significantly affect the project's performance, while changes in the power price and power plant operating efficiency would have less effect. Even the worst-case scenario would still allow for the sale of the drilling and power generation equipment to other mines in the Huainan region at an estimated 80% salvage value.

SECTION 10

Potential Impacts and Recommendations

SECTION 10 CONTENTS

10.1 Summary

As discussed in detail in previous sections of this report, the proposed coal mine methane drainage and utilization improvement project at Liuzhuang has considerable positive technical, economic, and environment merit. The project would improve the safety and technical efficiency of CMM drainage and transport at the mine – particularly as the mine advances into deeper gas-prone geologic levels -- resulting in production of CMM with significantly higher methane concentration that is more feasible to utilize. By utilizing CMM supplies that currently are being vented, the project would convert a cleaner energy source to power and help to reduce overall GHG emissions related to the mine.

The estimated financial performance of the Liuzhuang project is robust, while the risks of increased capital and operating costs, reduced power prices, and other variables appear to be moderate and manageable. If successful, the advanced techniques, equipment, and management practices demonstrated by the project could be applied broadly by SDIC-Xinji Energy and other coal mine operators throughout the Huainan Coal Field, resulting in significantly increased CMM utilization and reduced GHG emissions in this strategic coal mining region.

10.2 Potential Impacts of the Project

Environmental Impacts. In 2009 SDIC-Xinji prepared an environmental impact study of the conceptual 8 x 500 kW power generation project at Liuzhuang mine. This study evaluated potential surface, air, water, noise, traffic, and other impacts and concluded that no significant environmental impacts would be caused by the project.

Likewise, the currently proposed 10 x 1.255 MW power generation project is expected to have negligible overall environmental impacts, with the exception of small but manageable local increase in CO and NOx emissions from the IC engines. Impacts from increased coal production, traffic, and infrastructure construction related to the project are considered to be neglible.

Air Quality. The project is expected to have positive overall impacts on local and regional air quality. Power generation utilizing CMM fuel is far cleaner than that fueled by coal, which is the dominant fuel source for power generation and boilers in Anhui Province. The use of CMM-fueled power generation by the mine would back out coal-fired power purchased from the grid, thus resulting in lower overall emissions at the province level.

Locally, there would be a small increase in CO and NOx emissions related to the IC engines. However, the power station is located approximately 0.5 km from the nearest office and 1.0 km from the nearest residence. Prevailing winds (west to east) would tend to carry these emissions away from inhabited structures onto the nearby farmland.

Increased Coal Production. By enhancing the efficiency of CMM drainage, the project could facilitate and reduce the costs of coal production at Liuzhuang mine. However, the actual coal production target is set independently by the government and SDIC-Xinji Energy. Even if the project is not implemented, the coal production target at Liuzhuang mine still would be set at 7.85 million t/year, an achievable level even under the current CMM drainage practices. Thus, the project itself would have no significant impact on the increased production or use of coal in the region.

Increased Traffic. The CMM drilling and drainage sub-components are not expected to result in significantly increased traffic above or inside the mine. The drilling and pipeline equipment could be delivered in several large truck loads. Maintenance would take place primarily within the existing mine drilling repair shop. Very likely the improved borehole drilling will reduce the level of traffic at the mine, since there will be fewer (but longer) boreholes drilled and thus reduced equipment mobilization.

Regarding the power generation sub-component of the project, there would be a slight increase in traffic during the construction period (2010-2011), requiring several dozen heavy truck loads to deliver the IC engines and related equipment. However, current traffic at Liuzhuang mine is relatively light and easily handled by the existing road system both inside and surrounding this modern mine. During several visits to the mine, daily traffic was observed to be smoothly accommodated by existing infrastructure with no traffic issues at all. Following construction of the power station, starting about 2012, traffic levels would likely return to current levels, apart from the need for periodic engine maintenance. Overall, the project is expected to have negligible and easily manageable impacts on the traffic at Liuzhuang mine. No additional road construction or modification in traffic patterns would be needed to accommodate the project.

Infrastructure Impacts. The CMM drilling sub-component would be implemented within the existing mine design, with no significant modifications required to the mine infrastructure. The existing mine hoists, roads, power facilities, water supply, and cuttings disposal systems appear to be adequate to handle the proposed drilling and drainage improvements.

The power station requires construction of a small facility for housing the IC engines and related equipment and a short power transmission line would be constructed. SDIC-Xinji has already identified the location for this facility directly at the mine site. The basic foundation already exists and thus the power project also would have negligible infrastructure impacts.

Increased Employment. As a capital-intensive activity, the proposed CMM drainage and utilization project is not expected to create a significant number of new jobs at Liuzhuang mine. The current drilling and drainage personnel could be readily trained to operate the new drilling and pipeline construction equipment, with no overall increase in employment expected. However, the power generation sub-component would require approximately one dozen new positions, including several requiring advanced training in IC engine maintenance and power engineering. Complex tasks such as IC engine overhaul would be contracted to outside specialists, most likely the engine manufacturer; these costs have been accounted for under routine power operating expenses.

Housing for project-related personnel is available in the apartment buildings directly adjacent to the mine (within 1.0 km), as are other necessary living facilities such as markets, banks, dining halls, entertainment facilities, and a medical clinic.

Scientific and Technical Impacts. One of the most important aspects of the proposed project is its potential for improving CMM drainage and utilization in a most challenging sub-class of underground coal mine in China : low-permeability, low-moderate gas mines which currently produce CMM with extremely low methane concentrations (<10%). Many of the mines in the Huainan Coal Field are of this type. Successful implementation of the proposed advanced technologies at Liuzhuang mine could provide a demonstration that would facilitate adoption at dozens of other similar mines in the region. This could help dramatically reduce CMM emissions in the Huainan Coal Field.

10.3 Recommended Next Steps

Now that the evaluation and preliminary design phases have been completed, further steps to progress this proposed project could include:

- Internal SDIC-Xinji project technical and economic evaluation, make necessary modifications to final project design, obtain corporate go no/go decision.
- Obtain necessary approvals from project technical, financial, social, and environmental regulating authorities.
- Contact equipment and service providers to obtain site-specific quotes and timetables for the drilling, pipeline, and power generation equipment and installation, and operation.
- Conduct project scoping and training visits to other mine locations in China, U.S., and Australia where similar equipment is in operation.
- Register project with CDM approval authorities.